2011

Commercial science, scientist's values, and university biotechnology research agendas

Joseph Richard Welsh, *Syracuse University*
L Glenna
D. Ervin
W. Lacy
D. Biscotti

Research Policy 40 (2011) 957–968

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Commercial science, scientists' values, and university biotechnology research agendas

Leland L. Glenna[a,*,1], Rick Welsh[b,1], David Ervin[c], William B. Lacy[d], Dina Biscotti[e]

[a] Agricultural Economics and Rural Sociology Department, The Pennsylvania State University, University Park, PA 16803, USA
[b] Department of Humanities & Social Sciences, Clarkson University, Potsdam, NY 13699-5750, USA
[c] Department of Economics and Environmental Science and Management Program, Portland State University, Portland, OR 97201, USA
[d] Vice Provost for University Outreach and International Programs, University of California Davis, Davis, CA 95616, USA
[e] Department of Sociology, University of California Davis, Davis, CA 95616, USA

ARTICLE INFO

Article history:
Received 26 April 2010
Received in revised form 2 May 2011
Accepted 3 May 2011
Available online 31 May 2011

Keywords:
University-industry relationships
Scientist values
Bayh-Dole Act
Private research funding
Agricultural biotechnology
Commercial science

ABSTRACT

Policies designed to promote the commercialization of university science have provoked concern that basic and publicly accessible research may be neglected. Commercialization policies have altered traditional institutional incentives and constraints, which raises new questions regarding the influence of scientists' values on university research agendas. Our research builds on previous quantitative studies measuring changes in research outcomes and qualitative studies probing differentiation among scientists' value orientations. We developed a nation-wide survey of 912 plant and animal biotechnology scientists at 60 research universities. Our analysis reveals that scientists' value orientations on what we classify as "market" and "expert" science affect the amount of industry funding they receive, the proprietary nature of their discoveries, and the percentage of basic science research conducted in their laboratories. We also find that the percentage of industry funding is significantly associated with more applied research. Our findings provide insights for science and society theory and suggest that strong incentives for public-science research along with adequate public-research funds to preserve the university's vital role in conducting basic and non-proprietary research are needed to complement private-sector research investments at universities.

1. Introduction

The 1980 Bayh-Dole Act, which enabled universities to claim title to inventions and to license those inventions to the private sector, is often highlighted as the quintessential example of policies promoting the commercialization of academic knowledge, including technology transfers, university-industry research collaborations, and industry funding for university research (Eisenberg, 1996; Powell and Owen-Smith 1998; McSherry, 2001; Slaughter and Rhoades, 2004; Shane, 2004; Mowery et al., 2004; Kenney and Patton, 2009). The Bayh-Dole Act has also inspired debate regarding the impact of university-industry collaborations on academic scholarship (Welsh et al., 2008; Kenney and Patton, 2009; Lam, 2010).

Proponents of private–public research collaborations claim they will lead to more efficient knowledge and technology transfers which, in turn, will lead to higher social value (Rosenzweig, 1992; Etzkowitz, 2001; Etzkowitz and Leydesdorff, 2000; Beesley, 2003; Jain et al., 2009). Skeptics counter that universities and industries have distinct research cultures and that the commercialization of university science threatens these distinct cultures (Hong and Walsh, 2009; Kenney and Patton, 2009; Glenna et al., 2007a; Welsh and Glenna 2006; Slaughter and Rhoades, 2004; Johns et al., 2003; National Research Council, 2003; Krimsky, 2003; Lacy, 2001; Kleinman and Vallas, 2001; Campbell and Blumenthal, 2000). Following a similar argument, others claim that universities are uniquely structured to provide public goods to society and question the long-term social costs if that structure is compromised. In practical terms, this argument is based on the expectation that universities should produce more basic and non-proprietary research outputs than private-sector research institutions. Social welfare is dependent on the appropriate balance of private and public research and, therefore, the "norms and rules currently governing the institution of science must be preserved for economic reasons" (Beesley, 2003: p. 1529; see also Dasgupta and David, 1994: p. 487; Stephan, 1996; Wible, 1998; Mirowski and Sent, 2002; Bonilla, 2003). The university's contribution of public goods must be preserved, according to this argument, because the private sector lacks the incentive to conduct basic and non-proprietary research on a broad scale. Following this reasoning, a recent National Research Council (NRC, 2010) panel recommended increased support for

* Corresponding author. Tel.: +1 814 863 8636; fax: +1 814 865 3746.
E-mail address: llg13@psu.edu (L.L. Glenna).
[1] Indicates co-lead authorship.

0048-7333/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.respol.2011.05.002

university and government research to develop public-good applications from crop biotechnology innovations.

Within this broader debate about institutional norms and incentives governing scientific practice at universities, there is another debate over how to theorize the role of individual scientists. Lam (2010) observes that the focus on institutional norms and structures tends to mask the internal diversity of university researchers and the coexistence of complex, even contradictory, institutional rationales and scientist perspectives. Slaughter and Rhoades (2004) and Bercovitz and Feldman (2008) also argue that macro-level perspectives fail to capture the ways that scientists and other groups of actors within the university actively participate in and shape organizational change. Lam (2010) lists several studies revealing that university scientists vary in their perspectives on industry collaborations and commercializing science (e.g. Tuunainen, 2005; Smith-Doerr, 2005; Vallas and Kleinman, 2008). Others studies offer similar findings (Owen-Smith and Powell, 2001; Shin and Lamy, 2006; Glenna et al., 2007a,b; Welsh et al., 2008; Biscotti et al., 2009). Lam (2010) contends that there is a need to focus on the micro level to better understand scientists as strategic actors in the midst of shifting boundaries.

We agree that it is important to document the heterogeneity of scientists' values. However, such work is of limited value until analysis demonstrates that heterogeneous scientist values affect research outputs. The challenge, then, is not simply to document the heterogeneity of scientists' values, but to determine if that heterogeneity is linked to variation in basicness and proprietariness of research. Furthermore, following recent economic insights (e.g., Buccola et al., 2009), we seek to determine if variation in scientists' values and research outputs might also be explained by variation in funding source. Funding agents provide support to university scientists in exchange for research with certain goals and attributes. If research outputs vary according to funding source and scientist values, it can no longer be assumed that the university provides an institutional structure capable of preserving the full public-interest research agenda in an era of university-industry collaborations and the rise of commercial science.

Previous work in this area has tended to focus on a one-dimensional effect of external forces on university scientists without accounting for variation in scientists' values or activities (Slaughter and Rhoades, 2004). The research presented in this paper breaks new ground in at least two ways. First, we develop novel measures and questions on scientists' values for the types of research they conduct. Second, we use the survey responses to those value questions to construct latent variables to test their effect on scientists' research funding and research outcomes. We seek to understand and measure the relationships between how basic[2] and proprietary university scientists' research agendas are and their external research funds—e.g., public and private sources—as well as the scientists' value orientations.

The analytical goal for this paper, then, is to model the effects of external funding sources, intellectual property practices, and academic scientists' research values on applied-versus-basic and proprietary-versus-non-proprietary science outputs. We administered a national survey of university scientists who conduct research in plant and animal biotechnology. Our national survey of university plant and animal biotechnology researchers conducted in 2003 and 2004 enables us to examine effects of commercialization of science and academic-industry interactions on university biotechnology research agendas. The field of biotechnology deserves special attention because universities have contributed a greater share of the research in this field than in other fields of the knowledge economy (Busch et al., 1991; Nelsen, 1991; Powell and Owen-Smith, 1998). Using structural equation modeling, we measure the effects of scientist values, intellectual property practices, and external funding sources, as well as other relevant variables, on scientists' research outputs. Since universities are ostensibly structured to generate basic and non-proprietary research outputs, determining the effects of the selected set of variables on research outputs has implications for science policy. Specifically, our findings can inform the structure of agricultural biotechnology R&D for public good purposes (NRC, 2010).

2. Scientists' values and the commercialization of academic science

To guide our analysis and to highlight the social scientific and policy relevance of our findings, we engage two social theoretical perspectives. First, debates over the effects that the commercialization of science and increasing university-industry research collaborations have on universities tends to be framed by a modified Mertonian theory of science. Second, as we indicated in the introduction, scholars studying the effects of the commercialization of science tend to utilize competing theories of action. However, these competing theories tend to remain implicit. We contend that it is necessary to make these theories of action explicit if we are to justify measuring the structural influences (funding and university policies) and the agency of individual scientists (values) on research outputs.

2.1. The political economy of science

When we state that both the proponents and critics of commercializing academic science base their arguments on a modified Mertonian theory of science, we mean that they tend to accept Merton's description of university science as having different incentive systems and producing different types of knowledge and technology than do private, for-profit institutions (Dasgupta and David, 1994: p. 2; see also Aarow, 1962; Stephan, 1996; Powell and Owen-Smith, 1998). However, many of the scholars working in this area today do not accept the original functionalist assumptions of Merton's (1973) theory of science. Ever since Blume's (1974) influential critique of Merton, social scientists tend to recognize that universities are embedded in and influenced by social and economic contexts (Frickel and Moore, 2006). Blume (1974) and subsequent social studies of science have revealed that public-interest research is not inherent to university science. And studies have revealed that the national ideal of autonomous, basic science after the Second World War was never as autonomous or basic as the popular narrative often portrayed it (Kleinman, 1995; Croissant and Restivo, 2001).

