From Bench to Board: Gender Differences in University Scientists' Participation in Commercial Science[*]

Waverly W. Ding
545 Student Services #1900
Haas School of Business
University of California
Berkeley, CA 94720
510-643-4252
wding@haas.berkeley.edu

Fiona Murray
Massachusetts Institute of Technology
Sloan School of Management
50 Memorial Drive E52-568
Cambridge, MA 02142
617-253-3681
fmurray@mit.edu

Toby E. Stuart
Harvard Business School
211 Rock Center
Soldiers Field
Boston, MA 02163
617-496-4626
tstuart@hbs.edu

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ABSTRACT

This paper examines gender differences in the participation of university life science faculty in commercial science. Based on theory and field interviews, we develop hypotheses regarding how scientists' productivity, co-authorship networks, and institutional affiliations have different effects on whether male and female faculty become "academic entrepreneurs". We then statistically examine this framework in a national sample of 6,000 life scientists whose careers span more than 20 years. We find sharp gender differences in participation in for-profit ventures, which we measure as the likelihood of joining the scientific advisory board (SAB) of a biotechnology firm. Compared to men, women life scientists are much less likely to advise for-profit biotechnology companies. We also identify factors that contour this gender difference, including scientists' co-authorship network structure and the level of support for commercial science at their universities. Surprisingly, we find that the (conditional) gender gap is largest among faculty members at the highest status institutions.

I. Introduction

The incidence of "academic entrepreneurship", the significant involvement of university faculty in for-profit companies, has risen precipitously since the late 1970s (Blumenthal et al., 1996; Slaughter and Leslie, 1997; Etzkowitz, 1998). Commercial science opportunities for university faculty include patenting, consulting, joining scientific advisory and corporate boards, and even founding entrepreneurial firms (Murray, 2004; Ding and Choi, 2010). As the literature documents, these opportunities have been especially plentiful in the biomedical sciences. In fact, university-employed scientists have been members of the founding teams of at least half of the 300 or so publicly traded biotechnology firms in existence today, and continue to be scientific advisors to nearly all of them (Stuart and Ding, 2006); rates of patenting by life science faculty have increased (Azoulay, Ding, and Stuart, 2007, 2009); and a study of faculty authors in 14 biomedical journals found that fully one third held patents or an equity position in a biotechnology firm related to their research (Krimsky et al., 1998; for additional evidence, see Audretsch and Stephan, 1996; Zucker, Darby, and Brewer, 1998; Owen-Smith and Powell, 2001; Spencer, 2001; Murray and Stern, 2005; Evans, 2006).

Given these developments, the literature has begun to examine the characteristics of individual faculty that associate with active involvement in the commercial sector (e.g., Louis et al., 1989; Stuart and Ding, 2006; Hsu, Roberts, and Eesley, 2007; Bercovitz and Feldman, 2008; Jain, George, and Maltarich, 2009). In this spirit, our paper joins a few recent articles (Thursby and Thursby, 2005; Rosa and Dawson, 2006; Ding, Murray and Stuart, 2006) that consider the effect of a university scientist's gender on his or her likelihood of participating in commercial science.

For a variety of reasons, we believe this is an important question. First, although the amount of supplemental income academic scientists have collected from commercial activities is unknown, a recent survey of newly public biotechnology companies revealed that in half of the firms, university faculty had large enough equity holdings to be listed in Securities and Exchange Commission filings, with a median value of $5.6 million (Edwards, Murray and Yu, 2006). While the number of scientists that have acquired this level of wealth is small, because universities share licensing royalties with faculty inventors, commercial science has become a source of income for a growing number of faculty members. Therefore, opportunities for extramural work of this nature now meaningfully influence earnings differences among scientists,

and gender differences in commercial science may become a growing source of earnings inequality in the profession.

Second, we have long known that the gender composition of visible organizational positions has an impact on many aspects of management (Kanter, 1977; Blum et al., 1994). For example, greater female representation in senior management or advisory positions may increase a firm's appeal to potential female recruits, especially in the professional workforce. Research on gender effects in supervisory and mentoring relationships (Tsui and O'Reilly, 1989) also suggests that the presence of women at the top of an organization will improve the job experience and performance of female employees.

Third, through interactions with researcher at companies, opportunities to participate in commercial science potentially influence the type and the quality of the research that university faculty perform. Indeed, Agrawal and Henderson's (2002) interviews with MIT scientists reveal that connections with researchers in industry serve as fruitful sources for unearthing interesting research questions. An established track record with industrial firms may also help a scientist obtain industry funding or access to state-of-the-art equipment at corporate labs (Owen-Smith and Powell, 2001). Since both forms of resources may help increase a scientist's productivity, differences in access to opportunities in commercial science between male and female scientists could intensify any existing gender disparities in productivity among university faculty.

In this paper, we quantify the extent of the gender gap in commercial science and we explore the mechanisms that amplify and diminish it. The outcome we examine is the likelihood that scientists will become members of scientific advisory boards (SABs). The analysis we undertake draws from qualitative and quantitative data. We join insights from theory with in-depth interviews to derive hypotheses that we then test in an archival analysis. Since there is a dearth of literature on how gender relates to participation in commercial science, the qualitative component of our analysis proves to be an essential complement to the existing literature in guiding our formulation of hypotheses to test in the large-sample analysis.

We find evidence that women are less likely to join the SAB of biotechnology firms. In a case-cohort data archive containing career histories of a national sample of 6,000 university-employed life scientists, male scientists are more than twice as likely to become formal scientific advisors to companies and this gender gap proves to be particularly wide at elite universities. Our findings suggest that the gap exists because women receive fewer invitations for SAB

participation, rather than because they refuse opportunities to join SABs or because they lack interest in academic entrepreneurship. However, the gender gap is diminished by at least three factors: unambiguous signals of scientific success, direct social ties to co-authors who are academic entrepreneurs, and working at a university that has institutionalized sources of support for commercial science.

The paper is organized as follows: section II briefly reviews the literature on gender and careers, focusing on studies of scientific careers and on stratification in entrepreneurship; section III describes the process of constructing SABs based on our qualitative evidence; in section IV we formulate the hypotheses we test on the archival data; section V describes the research design, data sources, and the estimators we use; section VI presents findings; section VII discusses alternative interpretations of the results; and section VIII concludes.

II. Gender Differences in Academic Careers and Entrepreneurship

Few studies relate a university scientist's gender to his or her likelihood of participating in commercial science, but insights from related literatures may inform gender patterns in academic entrepreneurship. First, there is a long tradition of research examining the effect of gender on different aspects of scientific careers. Much of the empirical work in this area has examined gender differences among academic scientists across four outcome variables: appointment to positions in prestigious departments, research productivity, compensation, and rates of advancement (e.g., Farber, 1977; Reskin, 1978; Long, 1990; Long, Allison, and McGinnis, 1993; Xie and Shauman, 1998, 2003). Although debate remains about the mechanisms that create the gender gap in science, existing studies, with few exceptions, conclude that female scientists who are otherwise comparable to their male colleagues experience less successful careers by the standard metrics of attainment (Haberfeld and Shenhav, 1990; Long and Fox, 1995; Fox, 2001). Specifically, women scientists are less productive than men (Reskin, 1978; Cole and Zuckerman, 1984; Long, 1990; Xie and Shauman, 1998); they are less likely to be on the faculties of elite institutions (Long and Fox, 1995); they advance ranks at a slower rate than men (Farber, 1977; Long et al., 1993; NSF, 2005); they exit the profession at a higher rate (Zuckerman and Cole, 1975; Preston, 1994; Xie and Shauman, 2003); they are disadvantaged in the peer review process (Wenneras and Wold, 1997); and a salary gap continues to separate the sexes (Haberfeld and Shenhav, 1990; NSF, 2005).

The biological sciences, however, are now recognized as an exception to the pronounced gender difference in scientific careers: women in these fields have "broken through" (Long and Fox, 1995; CPST, 1996; Sonnert and Holton, 1996; Xie and Shauman, 2003; we report additional data). For instance, Sonnert and Holton (1996) found no statistical difference between men and women in rates of progression through academic ranks in biology, whereas women were promoted considerably more slowly than men in other areas of science. In our data, female graduate students in recent cohorts are actually slightly more likely than males to attend top 20 Ph.D. programs, and women increasingly populate the junior faculty ranks in highly regarded research universities.

On one hand, the steady progress toward gender equality in career outcomes in the biological sciences may presage gender parity in involvement in commercial science; on the other hand, the expectation of a marked difference in rates of academic entrepreneurship follows from recent evidence concerning related labor market phenomena. Specifically, there is a wide gender gap in involvement in entrepreneurial ventures. Overall statistics indicate that men found new businesses at approximately twice the rate that women do (US SBA, 2001), although the gender-based "self-employment gap" has declined in recent years (Devine, 1994). However, the disparity between the sexes in rates of business founding and occupancy of high-level managerial positions increases with the technological intensity of the sector (Baron et al., 2001)[1]. Likewise, a recent study found that a meager six percent of the $69 billion in venture capital funding dispensed in 2000 was invested in companies with a female chief executive officer (Brush et al., 2001). This last statistic is particularly discouraging for the prospects of female faculty wishing to take their research to the marketplace. Since substantial investment funds are typically required to commercialize university science, access to venture capital or other forms of funding is critical for academic scientists hoping to launch a new company.

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[1] In contrast, women have been relatively successful in full-time scientific careers in biotechnology firms. In a comprehensive study of employment and promotion of Ph.D. life scientists in biotechnology firms, Smith-Doerr (2004) shows that men and women Ph.Ds enter at similar rates. However, in a separate analysis of *all* venture capital funded healthcare companies started after 2001, we have found that of 21,484 executives, board members, and scientific advisors, only 2665 (12.4%) are women. Thus, a reasonable conclusion would be that women have had more success in entering and earning promotions in early stage life sciences companies than in other fields of high technology, but at least in high potential companies, the gender composition remains dauntingly skewed toward male dominance at the highest ranks of the organization.

The role of gender in shaping faculty participation in commercial science may be particularly revealing because academic entrepreneurs are boundary spanners straddling two very different arenas—universities and technology-based industries. The progress women have made toward obtaining representation in high-ranking positions differs across these two settings, which raises the question of how women fare at the interface of these domains. If the gender differences observed in corporate settings extend to advisory board memberships, women academic scientists will be less likely than men to participate in commercial science. In contrast, if representation on advisory boards is proportionate, we will observe over time increasing parity in board composition, reflecting changes in the demographic makeup of life sciences faculties. As yet, the existence, magnitude and moderators of the gender gap are unknown. In the following sections, we first describe the role of SAB as seen from the vantage points of faculty members in the life sciences. Subsequently, we develop predictions that are tested in the archival dataset we have assembled.

III. Evidence from the field: Constructing Scientific Advisory Boards

We conducted interviews with scientists at a single elite university that is among the top producers of biotechnology SAB members and company founders.[2] This institution has a history of excellence in the life sciences and members of its faculty sit on the SABs of many public and private biotechnology firms.

We interviewed 50 scientists. To begin, we identified five departments with faculty that were SAB members and founders of biotechnology firms. We then requested interviews with all female faculty in these departments. Our response rate was 77% (22 women). Next, we completed interviews with a matched sample of male faculty, each of whom was nominated by a female faculty member as her closest peer along the dimensions of academic field, career stage, and research. The response rate among male faculty was 95%. We also completed an additional six interviews with senior male faculty who had been active on a large number of SABs but for whom there were no "matching" female faculty. Through open-ended interviews we sought to

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[2] Our large sample data described below show that SAB members are disproportionately drawn from the life science faculty of elite universities. It is for this reason that we chose to conduct interviews at one of the nation's leading universities.

understand faculty interest in SABs, the sources of the invitations they had received to join SABs, and whether and why these opportunities had been pursued. In addition, we investigated the function of SABs, the characteristics of scientists who would be invited to join, and the process of constructing the board.

Table 1 describes the characteristics of this matched interview sample. As a subsequent comparison with Table 3 will clarify, the interview sample is an exceptionally accomplished group of individuals. Compared to the general population, the men and women we interviewed were prolific in terms of both the quantity and impact of their academic output, and the extensiveness of their participation in academic entrepreneurship. Thus, we note that these scientists' views (and their opportunity sets) are perhaps only representative of those of other accomplished scientists at leading research institutions.

-- Insert Table 1 about here --

Role of the Scientific Advisory Board

There has been relatively little research on the form and function of SABs. These boards have neither fiduciary responsibility nor a formal place in a firm's governance structure. Nevertheless, they have become a near-ubiquitous organizational feature of biotechnology companies. Typically SABs are formed by the founding scientist very early in the development of the firm and have between five and ten members. Board members are rewarded with stock grants and consulting fees.