Notwithstanding these caveats, what is retained is the "Mertonian conception of science as an institution characterized by a system of strong norms and distinct rewards" (Owen-Smith, 2006: p. 65). Researchers emphasize that universities tend to produce more public goods[3] because they are structured to promote such outputs from their scientists. Industry scientists tend to produce private goods because they operate in a different organizational

[2] Basicness refers to the level of basic research conducted in the laboratory. According to the NSF (2004: p. 4.8), "The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study without specific applications in mind." In contrast, "The objective of applied research is to gain the knowledge or understanding to meet a specific, recognized need."

[3] Public goods are defined as *nonexcludable* and *nonrival*, meaning that no one can effectively be excluded from using a good and that the consumption of a good by one individual does not reduce its availability for consumption by others. In the university research context, a journal article is considered a public good and a patent is considered a private good if it is licensed to users who exclude others.

structure and culture (Lacy, 2001). The concern, then, is not that functional norms might be undermined. Rather, the concern is that commercialization of university science is blurring distinctions between research cultures (Powell and Owen-Smith, 1998) or that the research cultures are converging (Kleinman and Vallas, 2006).

Industry representatives and international policy making bodies have raised concerns about these trends and contend that it is socially desirable to structure and fund universities to promote public-interest research. For example, Glenna et al. (2007b) report that industries that participate in university-industry research collaborations claim that they do so because university scientists have incentives to emphasize basic and non-proprietary research. Even when universities conduct proprietary and applied research, those university scientists may still be expected to focus in areas where industries lack adequate economic incentives. In the area of crop biotechnology, universities may be expected to focus on minor food crops, since industry lacks a profit incentive to conduct such research (FAO, 2004; Welsh and Glenna, 2006).

The proponents and critics tend to start with this same assumption that university and industry research structures and cultures are different. However, they disagree when predicting how the commercialization of science will affect the university. Croissant and Restivo (2001) claim that the proponents tend to assume that universities can participate in commercial science activities without compromising the public-interest research focus. Some research has supported this assumption. For example, Thursby and Thursby (2002) found that patenting activity and licensing revenue have increased because of efforts to promote university-industry transfers, not because of changes in university scientists' research interests. Others have also found evidence that scientists involved in university-industry collaborations tend to produce more private goods, but also produce more public goods than other academic researchers (Blumenthal and Campbell, 1996; Lee and Bozeman, 2005).

In contrast, the critics tend to argue 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. Theoretical and empirical work highlights areas where the university and industry are deviating from the public or private ideal types (Hong and Walsh, 2009; Kenney and Patton, 2009; Biscotti et al., 2009; Vallas and Kleinman, 2008; Glenna et al., 2007a; Welsh and Glenna, 2006; Slaughter and Rhoades, 2004; Johns et al., 2003; National Research Council 2003; Krimsky, 2003; Lacy, 2001; Kleinman and Vallas, 2001; Campbell and Blumenthal, 2000; Varma, 2000). Some claim the distinctions between research activities in private and public institutions are less obvious today than in the past. Research institutes, governments, and private industry are engaged in basic research, and universities are involved in the production of intellectual property and the creation of start-up companies that yield revenue streams (Powell and Owen-Smith, 1998; Beesley, 2003; Bleiklie and Powell, 2005; Kleinman and Vallas, 2006).

It is important to keep in mind that, although universities are increasingly involved in more private-science activities, "the changes in universities are matters of degree. . ." (Croissant and Restivo, 2001: p. xiii). Universities conduct 56% of the basic research in the U.S., while industry accounts for just 15% (NSF, 2008: pp. 4–14). A majority (59%) of the basic research conducted in the U.S. is funded by the federal government (NSF, 2008). And although university patenting activity has increased dramatically, universities still account for less than 5% of patents granted in the U.S. (NSF, 2008: pp. 5–51). Despite the funding and university structural changes, and more university-industry interactions, university research funding and outputs are still generally distinguishable from private sector research institutions.

However, there are reasons for concern regarding an erosion of public-interest research at universities. Studies have found a rise in data withholding, secrecy and impaired communication between university scientists (Vogeli et al., 2006; Blumenthal et al., 1986: p. 246; Curry and Kenney, 1990). Studies have also explored how academic-industry interactions obscure organizational boundaries (Cummings and Kiesler, 2005) and foster institutional conflicts of interest (Johns et al., 2003); how university research over time comes to mirror private sector research topics (Welsh and Glenna, 2006); and how science fraud may be connected to commercial ties (Martinson et al., 2005; Martinson et al., 2009). Industry funding has also been linked to researcher bias and conflicts of interests. For example, a study published in the *New England Journal of Medicine* found a strong association between authors' findings on the safety of a drug and "their financial relationships with pharmaceutical manufacturers" (Krimsky, 2003: p. 148).

A key shortcoming in many of these studies is that they fail to specify the path by which external pressures interact with internal academic structures to influence the research outcomes. As Bercovitz and Feldman (2008: p. 69) explain, "The mere presence of macro-level pressures does not guarantee that new initiatives will be embraced. The ability of organizations to change depends on the willingness of individuals to adopt supportive norms, routines, and behaviors." Indeed, many of the studies that address effects of the commercialization of science on universities tend to focus on structural and external factors, which mask the individual-level influences on scientists' activities and outputs (Lam, 2010; Slaughter and Rhoades, 2004). However, one of the reasons for this is that Merton's structuralist theory of action has persisted. A theory of action that bridges these structural and individual levels of analysis is needed.

2.2. Social theories of action

Two competing theories of action are implicit in the debates over the effects of the commercialization on university science. One emphasizes the social structural factors that influence individual decisions. This structuralist theory of action is evident in Merton's (1973: p. 293) assertion that scientists' public-goods activities are not so much the result of the scientists' personal characteristics, but the result of the institutional "norms that exert pressure upon scientists. . .." New institutional perspectives tend to share this structuralist theory of action. Hackett (2001: p. 107), for example, applies one of DiMaggio and Powell's (1991) hypotheses on determinants of organizational change to develop a theoretical perspective on how academic science is affected by external research funding: "increased resource dependence and other transactions with government agencies will cause universities to adopt and enforce the rules and formal rationality of government bureaucracies." And, as Dasgupta (1999: p. 265) explained when considering the rise of proprietary science, "don't blame the individual researcher, qua researcher; blame instead science for failing to enforce the norms of science. . .." The problem with this theory of action, as we have already noted, is that the focus on institutional norms and structures tends to mask the internal diversity of university researchers and the coexistence of complex, even contradictory, institutional rationales and scientist perspectives (Lam, 2010; Bercovitz and Feldman, 2008; Slaughter and Rhoades, 2004).

The second theory of action, which emerges from neoclassical economic and rational choice perspectives, emphasizes that self-interested, purposively rational actors are motivated to act by personal preferences or tastes. Although this perspective purportedly focuses on the intentions of individual actors, in practice, neoclassical economists and rational choice theorists neglect the individual motivations when they assume that people's values and

preferences are exogenous and unvarying (England and Kilbourne, 1990). For example, Stigler and Becker (1977) argue that there is little variation in preferences and that individual behavior can be explained by prices and other incentives. Even when scholars from this perspective acknowledge that values may be heterogeneous and that preferences may vary, they treat the values and preferences as exogenous, meaning that they are assumed not to vary due to interactions with economic or structural influences (England and Kilbourne, 1990).

Following from these assumptions, both structural and neoclassical/rational choice theories of action tend to oversimplify complex interactions of macro-level factors and individual-level values. As Powell and Owen-Smith (1998: p. 254) explain, this perspective is based on the assumption that scientists enter different institutional settings "'precommitted' to different norms and rules of the game" (see Powell and Owen-Smith, 1998: p. 254). This does not mean that all of a scientist's values about research are precommitted or that a scientist's values may not change over time. Rather, the assumption is that scientists hold value commitments when they start a university position, even though their values and behaviors may be subject to influence from collaborations with other researchers, as well as economic and structural influences. Although we start with an assumption of exogeneity, we recognize that a theory of action is needed to account for structural- and individual-level influences on scientists' research.

New institutionalism in sociology provides a theory of action that justifies the study of agency in an organizational setting. Nee and Ingram (1998) claim that they retain the neoclassical assumption that individuals are rational, but they recognize that an individual's perceptions of self-interest can be influenced by cultural factors and even by endogenous preferences, to the extent that individuals within organizations can work collectively to generate informal rules that can eventually become normative. What they suggest is that theorizing values as either endogenous or exogenous masks the complexity of social life, and that a more dynamic theory of action is needed. People may hold exogenous values and preferences, since people do not enter an organizational setting as blank slates. But the expression of those preferences may be enabled or constrained by macro-level factors, especially in times of institutional change.

What makes this new institutional theory of action most useful for our paper is the recognition that neoclassical assumptions become "patently false" during periods of institutional change (Nee and Ingram, 1998: p. 30).In the case of the commercialization of science, the university structure and the political and economic structure, in which the university is embedded, have changed. University science is increasingly funded from external sources, including government and industry sources. And university researchers are embedded within universities that have altered structures to promote proprietary outputs. Prior to the passage of the Bayh-Dole Act, academic scientists in general had to work outside of institutional parameters to commercialize their research discoveries (Mowery et al., 2004). This suggests that, even if an academic scientist held a strong commitment to private-science values and wanted to act on those values prior to 1980, the university as an institution did not directly enable the expression of those values. Today there are state, federal, and university policies and structures to encourage the expression of private-interest research values. The implication is that the university once set parameters to promote public-interest scientific activities, but those parameters are far more fluid today than in the past.

Two recent studies provide support for the proposition that scientists' research values should be assumed to be endogenous during periods of institutional change. First, Bercovitz and Feldman (2008) examine the effects of funding source, as well as scientists' educational and current organizational environments, on medical school scientists' likelihood to submit invention disclosures. They find that scientists educated in places that promoted technology transfer are more likely to be active in technology transfer in their current faculty position, but that this educational effect lessened as years since graduating passed. They also report that scientists are more likely to engage in proprietary behavior if they have a department chair and other colleagues who engage in or promote technology transfer. Furthermore, they find that the norms of the current institution tend to trump the norms promoted at the institution where they received their graduate education. Second, Blumenthal et al. (2006) find that a scientist's industry support, as well as training from that scientist's educational years, influence the likelihood that the scientists' will withhold data.

These studies offer empirical data to advance the endogeneity and heterogeneity of values positions. However, the emphasis on endogeneity of scientist values presents theoretical pitfalls. Specifically, theorizing endogeneity minimizes the agency of individual scientists. If the institutional environment is ultimately determinative of scientists' outputs, then there is no need to account for the heterogeneity of scientists' values. Rather, scientists may be described as conforming to their institutional environments. Moreover, there are important empirical shortcomings in these studies. First Bercovitz and Feldman (2008) did not control for industry funding (or funding sources other than NIH). Second, neither Bercovitz and Feldman (2008) nor Blumenthal et al. (2006) measured scientists' expressed research values.

Numerous studies have demonstrated that university scientists and administrators interpret, negotiate, and remain persistent or compromise in the midst of quandaries over how to publish and patent discoveries, maintain open communication while protecting industry information, and maintain their broad public commitments while facilitating commercialization (e.g. Owen-Smith and Powell, 2001; Slaughter et al., 2004; Hackett, 2005; Shin and Lamy, 2006; Glenna et al., 2007a,b; Welsh et al., 2008). However, although these studies provide insights into how scientists' values vary and are constructed in relation to political and economic trends and structures, they tend to be qualitative and to have limited populations. When quantitative studies are conducted (e.g., Lam, 2010), they tend not to be incorporated into a causal model. The question that remains is whether scientists' varying value orientations have any impact on research outcomes when included in a statistical model that controls for external influences, such as funding sources, as well as a university's institutional environment.

Several quantitative studies attempt to account for variation in professional or business values, sometimes called propensities, in models of scientific behavior (e.g., Harter, 1994; Hall et al., 2001; Thursby and Thursby, 2002; Campbell and Bendavid, 2002; Stern, 1999; Walsh et al., 2005, 2007). However, only broad proxies to such preferences are normally possible with aggregate time series data. More direct observations must be obtained with individual scientist data collected by surveys or interviews. For example, Thursby and Thursby (2002) use indirect measures of scientist propensities, but do not measure scientists' values directly. Therefore, Thursby and Thursby (2002) are unable to determine heterogeneity of scientists' values or whether such heterogeneity has explanatory power, while controlling for other factors. Accounting for variation in professional values seems particularly important in scientist-level studies.

Analyzing a survey of agricultural scientists, Busch et al. (1983) found that scientists engage in complex processes that involve drawing upon personal interests and values, as well as views on how science generates public benefits, as they make research decisions. Furthermore, in partial support of the proposition of explicitly incorporating scientists' values, they found that scientists could be grouped according to their rationales for research decisions. Other analysts have measured differing value orientations

among agricultural scientists relative to sustainability issues (e.g. Beus and Dunlap, 1992). However, these studies did not apply their findings to demonstrate that variation in values explains variation in behavioral outcomes.

This review of literature justifies exploring heterogeneity in scientists' values, while also exploring the influences of political and economic factors on scientists' research outcomes. To do this, we follow a similar strategy of Bercovitz and Feldman (2008) and include indicators of institutional environmental influences as controls, while measuring the significance of heterogeneity of scientists' values in relation to funding sources and research outputs.

It is our intention to shed new light on the social structure and conduct of plant and animal biotechnology research by more completely modeling the relationships between external factors and internal factors and the character of scientists' research programs than has been accomplished to date. We developed six research questions to guide our analysis:

1. Can university scientists be grouped by their values and orientations in regards to the appropriate focus of their research programs?
2. To what extent are the scientific values of academic researchers associated with the amount of research funding they receive from industry sources?
3. To what extent do the values of individual scientists influence the proprietary nature (proprietariness) of their discoveries?
4. To what extent do the values of individual scientists affect how basic versus applied (basicness) their research program is?
5. To what extent does industry funding affect how basic versus applied (basicness) the scientists' research program is?
6. To what extent does the proprietary nature (proprietariness) of the university scientists' discoveries affect how basic versus applied (basicness) the scientists' research discoveries are?

3. Data and methods

We address our research questions through a national survey of academic principal and co-principal investigators who are conducting research at the molecular or cellular level with implications for agricultural biotechnologies. The survey was conducted from October 2003 through March 2004. A comprehensive list of scientists in the target population does not exist, primarily because research related to agricultural biotechnology spans multiple disciplines and departments. Therefore, we developed the following process to create the sampling frame.

1. Universities in the "Doctoral/Research Universities – Extensive" category from the 2000 Carnegie Classification of Universities were sorted into three strata – land grant (LGUs), non-land-grant public, and private. Twenty universities were randomly sampled from each stratum.
2. Departments judged by project staff to have faculty involved in agricultural biotechnology research were selected for each sampled university. The potential departments were identified through website research. The department lists were then reviewed by six independent academic scientists working in agricultural biotechnology. Each independent scientist selected 15 major categories of departments that would hold the highest concentrations of our target population.
3. We used each department's website to gather all faculty names listed. Written requests were then mailed to department chairs via Priority Mail asking them to identify their faculty members who met the definition for our target population, or to offer additional names that were not on our list. The response rate by department chairs to this request was over 70%. Tests of chair non-respondents did not indicate systematic bias.
4. Starting from this basis, a list of faculty was developed resulting in a total sample of 1441 academic scientists.

The survey was constructed following the Dillman (2000) tailored design method in collaboration with the Social and Economic Research Center at Washington State University. Cognitive pretests, a focus group of biotechnology scientists not in the sample, and pre-tests of a subset of the sample were used to refine the survey instrument structure and content. The enumeration phase began with a letter to each potential respondent explaining the survey purpose, a request to complete the on-line survey, and a $5 payment to indicate the seriousness of the request.

The overall response rate was 64% ($N = 912$). The potential for non-respondent bias was investigated with an email survey to 433 scientists asking questions about key study variables, e.g., academic rank, percentage of research budget represented by industry, number of publications. Statistical tests of 57 responses did not reveal significant differences in the variables for respondents and non-respondents.

The Internet-based survey was designed to last approximately 20 min. In addition to socio-demographic questions such as gender and academic rank, we asked respondents about: (1) the amount of research funds they received from private firms and trade groups (industry) versus other sources (i.e., public sector agencies and non-profit foundations); (2) the percent of their research program they considered to be basic versus applied;[4] (3) whether or not they participated in a number of actions that influence the proprietary nature of their discoveries; and (4) the values and orientations they have in regards to the conduct of research and technology development and commercialization.

Regarding question (3) we asked specifically if the scientists had, since January 2000, applied for a patent, been issued a patent, licensed a patent, developed a trade secret, produced a technology under regulatory review, produced a technology on the market, or formed a start-up company. Based on the responses, a proprietary index was constructed by assigning a value of "1″ for every activity in which a scientist participated and using the total as the index value.[5]

Regarding question (4), we presented the respondents with Likert scales to measure their commitment to a set of science values on a scale of 1–5 (1 = strongly agree, 5 = strongly disagree, and a sixth "Do not Know" category, which no respondent selected). The factors for Expert Scientists and Market Scientists were constructed from responses to these statements[6] (see Table 2):

[4] Basicness was defined on the survey as "experimental or theoretical discoveries that add to fundamental science and engineering knowledge (for example, fundamental genomics)." Appliedness was defined as "research that draws from basic or other applied research to create new products (for example, a transgenic plant)." We used two questions to measure this variable. The first question treated basicness and appliedness as a continuum on a scale. The second asked scientists to explain the percentage of their appliedness versus basicness. As one might expect, the variables were highly correlated. We used the percentage measure for this analysis because it was more conducive to our SEM analysis.