The scientists we interviewed believe that SABs perform three primary functions for companies. First, they provide expertise, ranging from very specific tacit knowledge to general advice on broad scientific strategy and experimental design. SAB members we interviewed describe how they support the firm's internal research activities; during board meetings, they critique experiments designed by the firm's internal researchers and debate the direction of the next series of experiments. One faculty member commented that he was asked to join a company's SAB when they in-licensed patents developed in his academic laboratory. His presence on the SAB ensured that the firm retained access to his advice for how to integrate his technology into the firm's scientific strategy. In general, our interviewees felt that deep scientific expertise and a basic understanding of business issues made an ideal combination for SAB members.

In addition to offering their expertise, SAB members are chosen to signal scientific quality to external investors. Our interviewees often likened advisory boards to "window dressing". In effect, prestigious academic scientists lend their reputations to the early stage firms they advise, which aids firms in attracting resources (Stuart, Hoang, and Hybels, 1999). A third obligation is that advisors are expected to share their social networks with the firm: they assist in identifying other academics that might provide a critical resource through collaborative research, and they locate suitable students to be hired by the firm.

The SAB members we met volunteered that, in addition to the potential for remuneration, they garnered non-pecuniary benefits from their work with companies. For many, SAB participation was fun; it offered a chance to interact with peers and an opportunity to engage in "real-world" problem solving. Scientists also regarded SAB activities as a chance for leverage and influence. Through their connections with industry, they perceived the chance to extend the impact of their research in the community of corporate researchers. Many scientists also spoke of the opportunity to commercialize their scientific research to benefit those suffering from diseases. And some viewed being in the company of other prominent scientists in the service of promising companies as a form of prestige in itself.

IV. Hypotheses: Gender Stratification in Commercial Science

What are the characteristics of faculty members who are most likely to join a SAB? Relying on the previous description of SABs, insights from our interviews, and the literature on gender and careers, we formulate hypotheses that identify individual-, network-, and university-level factors that contour gender differences in faculty participation in SABs.

Overall Gender Gap

Our interviews reinforced many of the findings of the literature on female participation in entrepreneurship. Even though our interviewees were employees at the same institution and were matched by discipline and cohort, our conversations revealed widespread gender differences in SAB participation: the women we met were much less likely to be invited to serve on SABs and joined them at a much lower rate. Many of the women we interviewed believed that this difference arose because of overt gender discrimination. One illustrative example came when we interviewed a woman with 25 years on the faculty. We initiated our interview by explaining that we wanted to discuss her involvement in commercial science. Her immediate reaction—before

we mentioned the focus of our project—was to ask, "*are you going to address any gender issues?*" She went on to say "*I have never been asked to consult or advise, never once and I have been a faculty member for more than two decades and I work on things related to cancer … that are very relevant to drug development… And many of my male colleagues, who frankly know less than I do, do consult all the time … I just think it's incredibly sexist.*" As we report below, this view was echoed by a number of the most accomplished women faculty in our interview sample. Because of the gender difference in participation in entrepreneurial activity in general, the particularly sizeable gap known to exist in technology-intensive industry sectors, and viewpoints expressed during our interviews, we expect to find that:

Hypothesis 1: women academic scientists will be less likely than men to transition to commercial science.

Assuming the existence of a gender gap, the precise mechanisms through which it emerges will be a challenge to disentangle. We therefore next consider potential factors that moderate the gender-commercial science relationship, with the goal that knowledge of these will illuminate the mechanisms that underlie gender differences in commercial science. We examine three potential areas of contingent effects: individual achievement, social capital, and institutional prestige and resources. In a later section, we then explore the most likely alternative interpretation of the findings. We ask, might the gender differences we observe arise from the limited interest of women to take part in commercial science for reasons such as research priorities or family-related time constraints (Section VII)?

Individual Characteristics

We know from our interviews and from the general function of advisory boards that company founders seek domain expertise in SAB members. However, beyond a consensus that relevant expertise is important, the other criteria for identifying SAB members are ambiguous.

One factor underscored in the interviews is the premium placed on perceived legitimacy within the scientific community. From existing literature, we know that success in the resource mobilization process for new ventures hinges on the legitimacy of the entrepreneurs attempting to attract resources (e.g., Aldrich, 1999; Shane and Stuart, 2002). A number of senior female scientists we interviewed in fact believe that there is gender bias in the SAB formation process precisely because company founders have concerns about the external legitimacy of women

board members. One senior, female scientist explained: "*They would politely say that we [women] weren't invited…I do remember [Bill] telling me women won't do it [serve on SABs or as founders] because business people won't interact with them…I just intuitively knew he was correct…it was just a conversation that was very frank.*" We might interpret this attitude as arising because some external resource holders perceived women to lack credibility in the role of high technology company founder or advisor—gender-typed positions due to the virtual absence of women in these roles in other domains. Even when a woman occupies the same formal position as a man at the time of new venture creation (e.g., professor at the same university), the fact that women are gender-atypical occupants of such positions may lead others to perceive them as less capable than men at performing the tasks demanded by the job (Kanter, 1977; Ibarra, 1992; Ridgeway and Smith-Lovin, 1999).

Research in the literature on expectation states similarly finds that characteristics such as gender often become associated with anticipated performance even when there is no actual relationship between the characteristic and outcome (e.g., Berger, Cohen, and Zelditch, 1972; Ridgeway and Erickson, 2000). In other words, an individual's gender may elicit presumptions about his or her ability to perform a particular task in cultural contexts in which there are gendered assumptions about ability, even in situations in which gender is orthogonal to ability.

In describing the flow of opportunities to join SABs, however, a few women highlighted the impact of particularly visible accomplishments in overcoming these assumptions and therefore changing external perceptions of their work. In contrast to their male colleagues who more often described a "steady flow" of opportunities accruing throughout their career, several women commented that "*the phone started to ring when I was invited to be [Dean, provost, director].*" For women, appointment to a visible administrative position in academe (of little relevance to their scientific expertise) seemed necessary for them to obtain the external status that made them credible contenders for SAB positions. One woman working at the interface of biology and chemistry described it thus: "*About twenty invitations [for engagements with industry] followed my getting this new [administrative] position from companies big and small…I am not sure why…certainly my lab looks at broad problems across many fields – it's an unusually diverse lab – but this is not new! I suppose with the new job I have achieved a level of stature or position that people think is interesting.*"

Social cognition theory offers a plausible explanation for the importance of visible accomplishments in creating opportunities for women scientists (Fiske and Taylor, 1984). It contends that an individual's group membership is often used as a proxy in assessments of ability. Adopting this reasoning to the case of gender differences in invitations to join SABs, one possible cause of perceived differences in desirability is the proclivity of evaluators to invoke the stereotypic beliefs associated with an individual's gender to inform their judgment about his or her potential to perform a task (Festinger, 1954). This is especially likely to occur when few objective facts are available to an evaluator to update his stereotyped appraisals. An implication of such a process is that a readily observable record of outstanding performance, a prize, or another external endorsement may elevate the reputation of a member of a group generally regarded to be of marginal status more than it does an affiliate of a dominant group. Members of the latter group are often endowed with the presumption of competence, and thus an evaluator's assessment of merit is relatively insensitive to additional, verifiable evidence of skill. If participants in the arena of high technology entrepreneurship, such as company founders and venture investors, hold different unconditional probability assessments about the likelihood that men and women will succeed in the role of advising early-stage firms, we would expect:

Hypothesis 2: an observable record of excellent performance will have a greater effect on women scientists' likelihood of joining a SAB than it will on the likelihood for men.