[5] One may question whether it is appropriate to assign equal ranking to each of these criteria in the proprietary index. For example, one might assume that it takes more effort to create a start-up company than to file for a patent or to develop a trade secret. We checked with the heads of research offices and scientists who have filed patents and formed start-up firms on the issue of the difficulty of forming a start-up company versus the other five items in the proprietary index. Our informants indicated that forming a start-up firm is notdifficult, as it entails filing a number of forms and paying a set of fees. It therefore is comparable to filing for a patent.

[6] The scientist types or constructs were the result of a factor analysis with a varimax rotation. Adding additional items to the factor analysis did not alter the results. Therefore we are confident that the constructs accurately reflect the data collected. In addition, it is likely the latent variables (factors) are statistically and concep-

Table 1
Means and standard deviations for selected variables.

Variable	Mean	Std. deviation
Percent industry funding	9.29	20.8
Gender of respondent (1 = male)	0.78	0.42
Full professors (1 = full professor)	0.48	0.50
Private university (1 = pvt. university)	0.18	0.381
Proprietary index (6 maximum)	0.73	1.24
Public scientists should focus on producing for market potential	3.37	1.051
Industry should influence research agendas of public scientists	4.06	1.027
Scientist panels should set research agendas of public scientists	2.51	1.260
Market is the most effective arbiter of social value of new technology	3.79	1.174
Trained scientists are the most accurate arbiters of value to society	3.06	1.060

Values variables (final five in table) were measured using Likert scales (1 = strongly agree and 5 = strongly disagree).

Table 2
Factor analysis results – varimax rotation.

Likert scale item	Factor loadings	
	Market science	Expert science
Public scientists should focus on producing for market potential	0.780	−0.006
Industry should influence the research agendas of public scientists	0.745	−0.089
Market is the most effective arbiter of the social value of new technology	0.637	0.101
Scientist panels should set the research agendas of public scientists	−0.092	0.779
Trained scientists are the most effective arbiters of social value of new technology	0.107	0.787
Eigen Values	1.589	1.244
Percent Variance Explained	31.78	24.88

- Public scientists should focus on producing knowledge with market potential.
- Industry should play a central role in influencing public research scientists' agendas.
- The market is the most accurate arbiter of the relative social value of a new technology.
- Scientist panels are the most appropriate vehicles for setting the research agendas of public research scientists.
- Trained scientists are the most accurate arbiters of the relative social value of a new technology.

We included scientists' answers to scale items concerning the appropriate role of scientists in developing and transferring knowledge and technology, the degree to which private firms should influence the research agendas of scientists, and whether market forces or scientists themselves are the best arbiters of the social value of new technologies. The scale items were developed by adapting and substantially augmenting Dunlap's environmental paradigm scales (see Olsen et al., 1992) to accommodate insights from the science studies literature. The means and standard deviations for the scale items and other selected variables are presented in Table 1.

We used exploratory factor analysis to discern whether the responses to the Likert scale items were components of constructs that indicated varying sets of values and orientations that scientists employ in developing their research programs. The factor analysis resulted in two factors with Eigen values above 1 (see Table 2). By definition, the two factors are not correlated, and the components within factors are correlated. Therefore, scientists who agreed with the statement that the market is the most effective arbiter of the social value of a new technology also tended to agree that public scientists should focus on producing products with market potential and that industry should influence the research agendas of public scientists. But the same responses are not correlated with agreement that scientist panels should set research agendas of public scientists and that trained scientists are the most effective arbiters of the social value of a new technology. These findings indicate that it is possible to group university agricultural biotechnology researchers according to their values and orientations toward the conduct of academic science, including interaction with industry, technology transfer and technology assessment.

Using the factor analysis results, we developed two latent explanatory variables (Fig. 1) in the SPSS structural equation modeling (SEM) package, AMOS 7.0. We labeled our resulting latent variables "expert science" and "market science." Market science differs from expert science in that it emphasizes industry goals, such as producing a marketable product. Expert science assumes that scientists are able to generate public value and benefits through their work and accumulated knowledge, generally independently of market forces. These definitions are consistent with other efforts to categorize scientists (see Lacy and Glenna, 2005/2006).

SEM enables us to incorporate measurement and structural models. The two explanatory latent variables represent the measurement model. The structural model is the full path model that incorporates the latent variables with the observed independent control variables and dependent variables. Fig. 1 illustrates the measurement and structural models. The dependent variables are: (1) the proprietary index, (2) the percentage of basic research in a scientist's research portfolio, and (3) the percentage of the scientist's total research funding from industry. The control variables include binary variables measuring whether the scientist was a full professor or held a lower ranked position on the academic career ladder (1 = full professor) and the gender of the scientist (1 = male). Gender was included as a control because recent research indicates that systemic disadvantages lead female scientists to be less productive than male scientists (Keith et al., 2002; Long, 1990; Xie and Shauman, 1998), female scientists receive less industry funding and less industry consulting opportunities (Crowe and Goldberger, 2009), and female scientists produce less commercial work than male scientists (Ding et al., 2006; Whittington and Smith-Doerr, 2005). We also included type of university where the scientist

tually valid since they are reliable predictors in the SEM regression analysis. We used exploratory factor analysis, instead of confirmatory factor analysis, because it is possible that the Likert Scale items could have combined in a number of different types of factors. Therefore, we used exploratory factor analysis to measure actual correlation patterns among variables.

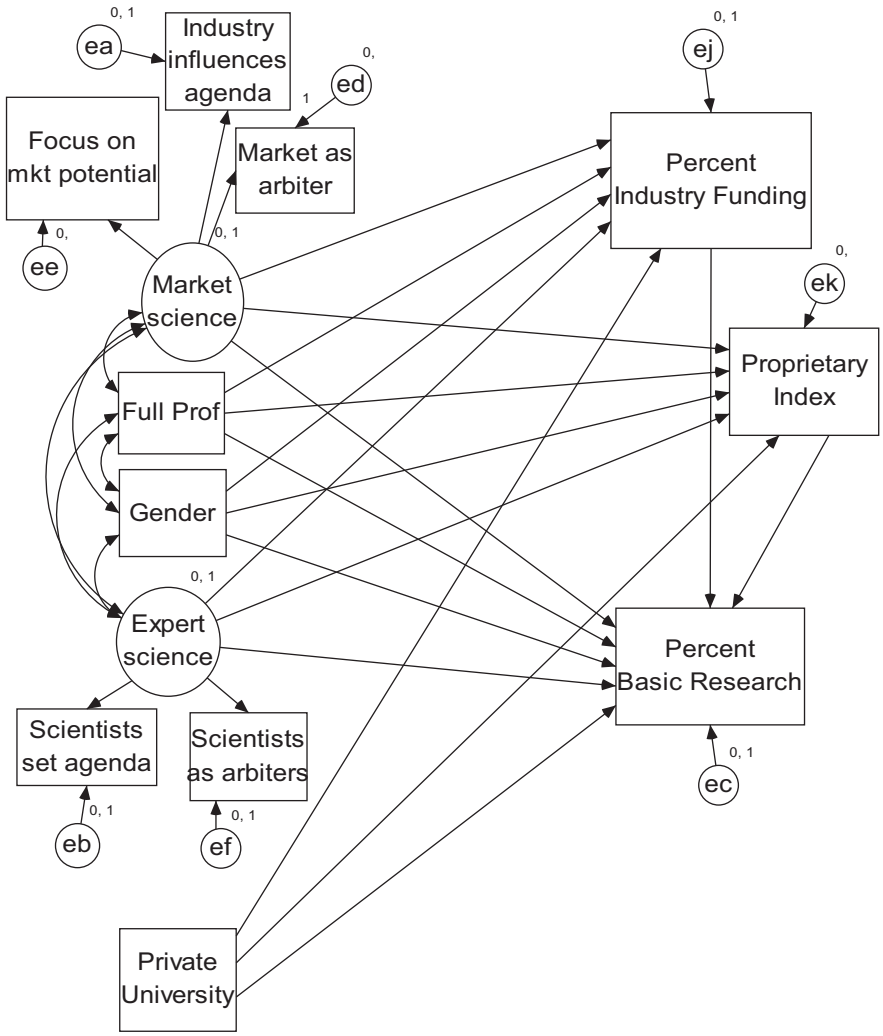

Fig. 1. Measurement and structural models.

works as a control variable to account for variances in institutional factors that might affect the character of research programs and industry funding levels: public or private (1 = private) and whether the technology transfer office is self-funded (self-funded = 1).[7] Public is comprised of public land-grant and public non-land-grant universities. Self-funded means that the university technology transfer office generates sufficient revenue to operate, without support from the university. The double arrows (←→) between variables are considered unanalyzed associations. That is, the variables are assumed to co-vary, but for unknown reasons. The single direction arrows (→) represent analyzed associations between variables in which we have posited explanations to account for causal co-variation (see Kline, 1998: p. 101). The "*e*" variables represent error terms.