A scientist's employer can also provide him or her with another tangible source of legitimacy: faculty at elite universities benefit from the status conferred by their affiliation. A few faculty noted that after moving to the high status institution where we conducted interviews, they received invitations to serve on SABs and to work with venture capital groups – they had suddenly become more visible. One woman working on drug discovery tools and techniques described: "*I did have one opportunity arrive on my doorstep after I moved to [institution] for the first time ever. The company had read my papers and had seen that I was now here and wondered if I would be interested in developing what we were doing in a more high throughput way and that ended up in a million dollar award and consulting.*" Another woman described how commercial science "*just felt like it was in the air*" when she moved and "*since I came here I have been asked by a former student to sit on a SAB and a couple of other smaller companies although it's still quite limited.*" We heard similar stories from a few male faculty, although none emphasized as sharp a change in opportunities as did the women. Because evaluators hold

different assessments of the SAB expertise of men and women, we anticipate that, compared to men, women will derive greater opportunities for commercial science through association with a prestigious employer. We expect:

Hypothesis 3: an affiliation with a high prestige institution will have a greater effect on the rate that women scientists transition to entrepreneurial science than it will on men's rate.

Social Networks

The selection of SAB members is a highly relational process unfolding across the social circles in science. While the individual and institutional signals of expertise and credibility accrued by faculty are crucial in guiding their selection as SAB members, our interviews suggest that SAB selection also relies upon a mix of direct invitations from former advisors, collaborators and colleagues, invitations from "commercial" colleagues, and third-party referrals as well as "cold-calls."

The most immediate sources of SAB members are a founder's co-authors and co-workers. We discovered that it was common for a founder to invite scientific collaborators both to serve as co-founders of a start-up and as SAB members. Founders might also invite former Ph.D. advisors to lend their reputation to a SAB, or draw upon the expertise of their former students. The social circles from which SABs are drawn also extended beyond the traditional boundaries of invisible colleges (which are generally constrained within a narrow domain of scientific expertise) to incorporate commercially oriented networks formed through commercial science, including SAB participation itself. Consistent with previous research on the role of social networks in facilitating matches between workers and jobs (Granovetter, 1973; Fernandez, Castilla, and Moore, 2000), founders describe the importance of a broad contact network to identify individuals who would be strong candidates to join a SAB.

The picture presented by male faculty is that SABs are assembled from the mobilization of an eclectic and far-flung referral network made up of strong and distal ties. Quotes from male faculty illustrate the diversity of the connections that generated some of their SAB opportunities. For instance, a highly accomplished organic chemist noted, "*my first SAB experience came with X [biotech firm] who found me because one of my friends was on the SAB – he had been a post-doc whom I had mentored and was now a colleague at Y [another institution]…another opportunity came from a friend of Y [the dean] so that's how I got involved in that; they were*

interested in drug delivery and needed a chemist…and I then brought in [Dick] and [Tom] who are both colleagues of mine. I think in the case of Z someone suggested my expertise … ."

Among women faculty, the stories we heard about referrals tended to be limited to close colleagues, collaborators and students who were founding companies; typically individuals with whom they shared research projects rather than more distant social connections. This is consistent with studies suggesting that for entrepreneurial activity, women are poorly positioned relative to men to receive referrals. For example, Renzulli, Aldrich, and Moody (2000) found that women in a sample of would-be entrepreneurs have less diverse networks than do men, and that the lack of multiplicity in women's networks constrains the identification of entrepreneurial opportunities and the transition to company formation (*cf.* Aldrich and Ruef, 2006).

Experienced women felt their colleagues and acquaintances sometimes ignored them when considering commercial opportunities. When asked if she had been invited to join a SAB or offered consulting opportunities by a senior colleague, one woman replied: "***no, I am a woman and so that would never happen to me…I am not bitter about it…it never happens to any of my female colleagues…it's just a fact of life. Maybe I have more female friends in science than male friends and so they ask their friends not me.***" And, we repeatedly heard that when women received opportunities through their networks, the opportunities usually arrived from a strong tie. An experienced biochemist with a limited history of SAB participation explained, "*the only biotech companies I have ever been associated with are developed by [Paul]- a close colleague…he likes me and that's the only reason I am involved…I have a few friends who give me opportunities - people like [Paul]- he has been very good to me…we work on similar things.*" For another woman with expertise in the mechanical properties of tissues and how they change in disease states, her SAB and founding opportunities have come from only two close contacts. The first is a co-author: "*It was [Jim] my collaborator's idea to start the company…someone else was driving it pretty hard getting the whole thing off the ground.*" Her other SAB opportunity came from a woman with whom she had developed a close friendship early in her career and who had provided her with several consulting jobs and recently a referral to a SAB.

Taken together, strong ties appear to be more important for women than men. If, as we have argued above, women scientists may be perceived as less suited to the role of scientific advisor, then to the extent that invitations are accrued, referrals from trusted insiders and close

mentors or collaborators (with first-hand information about an individual's qualifications) will be particularly valuable for women scientists. Stated differently, we examine whether:

Hypothesis 4: location in a direct-tie network conducive to entrepreneurial activity has a greater effect on women scientists' likelihood of joining SABs than it has on male scientists' likelihood.

Employer Resources

Our interviews also suggest a third set of factors that may influence opportunities to join a SAB: institutional resources. One university-level factor noted by interviewees and widely discussed in the literature is the effectiveness of the technology transfer office (TTO) in guiding faculty as they develop relationships with industry. For faculty with few private sector connections, the TTO can serve as a broker that facilitates ties with industry. According to Etzkowitz (2003), these offices are "reservoirs" of social capital; their staffs cultivate relationships with the business community, which are then exploited to connect individual faculty members to potential users of their technology.

We foresee that women scientists are more likely than men to benefit from the institutional support for entrepreneurial activity that exists in universities with active a TTO. The basis for this difference is that scientists who already possess independent relationships with external resource holders (men) are unlikely to rely on the services of a third-party broker to link to established companies. Our interviews reinforced this point; men and women expressed counterposing views of the usefulness of the TTO. None of the men we interviewed had found a SAB opportunity through the TTO. Moreover, they preferred to minimize interactions with the TTO when founding companies—even though the university where we conducted our interviews is known for the success of its technology transfer activities. A senior chemistry professor bluntly expressed his view: "*the TTO is not entirely useless but pretty close to it*". A more junior male scientist felt that the TTO was "*either non-responsive or just difficult to get approval from.*" Instead he found that "*senior faculty guide junior faculty to specific projects and opportunities…I feel I can ask anyone in the department for advice; once Manny [former departmental chair] hooked me up with a company and Bill [another senior faculty member] did another time, so I don't really need the TTO.*" A senior faculty in pharmacology noted that the TTO "*has never found me a licensee or a new opportunity; I have always found my own.*"

In contrast, women we interviewed commented on the importance of support from the TTO in overcoming their lack of contacts and their reluctance to "sell their science." For one woman, the lack of support at her old institution was an obstacle to her commercial participation: "*I had to go out and peddle [my discovery] to find my own licensees so I flew to XX and talked to YY and one other company about the ideas and I came away with the impression that they were cool ideas but might be ahead of their time …without support we had no motivation to push it further.*" After moving institutions she found that "*it's great here - there are sources of support and you don't have to be out on the street peddling an idea that is too soon for the outside…*" In a similar vein, a senior woman in biochemistry stated, "*…when I came to [current institution] they are so good at doing this stuff [patenting] that it's very painless and this makes a huge difference*". Furthermore, while their commentary was subtle, a few women faculty were ambivalent about commercial science, professing a "fear of money" or the potential for being "incompetent with money and finance". For these women, the TTO played a particularly salient role in encouraging their interest in pursuing commercial opportunities.

For women with limited experience in and doubts about their aptitude for commercial science, the TTO becomes an important source of advice, support, and expertise. Because women scientists are less likely to have relationships with industry, and may be less confident in their ability to succeed at commercial science, we anticipate:

Hypothesis 5: the presence of a formal technology transfer office will have a greater effect on women faculty members' likelihood of joining a SAB than it will on the male scientist rate.

V. Archival Data and Methods

To systematically examine these ideas, we have assembled a data archive with career histories of approximately 6,000 life scientists. These data enable us to empirically gauge the determinants of the rate of transition to commercial science. As we discuss next, because there are a large number of academic life scientists and a relatively small number of events for which we are able to obtain detailed information, we employ a sampling procedure known as the "case cohort" design. This method was developed by biostatisticians (Prentice, 1986; Self and Prentice, 1988) and is commonly used in epidemiological research.

Sample and Statistical Estimator

Case-cohort designs are employed when there are few events in a large population of actors, rendering it costly to draw a random sample containing enough events (in the biostatistics literature, events are deemed "failures") for precise estimation. To sample in this way, one first compiles the event histories of some or all of the individuals in a population that experience the event under examination. One then randomly draws a comparison sample, known as the "sub-cohort," from the population. The observations in the sub-cohort are then weighted in the estimation routines to mirror the distribution of events and non-events in the population.

To construct our dataset, we first collected information about *all* Ph.D. scientific advisors at *every* biotechnology firm that has *ever* filed an initial public offering (IPO) prospectus (Form S-1, SB-2, or S-18) with the U.S. Securities and Exchange Commission.[3] A total of 533 dedicated biotechnology firms headquartered in the U.S. have filed IPO prospectuses between 1972, when the first biotechnology firm went public, and January 2002, when we concluded our data collection. We were able to retrieve filings for 511 of these companies, from which we obtained biographical sketches of founders, scientific advisors, and senior executives. In this analysis, we retain only those individuals who hold a Ph.D. degree and were in the employ of a U.S.-based university or research institution at the time they started or joined the biotech company. We have identified 715 unique members of scientific advisory boards. The transitions to *first* SAB membership of these faculty members constitute the events we analyze (the "failure set").

The next step was to create a comparison set (the sub-cohort) of scientists who were eligible to transition to commercial science. We did this by drawing a stratified, random sample of 13,000 doctoral degree holders listed in the UMI Proquest Digital Dissertation database, which reports the name, academic discipline, and date of all U.S. Ph.D. program graduates. The sub-cohort was constructed so that its disciplinary composition and Ph.D. year distribution

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[3] One limitation of these data is that we were only able to obtain information about biotech companies that have filed papers with the SEC. Unfortunately, there are no systematic data sources identifying advisors of private companies. This has two consequences. First, we significantly under-count the actual number of SAB members; thus, the numbers we report below understate the true amount of commercial science in this domain. Second, we are working with a selected sample of companies: it would be reasonable to assume that the firms in our database are relatively successful compared to the average startup company in the biotechnology sector. Thus, the transition events we observe among the scientists in our database are to affiliations with relatively high performance firms.

matched those of the failure set (e.g., 15 percent of biotechnology company advisors hold doctorates in biochemistry, so the random sample contains 15 percent Ph.D.s in biochemistry). We stratified on these two dimensions so that the individuals in the comparison cohort hailed, in exact proportions, from the specific disciplines responsible for the knowledge base exploited in the commercial sphere.

The members of this sample are prospectively followed from the time they earn a Ph.D. We created publication histories for all scientists in our database by querying the ISI's "Web of Science" database. We then used the affiliations listed on papers to identify each scientist's employer and, assuming frequent enough publications, to track job changes.

Approximately 2,000 of the 13,000-person random sample were deleted because they do not appear in the Web of Science in any year after earning their doctoral degrees. We further deleted those who (i) publish exclusively under corporate affiliations, (ii) have zero publications for a period of five consecutive years,[4] or (iii) exit academia during the early stage of their career (those who stop publishing within five years after receiving their Ph.D. are likely to have only held post-doctoral positions before exiting academia). The final matched sample contains 5,229 scientists in the randomly drawn sub-cohort, augmented by the 715 failure cases (SAB members), yielding a ratio of matched sample members-to-failures over 7:1. It has been demonstrated that a cohort-to-case ratio of 5:1 (or higher) results in little loss of efficiency in estimation (Breslow et al., 1983; Self and Prentice, 1988).