The single direction arrows (→) imply causality but in a probabilistic sense. Making a distinction between deterministic causality and probabilistic causality is important, according to Kline (1998: p. 98), because:

> . . .the causes of exogenous variables are not represented in path models. In contrast endogenous variables are specified as *caused* by exogenous variables or other endogenous variables. Every endogenous variable has a disturbance, which represents variance unexplained by other observed variables in the model. A disturbance can also be seen as an unmeasured exogenous variable that represents all omitted causes of the endogenous variable. Path models thus assume that causality is probabilistic rather than deterministic. Deterministic models assume a one-to-one correspondence between cause and effect.

In our model, we assume that funding influences the character of research outputs, but also that the relationship between funding and research outputs is influenced by scientists' values. In this case, we measure the direct effect of the exogenous variables, including scientists' values and the percentage of industry funding on the dependent variables, proprietariness and basicness. When we use a uni-directional arrow *from* percent industry funding *to* percent basic research, we are assuming that there is a probability that an increase in industry funding causes a decrease in basic research. Similarly, when we use a uni-directional arrow from market science values to percent basic research, we are assuming that there is a probability less than one but greater than zero that changes in the market science value variable cause changes in the basic research variable. We also measure the indirect association between the

[7] By including this technology transfer office variable, we are not taking a position on debates regarding the relationship between the scientist as inventor and the university technology transfer office (see Kenney and Patton, 2009). Rather, we use this variable as an indicator of the university's entrepreneurial environment in which the individual scientist is working.

exogenous variables and the level of basicness *through the percent of industry funding and our proprietary index variables*. Furthermore, we measure whether the effects of percent of industry funding, the scientist's degree of proprietariness, and the basicness of a scientist's research are affected by the scientist's value orientations.

We developed two hypotheses to be tested by our model:

H_1. University scientists interact differently with structural requirements and external influences depending on their values and orientations.

The core assumption here is that scientists' values are exogenous *and* heterogenous and that those values shape the scientists' activities. However, following Nee and Ingram (1998), we resist reifying these assumptions. We assume that values are exogenous, but we also include variables to control for potential endogenous institutional influences. To control for influence of university environment favorable to market science, we used the variable measuring self-funded TTO, since our analysis indicates that self-sustaining technology transfer offices have higher levels of licensing revenues than do the other types of TTOs. In the end, however, we excluded the self-funded TTO variable from the final models after our preliminary analysis revealed it was not a significant predictor of basicness or proprietary behavior, and only weakly predicted industry funding. To control for how values might change over a scientist's career, we include a variable for Full Professors (1 = Full Professor and 0 = Other rank) and a variable for time since degree. Because the variable measuring time since degree and the Full Professor dummy variable were significantly correlated (0.663; $p = 0.000$), we performed a number of analyses with either or both variables and found that the rank dummy variable and the time since degree variable were similarly predictive. Therefore, we present the results using only the Full Professor dummy variable. If professor rank is significant, we must acknowledge that scientists' research values may change over time.

H_2. External influences, such as research funding sources, are not monolithic in their effects.

Agricultural biotechnology researchers, and agricultural researchers in general, receive substantial funding from private industry, not-for-profit foundations, and the public sector. And different industry and non-industry funding sources may have very different missions and goals. Therefore, we do not assume that all external funding sources will have the same influence on a scientist's research outputs.

4. Results

Regarding model fit, the model chi-square divided by the degrees of freedom equals 1.918. Because the chi-square statistic is sensitive to sample size, it is common to divide its value by the degrees of freedom (chi-square/df). Values under 3 for this statistic indicate an acceptable model fit (Kline, 1998). In addition, AMOS 7.0 provides a number of other fit measures, including the Normed Fit Index (NFI) and the Comparative Fit Index (CFI). The value of NFI provides an estimate of the fit of the model compared to a null model. The CFI is interpreted the same as the NFI, but may be less sensitive to sample size (Kline, 1998). For the NFI and CFI, values range from 0 (no fit) to 1 (a perfect fit). Scores above 0.90 generally indicate an acceptable fit between the model and the data (Bentler and Bonnet, 1980). Our scores of 0.937 and 0.967 for the NFI and CFI respectively suggest an acceptable model fit.

The standardized regression weights for the explanatory variables in the path model are arranged in Table 3 for the percent of industry funding dependent variable, in Table 4 for the proprietary index dependent variable, and in Table 5 for the percent basic research independent variable. Although higher scores on the expert science and market science variables reflect less agreement with those concepts (i.e., 1 = strongly agree and 5 = strongly disagree), we transformed these variables so that negative signs on independent variables reflect a negative relationship with the dependent variables. Regarding the percent of industry funding results in Table 3, scientific values are associated with the percent of industry funding scientists receive. Specifically, market orientation is associated with higher levels of industry funding and expert science orientation is associated with lower levels. In addition, scientists employed at private universities have lower percentages of industry funding than do scientists employed at public universities, after controlling for other factors. The rank and gender of the scientists appear to have no significant influence on the scientists' level of industry funding. Researchers at universities with self-funded TTOs are more likely to have a higher percentage of industry funding than researchers at other universities. The influence is significant, but small.

Scientist value orientations are significant predictors of proprietary activity (see Table 4). A market orientation leads to higher levels of proprietary activity, while an expert science orientation leads to lower levels. In addition, full professors tend to act in a more proprietary fashion than do lower ranked professors. The sign on the gender variable is positive, suggesting that male professors conduct more proprietary research than do female professors, but the p-value of 0.150 indicates that the effect is not

Table 3
SEM regression results: Percent of industry funding dependent variable.

Variable	Beta	p-Value
Expert science	−0.298	0.000
Market science	0.316	0.000
Gender	0.031	0.415
Full professor	−0.030	0.418
Private	−0.099	0.003
Fit		
Chi-square/df: 1.918		
NFI: 0.937		
CFI: 0.967		

Table 4
Proprietary index SEM regression results.

Variable	Beta	p-Value
Expert science	−0.199	0.000
Market science	0.219	0.000
Gender	0.053	0.150
Full professor	0.130	0.000
Private	0.043	0.202
Fit		
Chi-square/df: 1.918		
NFI: 0.937		
CFI: 0.967		

Table 5
Percent basic research SEM regression results.

Variable	Beta	p-Value
Expert science	0.279	0.000
Percent industry	−0.247	0.000
Funding	−0.097	0.006
Proprietary index	−0.339	0.000
Market science	−0.045	0.188
Gender	0.004	0.907
Full professor	0.159	0.000
Private		
Fit		
Chi-square/df: 1.918		
NFI: 0.937		
CFI: 0.967		

significant. Employment at a private university had little influence on proprietary activity.

On the basic-applied continuum, market science values lead to less basic research and expert science values lead to more basic research, as hypothesized (see Table 5). Scientists at private universities conduct higher levels of basic research than do scientists at public universities. This may seem like an anomaly to readers who know that some large private universities tend to be among the top revenue generators and tend to be in the lead in generating start-up companies. This information suggests that private universities are doing more applied work. However, this anomaly may be explained by considering the historical origins of agricultural research. As Buttel (2005) points out, applied agriculture research traditionally has been done at public land-grant universities, and there is a well-developed infrastructure to support traditional plant breeding and animal research (e.g., field stations and experimental farms). Private universities traditionally have done little agricultural research. However, more agriculturally relevant research is being done at private universities since the application of molecular and biotechnological discoveries to agricultural research. Plant and animal biotechnology research at private universities tends to be at the molecular level, and therefore is more basic in nature.

The negative relationship between gender and basicness suggests that female scientists are more oriented to basic research, although the effect is not significant (p-value of 0.188). The rank of the scientists has little influence on the level of basicness of the research programs. However, the percent of industry funding and the proprietary output activity lead to lower levels of basic research performed.

Kline (1998) indicates that in general, standardized coefficients with values less than 0.10 represent small effects, while values around 0.30 indicate medium effects and values above 0.50 represent large effects. Therefore, the absolute value of the standardized coefficient for the effect of industry funding on percent basic research of 0.247 suggests that the direct effect of the industry funding variable is of medium magnitude. The 0.097 absolute value of the standardized coefficient for the direct effect of the proprietary index on percent basic research suggests a small but significant effect. To calculate total effects, it is necessary to sum the direct and indirect effects (Kline, 1998: pp. 118–120). Considering the relationship between the market science variable and the percent basic research variable, we see that the total indirect effect of a market science value orientation on percent basic research through the industry funding and proprietary index variables is $(0.316)(-0.247)+(0.219)(-0.097)=-0.099$. The standardized direct effect on percent basic from market science is -0.339. And the total standardized effect (direct + indirect) of market science on percent basic is -0.339, -0.099 or -0.438.

Industry funding combined with proprietary activity of university scientists enhances the impact of a market science orientation by moving it from a medium negative effect to a medium-to-large negative effect. Therefore, proprietary activity and industry funding have a moderate influence on the market-science variable's effect on the percent-basic variable. These results indicate that market-oriented scientists whose research funding is more dependent on specific projects funded by private firms or trade groups, such as crop herbicide tolerance of a particular brand or formulation of an herbicide, and who have engaged in patenting or other proprietary activity, rate their research programs as more applied than do market-oriented scientists with little or no industry funding. The finding that industry funding has a negative effect on the amount of basic research performed is relevant in light of recent research by Glenna et al. (2007b) that finds representatives of the agricultural biotechnology industry expressing concern that the universities have moved too far from their basic research mission.

5. Discussion and conclusions

Proponents of university-industry collaborations and commercialized academic science point to the benefits of economic growth and the promise of new university revenue to support research as they downplay concerns about effects on the university's traditional role of providing non-proprietary and basic research. However, critics contend that if those benefits come at the expense of the public-interest emphasis of academic science, the long-term capacity of the university to provide those benefits may be diminished. Our analysis of a survey of plant and animal biotechnology scientists at U.S. universities indicates that the critics' concerns are valid. Since university biotechnology research has been a key target in efforts to foster UIRs and to stimulate private sector benefits from publicly-funded research, we believe that trends in this area may be indicative of broader developments.

Our findings run counter to the findings of those with sanguine perspectives on the influence of commercial science on university research outputs. As we mentioned, for example, Thursby and Thursby (2002) contend that university patenting activity and licensing revenue have increased because of efforts to promote university-industry transfers, not because of changes in university scientists' research interests. According to our analysis, academic scientists manifest a diverse range of value orientations, even when they are working in an organization that is purportedly structured to promote public-interest science. Scientists holding particular views about the scientific enterprise as practiced within the university seem to act on their values in such a way that it shapes their research program net of other important variables such as organization type, structure of technology transfer office, funding source, gender, and rank. Moreover, our findings indicate that market-science values, which are traditionally associated with for-profit research institutions, have a strong positive association with scientists' applied research agendas, and that this association is stronger when scientists receive funding from industry and engage in proprietary activity.

We believe that this seeming incongruity provides a nuanced insight for future research on the endogeneity–exogeneity question. Contrary to Blumenthal et al. (2006) and Bercovitz and Feldman (2008), we follow the new institutional theory and assume that scientists' values are exogenous, but at the same time recognize that the ability of scientists to express their values might be enabled or constrained by their institutional environment and funding sources. Inclusion of variables to control for the influence of institutional environment did not change our findings about the significant influence of scientists' values. The market science and expert science variables remain strongest and most reliable predictors of the dependent variables. However, the variables measuring the type of university, time since earning degree, and full professor status are significant in some of the models, indicating that these factors are exerting some influence alongside the values. We believe that these findings lend support to the new institutional theory of action, which assumes the exogeneity of values, but also recognizes that individuals can be influenced by their institutional environment or act dynamically and collectively to create structures to support their values. We therefore conclude that our models confirm insights from numerous qualitative studies that describe how scientists wrestle with and develop new strategies to remain true to their core values while, at the same time, meeting the expectations of their funders and parameters and incentives of university structures (e.g. Welsh et al., 2008; Lam, 2010). The theory and assumptions about the role of scientists' values in contemporary academic research need to be updated to accommodate the complexity of reality.

Structural factors and funding sources matter, and they may matter more today than they did in the past. Although universi-

ties may have always had scientists who adhere to market-science values, those market values are more influential today because the policy changes since the 1980s provide structural incentives to encourage their expression. However, our findings also have important implications for social science models to account for the persistent variation in pre-committed scientists' values. Given the significance of the market- and expert-science values, their omission would lead to bias in the estimated effects of other explanatory variables on each dependent variable. Including value heterogeneity in the models is consistent with a theory of scientist decision-making under utility maximization (Buccola et al., 2009). Incorporating scientists' heterogeneous values into formal analytical models yields more realistic and robust findings than does excluding them.

We find partial support for the arguments that the distinction between university and industry is blurred (Powell and Owen-Smith, 1998) and that a type of hybrid system has emerged in which scientist-entrepreneurs bridge the university-industry divide (Owen-Smith and Powell, 2001, 2002). The hybrid that Owen-Smith and Powell call the "scientist-entrepreneur" roughly corresponds to the scientists in our study who adhere to market-science values. Furthermore, this category is socially relevant because these scientist-entrepreneurs are significantly different from their expert-science colleagues in terms of their utilization of industry research funding and in their production of more proprietary goods. At the same time, however, our model indicates that scientists with more traditional public-interest values persist. Therefore, it may be premature to conclude that a new hybrid system has overtaken the system in which university and industry research institutions are distinctive.

Our findings also have important implications for state and federal governments, companies, and industry associations that invest in university research, as well as for university administrators responsible for recruitment, hiring, and retention of scientists. Acknowledging that Mertonian theories of science are anachronistic does "not mean that science has been plunged into a normative void" (Nowotny et al., 2001: p. 241). Even if we theorize that science and society are mutually constitutive, we may still recognize the pragmatic need for policies that promote public-interest research in universities. However, it is unlikely that policy makers will seek to restore universities to the pre-Bayh-Dole era. Furthermore, as Owen-Smith (2006) and Glenna et al. (2007b) have argued, current trends have exposed the romanticized pre-Bayh-Dole era as less than idyllic. Furthermore, new opportunities may be emerging to construct alternative institutional arrangements to maximize the public-welfare orientation of university research (Kenney and Patton, 2009). The operative question for university administrators may concern what combination of expert-science and market-science values should be sought among their faculty to deliver that maximum. Peters et al. (2008) have noted that more research should focus on how university scientists conceptualize their work in relation to LGU missions and on more general political debates of civic engagement in American higher education. University administrators and policy makers may need to consider whether public-private research collaborations are sustainable if the university's public-interest research structures and values are diminished significantly. They may also need to consider what is needed to promote public-interest research values and civic engagement simultaneously at their research universities.

We recognize that our findings may not be generalizable across the life sciences. For example, as we indicated, it may seem counter-intuitive that one of our findings is that private university scientists are doing more basic research related to agricultural biotechnology than are public university scientists. After all, private universities generally conduct the most applied research in the biomedical and pharmaceutical sectors. However, those same private universities do a large share of the basic research in the biomedical and pharmaceutical sectors. And the fact is that more money is invested in biomedical and pharmaceutical research than is invested in agricultural research. Despite the fact that agricultural biotechnology research may be different from pharmaceutical and biomedical research, we believe that our findings are still relevant beyond the agricultural sector. Survey research that would allow comparison between different biotechnology sectors, as well as others sectors, such as nanotechnology, would need to be conducted to further test the proposition that scientists' values and funding sources are both important predictors of research outputs.

Perhaps more important than the implications for social theory, we believe that our findings have relevance for agriculture and food policy. The National Research Council recently conducted a comprehensive assessment of crop biotechnology on farm sustainability in the United States (NRC, 2010). One of four major recommendations that emerged from the assessment urges increased public investment in research to deliver public goods. Examples of such products from agricultural biotechnology R&D include applications for minor crops, climate change adaptation, and reduced water pollution from cropping practices. The recommendation also includes a call to make intellectual property patented in the course of developing the current generation of crops available for such public goods purposes. Finally, it recommends an expansion of the purview of both the public and private sectors in working on such public goods. The findings of the research reported here, including the roles of scientists' values and industry funding on research outputs, should inform the development of effective initiatives to address these purposes.

Ongoing research is needed to promote public debate with an eye toward envisioning the future science-society compact (Varma, 2000; Etzkowitz and Leydesdorff, 2000; Nowotny et al., 2001; Beesley, 2003; Bleiklie and Powell, 2005; Owen-Smith, 2005, 2006).In order to realize the maximum social benefits from plant and animal biotechnology research investments, it may be necessary to expect some university scientists to conduct applied and proprietary research and others to conduct basic and non-proprietary research. And it is reasonable to expect university research to be transferred through market mechanisms, as well as through the more traditional approaches of releasing new findings, crop varieties, and other technological innovations into the public domain. If university scientists in general are expected to perform proprietary, non-proprietary, basic, and applied research, then universities should have scientists representing a diverse array of values and approaches.

Link et al. (2007) discuss the dilemma created by the current emphasis on commercialization. They find that many successful university scientists are engaging in informal technology transfer, thereby bypassing the university technology transfer office and limiting the potential revenue stream for the university. They suggest that the university should change incentive structures, such as increasing the revenue stream to the inventor and giving greater weight to proprietary outputs in tenure and promotion decisions, as a way to promote engagement with formal technology transfer mechanisms (Link et al., 2007). However, changing these types of incentive structures would further erode the public-interest research values in the university. Given the current commercialization pressures and trends in the academy, *special* attention may be required to support scientific research agendas that are non-proprietary and basic in nature.