We structure the data as individual-level career histories and model the rate of transition to SAB member. Each scientist is considered to be at risk of engaging in commercial science at the later of the time when he or she is issued a Ph.D. degree or the year 1961, when the first-ever biotechnology company was founded.[5] All individuals who are known to be in academia and have yet to engage in commercial science are right-censored at the end of January 2002 or the

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[4] This is based on the assumption that some individuals exit from academia because they fail to earn tenure or choose to pursue professional opportunities outside of academia. We also re-ran all regressions censoring employment spells at 35 years of tenure rather than when publication ceases. The reported coefficients are almost identical in models estimated with the two different definitions of censoring.

[5] In unreported specifications, we also experimented with using 1976—the year that Genentech was founded—as the starting time for treating scientists in the sample as being at risk for the transition to SAB membership. Our results are robust to this alternative definition of time at risk.

(assumed) age of 65.[6]   In the estimations, we use a modification of Cox's (1972) proportional hazards model that adjusts for the case-cohort sampling design. (We describe the statistical properties of the estimator in Appendix 1.)

Variable Definitions

We consult a number of data sources to create covariates at the individual-, network-, and university-levels. All time-changing variables are updated annually and are included in the regression as one-year lags.

The gender of each scientific advisor and member of the control sample was coded based on first names. The literature on naming conventions suggests that gender is the primary characteristic choosers seek to convey in the selection of given names (Alford, 1988; Lieberson and Bell, 1992). We were able to confidently identify gender for 98 percent of the scientists in our data, either based on first names or from web searches. We have assumed that all scientists with androgynous first names are male. Most of the gender-ambiguous names belong to foreign-born scientists of East Asian decent. Given the gender imbalance in science education in these countries, we think it reasonable to assume that these individuals are male.

Previous studies have reported that highly accomplished scientists are most likely to participate in commercial ventures (Audretsch and Stephan, 1996; Zucker, Darby, and Brewer, 1998; Shane and Khurana, 2003). We thus include a number of time-changing measures of scientists' professional achievement. First, we produce an annually updated count of each scientist's total publications. Second, we include the cumulative number of citations received by each scientist's papers, again updating this quantity each year. (Because the citation distribution is truncated and we were only able to gather current-day citation totals for each paper rather than annual counts, it was necessary for us to impute the time path of citations to annualize the data. Appendix 2 describes the estimation procedure we used.)

Third, we compute the (time changing) proportion of a focal scientist's papers for which he or she was the *last* author. By convention in the life sciences, the principal investigator and

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[6] We do not actually know scientists' age, except for company founders and some scientific advisors. We assume that scientists are issued Ph.D.s at the age of 30 and remain in the risk set for a 35-year period, or until they have exited academia if this is known to occur first.

head of a research group occupies the position of last author on papers published by the group. Although last authors' intellectual contribution to joint research often is less than that of first authors, last authors provide crucial resources (e.g., laboratory access) to collaborative endeavors (Shapiro, Wenger, and Shapiro, 1994; Kempers, 2002). Scientists with many last-authored papers will thus be visible in their fields. We expect that these scientists will elicit more commercial-sector opportunities. Moreover, since productive scientists that head large research labs are prominent, we expect that having a high proportion of last authored publications will have a greater effect on the transition rate for women scientists.

Finally, the regressions include a time-changing dummy variable coded as "1" if a scientist is listed as an inventor on one (or more) U.S. patents prior to a given year. Given their visibility in industry, we expect scientists who have patented to be more likely to receive invitations to join SABs. As we discuss below, we also exploit the patent covariate to distinguish among scientists regarding their level of interest in pursuing private-sector opportunities.

Having retrieved information on all papers written by scientists in our sample, we can trace a large section of the evolving co-authorship network in the life sciences. Assuming that co-authorship ties represent reasonably strong relationships between scientists, we utilize these data to proxy for the amount of information about commercial opportunities available in each scientist's network. Although the co-authorship network admittedly is an incomplete representation of scientists' portfolio of connections, it offers the primary benefits of being traceable backward in time and available for the full population of academic scientists.

We create two measures from the co-authorship network. The first is an author's degree score, or the total number of unique coauthors. Individuals with higher degree scores are more likely to have direct and tertiary ties to contacts that could refer them to firms searching for advisors. Second, we count the number of academic entrepreneurs—individuals who have previously (prior to a given year) made the transition to found or advise a biotechnology firm—with whom a focal scientist has one or more co-authored publications. In experiments with different permutations of this covariate, we have found that it is most meaningful when we restrict co-authorship ties to those relationships that were in place *before* a focal scientist's

coauthor had made the transition to commercial science. We label this covariate "primordial ties to academic entrepreneurs" and assume that strong connections to scientists who have already entered the commercial sphere will abet the transition of a focal scientist.[7]

We include two university-level control variables, which are updated over time when individuals switch employers or the values of the covariates change. First, we obtain founding dates for all university technology transfer offices from the Association of University Technology Managers (AUTM) surveys. A time changing "TTO" dummy variable is coded "1" in each year in which the university employing a scientist has an active technology transfer office. Because the mission of all TTOs is to expedite the commercialization of university-owned intellectual property, we expect the transition rate to be higher at universities with TTOs.

Past research has found that elite universities seed more startup companies and have more commercially active faculty than do lower status institutions (Sine, Shane, and Di Gregorio, 2002). To capture the prestige of a scientist's employer, we collected Gourman rankings for all institutions that appear in the dataset. Rather than using the overall university ranking, we include the ratings for the biochemistry department, as this discipline has spawned the greatest number of commercial life scientists (and hence is the modal discipline in our dataset). Continuous rank proved uninformative in the regressions, so we collapsed the scale and dummy coded universities according to whether they occupy one of the top 20 ranks.

The regressions include two variables to accommodate time-related changes. First, we construct an indicator variable coded as "1" for all years prior to 1980, a watershed year for the development of the biotech industry due to the Supreme Court decision on *Diamond v. Chakrabarty* that established the patentability of bioengineered life forms and the successful IPO of Genentech. Second, we include in the regressions the year in which each scientist's Ph.D. degree was granted. This variable is added to adjust for the fact that transition rates may vary with the stage of development of the biotechnology industry.

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[7] In other words, we count the number of coauthors *j* in scientist *i*'s coauthorship network with whom the collaboration predated the time that *j* became an academic entrepreneur. We believe that this covariate has a stronger causal interpretation because if *i* and *j* initiate a collaboration *after j* already has become an academic entrepreneur, the relationship may have been established because the focal faculty member aspires to become involved in commercial science.

VI. Results

We begin with descriptive statistics. Notably, only 49 women are listed as scientific advisors, representing just 6.8 percent of the total number of academic scientists in this role. In comparison, almost 20 percent of the matched sample is female. A log-rank test establishes that the survivor functions for men and women are unequal ($p<0.00001$).

Insert Tables 2 to 4 about Here

Table 2 describes the gender composition of the random sub-cohort, broken out by five-year intervals based on the year of Ph.D. grant. Consonant with published statistics (NSF, 1996; CPST, 1996), the proportion of Ph.D. degrees earned by women in the random sample increases significantly over time. Before 1975, 14.8 percent of the members of the random sample were women; between 1976 and 2002, this percentage grew to 25.8.[8]

Table 3 reports means for the human and social capital variables at five different cross sections of scientists' tenure, broken out by gender and again including only members of the random sample. The relative standing of women scientists in Table 3 would decline substantially if we presented these statistics for the overall dataset, instead of just for the random sub-cohort. As we will demonstrate shortly, outstanding professional achievement is highly predictive of the transition to commercial science. Therefore, the gender imbalance in performance metrics would increase substantially if we were to include the male-dominated SAB members in the data used to generate Table 3. To facilitate comparisons to other studies, we report scientists' human and social capital characteristics for the random sample only.

Multivariate results are presented in Table 4. Following the statistical procedure discussed in Appendix 1, the estimates we report adjust for the case-cohort sampling design using Barlow's (1994) method. Model 1 includes only the time period and gender dummy variables, model 2 adds human capital covariates, model 3 reports the co-authorship network covariates, and model 4 reports employer level effects, along with controls.

Among the control variables, the parameters on the "Prior to 1980" dummy variable and "Year of Ph.D." (model 2) have the expected, negative signs. The human capital variables, number of papers published, number of citations received, and the dummy indicating whether or

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[8] Our interview sample shows a similar gender profile across different faculty cohorts.

not the scientist is an inventor on one or more patents are each strong, positive predictors of the likelihood of joining a SAB.

Considering magnitudes, the patent dummy has a very large effect on the transition to SAB membership—the multiplier of the baseline hazard rate is approximately 3.7. Likewise, a standard deviation increase in proportion of last-authored papers multiplies the rate of transition to commercial science by a factor of 1.7 (=exp[2.286 × 0.243]), and a standard deviation increase in the number of citations garnered by a scientist augments the hazard by a factor of 1.3 (=exp[0.015 × 19.3]) . Consistent with the findings of past studies (e.g., Zucker et al., 1998), the picture to emerge from the individual-level covariates is that academic entrepreneurship is concentrated among the scientific elite.

Turning to models 3 and 4, scientists who have collected a greater number of co-authors throughout their careers are substantially more likely to become academic entrepreneurs. Individuals who have co-authored one or more papers with an academic entrepreneur prior to the time the coauthor joined a SAB or started a company transition at a rate about 2.5 times as high as those who lack connections to academic entrepreneurs. The university-level (employer) variables also perform as expected. Holding a position at a university with a top-20 biochemistry department accelerates the rate of transition to commercial science by a factor of 2.4.

The descriptive statistics in Table 3 show that women scientists have fewer patents, papers, last-authored papers, citations, and co-authors at each career stage than do men. Even after controlling for these variables and the prestige and commercial orientation of a scientist's university employer, we find a large gender difference in the hazard: estimates of the effect of the gender dummy variable range between –0.87 in the unconditional results (model 1) to –0.60 in model 4, which includes human capital, social capital, and employer characteristics. This translates into a per-unit-time hazard rate for male scientists between 1.8 and 2.4 times higher than the transition rate for women.[9]

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[9] In an unreported analysis in which we treat SAB transitions as repeated events (141 scientists in the data were members of multiple public company SABs), we found a slightly more negative gender effect. Of course we cannot generalize beyond these data, but this result suggests a possible cumulative disadvantage for women when multiple forms and repeated episodes of commercial participation are considered.

Models 5, 6, and 7 add nuance to the effect of gender on the transition rate by including interaction terms between the "scientist is female" dummy variable and six covariates: "total publication count", "percent last-authored publication", "count of coauthors", "primordial ties to academic entrepreneurs", "university has a TTO", and "employer prestige". Examining model 5 first, there is no evidence of a difference in the effect of publication counts across the sexes. However, we find a positive interaction between female and percent last-authored publications. Based on our interviews and the literature on gender and careers, we have proposed a possible explanation for this effect, namely that objective indicators of performance matter more in creating opportunities for out-group members. This is supported by comments from some of the women we interviewed that held senior administrative positions, a few of whom noted that offers for SABs arrived after their taking up these roles. Although we do not have data on occupancy of administrative positions, there is evidence that strong academic credentials (running a productive lab) appear to particularly facilitate women scientists' transition rates.

Four interaction effects are reported in model 6. First is an interaction between the gender dummy and our primary proxy for a scientist's social capital, the cumulative number of coauthors the scientist has accrued. The positive, significant coefficient reveals the expected effect: the social capital effect is greater for women. One interpretation of this result based on our interviews is that network connections matter more for women because of their lower credibility in the business community, and thus their greater reliance on referrals, support and encouragement from within their close academic community for invitations to participate in commercial-sector opportunities.

The next finding to note is the large, strongly significant interaction effect between female and having previously coauthored papers with an academic entrepreneur. This result is consistent with our expectation that being in a direct tie network conducive to generating referrals is more important for women faculty than for men.

Turning to the affiliation-level interactions, the "Scientist is female"-by-"TTO" term allows the effect of a scientist being employed at a university that has a technology transfer office to vary with gender. The insignificant main effect on the TTO covariate in model 6, coupled with the positive, significant interaction effect demonstrates that formal institutional support for technology transfer has a statistically significant effect on the transition rate to commercial science, *but only for women scientists*. In this regression, the TTO coefficient shows

the effect for male scientists, and the fact that it is insignificantly different from zero implies that men at universities with TTOs have the same estimated hazard rates as those at employers without TTOs. The positive interaction with "scientist is female" suggests that the presence of a TTO assists women faculty in engagement in the commercial sector. Model 6 thus shows that women scientists often are reliant on institutional support to garner commercial sector opportunities, while men are not.

The last result in model 6 is unexpected: the interaction between "scientist is female" and "top-20 department" is negative, indicating that employment in an elite department boosts the hazard of joining a scientific advisory board more for men than women. The parameter estimates imply that male scientists in top-20 departments have a hazard that is 2.5 (=exp[0.910]) times higher than men in lower-ranked departments. By contrast, comparing a female scientist employed at a non-top-20 department to one holding a position at an elite institution, the woman in the top-20 department has a hazard that is only 1.2 (=exp[0.910 – 0.694]) times higher than her counterpart at a lower-ranked university. Put differently, since men experience a larger boost in the estimated hazard for being in a top-20 department than do women, the magnitude of the gender gap in the transition rate to commercial science is greater among faculty members in prestigious departments than it is among scientists in lower-ranked departments.