Some recommend that codes of conduct, or science norms, be established to promote public-interest research agendas (Dasgupta, 1999; Rotblat, 1999; Alberts, 2008). However, our findings indicate that focusing exclusively on the scientist is inadequate. University administrators and policy makers must also consider how various incentive structures, funding sources, poli-

cies, and practices reinforce and limit the expression of diverse scientific research values. Without sufficient commitment to and investment in basic and non-proprietary research that provides public goods, the scientific foundations that underpin the discovery and advancement of commercial technologies are likely to eventually decline.

Acknowledgement

This research is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, under Agreement No. 2001-52100-11217. In addition to the authors, project members include Steve Buccola (Oregon State University), Hui Yang (Bank of America), Walt Armbruster (Farm Foundation), Pam Ronald (University of California, Davis), Molly Jahn (University of Wisconsin), and Kristen Kim and Elizabeth Minor (Portland State University). Any opinions, findings, conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture or of the other project members. We thank John Walsh for helpful comments on an earlier draft of this paper and anonymous reviewers for valuable comments.

References

Alberts, B., 2008. A new editor-in-chief. Science 319, 1307.
Aarow, K.J., 1962. Economic welfare and the allocation of resources for invention. In: The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton University Press, Princeton, pp. 609–625.
Beesley, L.G.A., 2003. Science policy in changing times: are governments poised to take full advantage of an institution in transition? Research Policy 32 (9), 1519–1531.
Bentler, P.M., Bonnet, D.G., 1980. Significance tests and goodness of fit in the analysis of covariance structure. Psychological Bulletin 88, 588–606.
Bercovitz, J., Feldman, M., 2008. Academic entrepreneurs: organizational change at the individual level. Organization Science 19 (1), 69–89.
Beus, C.E., Dunlap, R.E., 1992. The alternative-conventional agriculture debate: where do agricultural faculty stand? Rural Sociology 57 (3), 363–380.
Biscotti, D., Glenna, L.L., Lacy, W.B., Welsh, R., 2009. The 'independent' investigator: how academic scientists construct their professional identity in university-industry agricultural biotechnology research collaborations. Economic Sociology of Work 18, 261–285.
Bleiklie, I., Powell, W.W., 2005. Universities and the production of knowledge—Introduction. Higher Education 49, 1–8.
Blume, S.S., 1974. Toward a Political Sociology of Science. The Free Press, New York.
Blumenthal, D., Campbell, E.G., Gokhale, M., Yucel, R., Clarridge, B., Hilgartner, S., Holtzman, N.A., 2006. Data withholding in genetics and the other life sciences: prevalences and predictors. Academic Medicine 81 (2), 137–145.
Blumenthal, D., Campbell, E.G., 1996. Participation of life-science faculty in research relationships with industry. New England Journal of Medicine 335 (23), 1734–1739.
Blumenthal, D., Gluck, M., Louis, K.S., Wise, D., 1986. Industrial support of university research in biotechnology. Science 231 (4735), 242–246.
Bonilla, J.P.Z., 2003. Peddling science: An essay review of science bought and sold: Essays in the economics of science. Philosophy of Science 70, 833–839.
Buccola, S., Ervin, D., Yang, H., 2009. Research choice and finance in university bioscience. Southern Economic Journal 75 (4), 1238–1255.
Busch, L., Lacy, W.B., Burkhardt, J., Lacy, L.R., 1991. Plants Power and Profit: Social Economic, and Ethical Consequences of the New Biotechnologies. Basil Blackwell, Oxford.
Busch, L., Lacy, W.B., Sachs, C., 1983. Perceived criteria for research problem choice in the agricultural sciences – A research note. Social Forces 62 (1), 190–200.
Buttel, F.H., 2005. Ever since hightower: The politics of agricultural research activism in the molecular age. Agriculture and Human Values 22 (3), 275–283.
Campbell, Eric G., Bendavid, Eran, 2002. Data-sharing and data-withholding in genetics and the life sciences: results of a national survey of technology transfer officers. Journal of Health Care Law and Policy 6 (2), 241–255.
Campbell, Eric G., Blumenthal, D., 2000. Academic industry relationships in biotechnology: A primer on policy and practice. Cloning 2 (3), 129–136.
Croissant, J.L., Restivo, S., 2001. Introduction. In: Jennifer, L., Croissant, Sal Restivo (Eds.), Degrees of Compromise: Industrial Interests and Academic Values Albany. State University of New York Press, pp. xi–xxiii.
Crowe, J.A., Goldberger, J.R., 2009. University-industry relationships in college of agriculture and life sciences: The role of women faculty. Rural Sociology 74 (4), 498–524.
Cummings, J.N., Kiesler, S., 2005. Collaborative research across disciplinary and organizational boundaries. Social Studies of Science 35 (5), 703–722.
Curry, J., Kenney, M., 1990. Land-grant university-industry relationships in biotechnology: A comparison with the non-land-grant research universities. Rural Sociology 55 (1), 44–57.
Dasgupta, P., 1999. Science as an Institution: setting priorities in a new socioeconomic context. In: Lecture delivered at the Plenary Session on Science in Society at the UNESCO/ICSU World Conference on Science , Budapest, 26 June–1 July, p. 1999.
Dasgupta, P., David, P.A., 1994. Towards a new economics of science. Policy Research 23, 487–521.
Dillman, D.A., 2000. Mail and Internet Surveys: The Tailored Design Method. John Wiley and Sons, Inc, Hoboken, NJ.
DiMaggio, P.J., Powell, W.W., 1991. The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. In: Powell, Walter W., DiMaggio, Paul J. (Eds.), The New Institutionalism in Organizational Analysis. University of Chicago Press, Chicago, pp. 63–82.
Ding, W.W., Murray, F., Stuart, T.E., 2006. Gender differences in patenting in the academic life sciences. Science 313, 665–667.
Eisenberg, R.S., 1996. Public research and private development: Patents and technology transfer in government-sponsored research. Virginia Law Review 82, 1663–1725.
England, P., Kilbourne, B.S., 1990. Feminist critiques of the separative model of the self. Rationality and Society 2 (2), 156–171.
Etzkowitz, H., 2001. Beyond the endless frontier: from the land grant to the entrepreneurial university. In: Wolf, S., Zilberman, D. (Eds.), Knowledge Generation and Technical Change: Institutional Innovation in Agriculture. Kluwer Academic Publishers, Boston, pp. 3–26.
Etzkowitz, H., Leydesdorff, L., 2000. The dynamics of innovation: from National Systems and 'Mode 2' to Triple Helix of university—industry—government relations. Research Policy 29, 109–123.
Frickel, S., Moore, K., 2006. Prospects and challenges for a new political sociology of science. In: Frickel, Scott, Moore, Kelly (Eds.), The New Political Sociology of Science: Institutions, Networks, and Power. The University of Wisconsin Press, Madison, WI, pp. 3–34.
Food and Agriculture Organization (FAO), 2004. The State of Food and Agriculture. Agricultural Biotechnology: Meeting the Needs of the Poor? Food and Agriculture Organization of the United Nations, Rome.
Glenna, L.L., Lacy, W.B., Welsh, R., Biscotti, D., 2007a. University Administrators, Agricultural Biotechnology, and Academic Capitalism: Defining the Public Good to Promote University-Industry Relationships. The Sociological Quarterly. 48 (1).
Glenna, L.L., Welsh, R., Lacy, W.B., Biscotti, D., 2007b. Industry perceptions of university-industry research relationships related to agricultural biotechnology research. Rural Sociology 72, 608–631.
Hackett, Edward J., 2005. Essential tensions: identity, control, and risk in research. Social Studies of Science 35 (5), 787–826.
Hackett, Edward J., 2001. Science as a vocation in the 1990s: The changing organizational culture of academic science. In: Croissant, J.L., Restivo, S. (Eds.), Degrees of Compromise: Industrial Interests and Academic Values. State University of New York Press, Albany, pp. 101–138.
Hall, B.H., Jaffe, A., Trajtenberg, M., 2001. Market Value and Patent Citations. RAND Journal of Economics 36 (1), 16–38.
Harter, J.F.R., 1994. The propensity to patent with differentiated products. Southern Economic Journal 61, 195–201.
Hong, W., Walsh, J.P., 2009. For money or glory? Commercialization, competition, and secrecy in the entrepreneurial university. The Sociological Quarterly 50 (1), 145–171.
Jain, S., George, G., Maltarich, M., 2009. Academics or entrepreneurs? Investigating role identity modification of university scientists involved in commercialization activity. Research Policy 38 (6), 922–935.
Johns, M.M.E, Barnes, M., Florencio, P.S., 2003. Restoring balance to industry-academia relationships in an era of institutional financial conflicts of interest. Journal of the American Medical Association 289 (6), 741–746.
Keith, B., Layne, J.S., Babchuk, N., Johnson, K., 2002. The context of scientific achievement: Sex status, organizational environments, and the timing of publication on scholarship outcomes. Social Forces 80 (4), 1253–1282.
Kenney, M., Patton, D., 2009. Reconsidering the Bayh-Dole Act and the current university invention model. Research Policy 38, 1407–1422.
Kleinman, D.L., Vallas, S.P., 2006. Contadiction in convergence: Universities and industry in the biotechnology field. In: Frickel, S., Moore, K. (Eds.), The New Political Sociology of Science: Institutions, Networks, and Power. The University of Wisconsin Press, Madison, WI, pp. 35–62.
Kleinman, D.L., Vallas, S.P., 2001. Science, capitalism, and the rise of the 'Knowledge Worker': The changing structure of knowledge production in the United States. Theory and Society 30, 451–492.
Kleinman, D.L., 1995. Politics on the Endless Frontier: Postwar Research Policy in the United States. Duke University Press, Durham, London.
Kline, R.B., 1998. Principles and Practice of Structural Equation Modeling. Guilford Press, New York.
Krimsky, Sheldon, 2003. Science in the Private Interest: Has the Lure of Profits Corrupted Biomedical Research? Rowan & Littlefield Publishers, Inc, Oxford, UK.
Lacy, W.B., Glenna, L., 2005/2006. Democratizing science in an era of expert and private knowledge. International Journal of Technology, Knowledge, and Society 1(3), 37–46.
Lacy, W.B., 2001. Generation and commercialization of knowledge: trends, implications, and models for public and private agricultural research and education. In: Wolf, S., Zilberman, D. (Eds.), Knowledge Generation and Technical Change:

Institutional Innovation in Agriculture. Kluwer Academic Publishers, Boston, pp. 27–54.
Lam, A., 2010. From 'ivory tower traditionalists' to 'entrepreneurial scientists'? Acadmic scientists in fuzzy university-industry boundaries. Social Studies of Science 40 (2), 307–340.
Lee, S., Bozeman, B., 2005. The impact of research collaboration on scientific productivity. Social Studies of Science 35 (5), 673–702.
Link, A.N., Siegel, D.S., Bozeman, B., 2007. An empirical analysis of the propensity of academics to engage in informal university technology transfer. Industrial and Corporate Change 16 (4), 641–655.
Long, J.S., 1990. The origins of sex differences in science. Social Forces 68 (4), 1297–1315.
Martinson, B.C., Crain, A.L., Anderson, M.S., de Vries, R., 2009. 'Institutions' expectations for researchers' self-funding, federal grant holding, and private industry involvement: manifold drivers of self-interest and researcher behavior. Academic Medicine 84 (11), 1491–1499.
Martinson, B.C., Anderson, M.S., de Vries, R., 2005. Scientists behaving badly. Nature 435 (9), 737–738.
McSherry, C., 2001. Who Owns Academic Work: Battling for Control of Intellectual Property. Harvard University Press, Cambridge.
Merton, Robert K, 1973. The Sociology of Science: Theoretical and Empirical Investigations. University of Chicago Press, Chicago.
Mirowski, P., Sent, E.-M., 2002. Science Bought and Sold: Essays in the Economics of Science. The University of Chicago Press, Chicago.
Mowery, D.C., Nelson, R.R., Sampat, B., Ziedonis, A.A., 2004. Ivory Tower and Industrial Innovation: University-Industry Technology Transfer Before and After the Bayh-Dole Act. Stanford Business Books, Stanford, CA.
National Research Council (NRC), 2003. Frontiers in Agricultural Research: Food, Health, Environment, and Communities. National Academies Press, Washington, DC.
National Research Council (NRC), 2010. Impact of Genetically Engineered Crops on Farm Sustainability in the United States. National Academies Press, Washington, DC.
National Science Foundation (NSF), 2008. Science and Engineering Indicators – 2004. National Science Foundation, Arlington, VA.
Nee, V., Ingram, P., 1998. Embeddedness and beyond: Institutions, exchange, and social structure. In: Brinton, Mary C., Nee, Victor (Eds.), The New Institutionalism in Sociology. Russell Sage Foundation, New York, NY, pp. 19–45.
Nelsen, L.L., 1991. The lifeblood of biotechnology: University-industry technology transfer. In: Ono, R.D. (Ed.), The Business of Biotechnology: From the Bench to the Street. Butterworth-Heinemann, Boston, pp. 39–75.
Nowotny, H., Scott, P., Gibbons, M., 2001. Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty. Polity Press, Cambridge, UK.
Olsen, M.E., Lodwick, D.G., Dunlap, Riley E., 1992. Viewing the World Ecologically. Westview Press, Boulder, CO.
Owen-Smith, J., 2006. Commercial imbroglios: Proprietary science and the contemporary university. In: Frickel, S., Moore, K. (Eds.), The New Political Sociology of Science: Institutions, Networks, and Power. The University of Wisconsin Press, Madison, WI, pp. 63–90.
Owen-Smith, Jason, 2005. Trends and transitions in the institutional environment for public and private science. Higher Education 49, 91–117.
Owen-Smith, J., Powell, W.W., 2002. Standing on shifting terrain: Faculty responses to the transformation of knowledge and its uses in the life sciences. Science Studies 15 (1), 3–28.
Owen-Smith, J., Powell, W.W., 2001. Careers and contradictions: Faculty responses to the transformation of knowledge and its uses in the life sciences. In: Vallas, S.P. (Ed.), Research in the Sociology of Work, vol. 10. The Transformation of Work. JAI Press, New York, pp. 109–140.
Peters, S.J., Alter, T.R., Schwartzbach, N., 2008. Unsettling a settled discourse: faculty views of the meaning and significance of the land-grant mission. Journal of Higher Education Outreach and Engagement 12 (2), 33–66.
Powell, W.W., Owen-Smith, J., 1998. Universities and the market for intellectual property in the life sciences. Journal of Policy Analysis and Management 17 (2), 253–277.
Rosenzweig, R.M., 1992. The Research Universities and Their Patrons. University of California Press, Berkeley.
Rotblat, Joseph, 1999. Science and human values. In: Lecture delivered at the Plenary Session on Science in Society at the UNESCO/ICSU World Conference on Science , Budapest, 26 June–1 July.
Shane, S., 2004. Encouraging university entrepreneurship? The effect of the Bayh-Dole Act on university patenting in the United States. Journal of Business Venturing 19 (1), 127–151.
Shin, T., Lamy, E., 2006. Paths of commercial knowledge: Forms and consequences of university–enterprise synergy in scientist-sponsored firms. Research Policy 35 (10), 1465–1476.
Slaughter, S., Rhoades, G., 2004. Academic Capitalism and the New Economy: Markets, State, and Higher Education. The Johns Hopkins University Press, Baltimore.
Slaughter, S., Archerd, C., Campbell, T.I.D., 2004. Boundaries and quandaries: How professors negotiate market relations. The Review of Higher Education 28 (1), 129–165.
Smith-Doerr, L., 2005. Institutionalizing the network form: How life scientists legitimate work in the biotechnology industry. Sociological Forum 20 (2), 271–299.
Stephan, P.E., 1996. The Economics of Science. Journal of Economic Literature 34 (3), 1199–1235.
Stern, S., 1999. Do scientists pay to be scientists? Management Science 50 (6), 835–853.
Stigler, G.J., Becker, G.S., 1977. De gustibus non est disputandum. American Economic Review 67, 76–90.
Thursby, J.G., Thursby, M.C., 2002. Who is selling the Ivory Tower? Sources of growth in university licensing. Management Science 48 (1), 90–104.
Tuunainen, J., 2005. Contesting a hybrid firm at a traditional university. Social Studies of Science 35 (2), 173–210.
Vallas, Steven P., Kleinman, Daniel L., 2008. Contradiction, convergence and the knowledge economy: The confluce of academic and commercial biotechnology. Socio-Economic Review 6 (2), 283–311.
Varma, Roli, 2000. Changing research cultures in U.S. industry. Science, Technology, & Human Values 25 (4), 395–416.
Vogeli, C., Yucel, R., Bendavid, E., Jones, L.M., Anderson, M.S., Louis, K.S., Campbell, E.G., 2006. Data withholding and the next generation of scientists: results of a national survey. American Medicine 81 (2), 128–136.
Walsh, J.P., Cohen, W., Cho, C., 2007. Where excludability matters: Material versus intellectual property in academic biomedical research. Research Policy 36, 1184–1203.
Walsh, J.P., Cho, C., Cohen, W., 2005. View from the Bench: Patents and material transfers. Science 309 (5743), 2002–2003.
Welsh, R., Glenna, L., Lacy, W., Biscotti, D., 2008. Close enough but not too far: assessing the effects of university-industry research relationships and the rise of academic capitalism. Research Policy 37, 1854–1864.
Welsh, R., Glenna, L., 2006. Considering the role of the university in conducting agri-biotechnology research. Social Studies of Science 36, 929–942.
Whittington, K.B., Smith-Doerr, L., 2005. Gender and commercial science: Women's patenting in the life sciences. Journal of Technology Transfer 30, 355–370.
Wible, J.R., 1998. The Economics of Science: Methodology and epistemology as if economics really mattered. Routledge, London, New York.
Xie, Y., Shauman, K.A., 1998. Sex differences in research productivity: New evidence about an old puzzle. American Sociological Review 63 (6), 847–870.