We had expected to find that a high status university affiliation conveys legitimacy to scientists wishing to participate in the commercial sector, and that the certification of a high status affiliation would be most valuable for creating opportunities for women scientists. To the extent that this process is at work, forces operating in the reverse more than counterbalance it. One possible factor suggested by our interviews is that as commercial science was initiated, a process of cumulative disadvantage may have developed (*cf.* Cole and Zuckerman, 1984). While some male faculty became central actors in commercial networks, women rapidly became peripheral and lacked the relevant experience. We suggest that this process may have occurred most rapidly in elite universities because of the greater opportunities at these institutions for male scientists to become entrepreneurs.

Wrapping up the discussion of Table 4, model 7 reports the full models with all of the interaction effects. The results are unchanged from the previous regressions. Similarly, although not reported separately, there are only modest changes to significance levels and magnitudes of coefficients for each of the interaction effects when they are individually added to the baseline

(model 3) specification.

VII. Alternative Explanations of the Gender Gap

The archival analysis concludes that women scientists are substantially less likely to join SABs. The results, though, raise questions about causality: Can the gender difference in SAB participation really be attributed to a paucity of opportunities for women scientists to work with companies? There are at least two alternative interpretations of the results that require further investigation. First, there may be "supply-side" factors that deter women from pursuing commercial science. Many studies find that, relative to men, women in the full-time workforce assume greater family responsibilities (e.g., Hochschild and Maschung, 1989; Robinson, 1996). Although there are documented high rates of non-parenting and non-marriage among women faculty, survey data suggest that women faculty (but not men) with children at home work fewer hours per week than their male peers (Jacobs and Winslow, 2004). In addition, a very large fraction of the married female faculty members have spouses with full-time jobs. Therefore, female faculty may have both greater non-professional time commitments and higher household incomes than do male faculty, which may dampen women scientists' interest in allocating their time to SABs.

A second possibility is that net of differences in the amount and impact of scientists' publications, there may yet be a gender difference in the actual *content* of research. If female life scientists develop research streams that are less relevant to questions of interest to commercial enterprise, then the estimated gender gap and the apparent differences in opportunities may be spurious. We now consider each of these possible alternative explanations.

What evidence can be marshaled to adjudicate between supply- and demand-side interpretations of the findings? First, for the interview sample we have detailed accounts of faculty members' level of interest in joining SABs and their perceptions of the opportunities available to them. These views are summarized in Table 5, which categorizes the replies of the scientists we interviewed to questions that we consider to be germane to the sources of the gender gap. Over half (13 of 22) the women we interviewed perceived an explicit gender bias in the SAB formation process. In answering questions to assess their interest in commercial science, 16 of 22 the women faculty expressed a desire to do work of this nature (three with some

reservations), compared to 17 of 22 male faculty. Among those who have been invited to join a SAB, the rate of declining the invitation was actually *lower* among the women than the men.

<div align="center">***Insert Tables 5 & 6 about Here***</div>

In addition to the interview-based evidence, we present three supplemental analyses of the archival data. First, we compare the professional age distribution of time at first SAB transition for men and women; second, we assess whether the magnitude of the gender gaps differs for patenters and non-patenters; third, we investigate gender differences in the content of scientists' research, specifically the likely appeal of scientists' work to industrial firms.[10]

The analysis of the age distribution of first transition is relevant to the issue of labor supply because, in the majority of cases, we believe that opportunities to join SABs will arise at a life stage that follows the time at which many (but not all) women have young children. Moreover, if responsibilities at home preclude women from joining SABs, we might expect to observe that, among SAB members, the distribution of ages at the time of transition for women will be shifted to the right of that for men—we would find that women become advisors to companies at older ages.

The typical scientist in our sample does not engage in commercial science until relatively late in his or her career. For scientists who do join SABs, Table 6 presents the distribution, by gender, of the professional age (measured as years since Ph.D.) at which individuals join their first SAB. Among the 49 female SAB members, 42 transitioned eleven or more years after they obtained their Ph.D., with the hazard peaking in approximately the 20th year after the Ph.D. Assuming that life scientists obtain their doctoral degrees at an average age of 31 (Jacobs and Winslow 2004), this suggests that the times of highest risk are between 46 and 56 years of age. However, the data indicate that transition times are indistinguishable by gender; a two-sample Kolmogorov-Smirnov test for equality of the distribution of tenure at time of first SAB does not reject the null that male and female scientists join SABs at similar career stages (D = 0.119, p-value = 0.536).[11]

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[10] Our interpretation of the findings from the archival analyses is heavily influenced by what we learned in our interviews. The complete qualitative evidence is not included in this section, but available upon request.

[11] Note that the Kolmogorov-Smirnov test is performed on the distributions of failure times defined only for those that have transitioned. As noted previously, the survival functions vastly differ by gender.

While the similarity of the age distributions is suggestive, it is not conclusive. If the population of women scientists is segmented by level of interest in joining SABs, it remains possible that, when selecting on SAB members, we merely observe the similarity of transition times among typical male scientists and the subset of highly interested women. To precisely determine whether the gender gap in SAB membership persists net of differences in scientists' interest in joining boards, we would ideally compare the (conditional) hazard rates for male and female scientists that we know to be interested in commercial-sector work. Otherwise, if a large proportion of the women in the data prefer not to join SABs but most men do seek SAB positions, our empirical results will overestimate the true gender difference—at least the component of it that is based on differences in the opportunity structure. This is because many of the women in the risk set will have (unknown to us) self-selected out of consideration for SAB positions.

Although we cannot directly observe whether the scientists in the data are interested in joining SABs, we do have a reasonably good expression of interest for certain members of the sample. Specifically, 14.6 percent of the scientists in the data are listed as inventors on patents assigned to their universities. Because a scientist's university is unlikely to purse patent protection for research discoveries without the willing participation of the faculty inventor, being listed on a university-assigned patent reveals that a scientist has a genuine interest in exploring the commercial aspects of his or her research. If we examine the magnitude of the gender difference among only those scientists that hold one or more patents, we can reasonably assume that our estimate of the gender gap is unlikely to be explained by inter-scientist differences in commercial interest. Thus, if the gap between male and female patenters parallels that between male and female non-patenters (i.e., if the interaction effect is the null such that the conditional gender gap for women patenters is equivalent to that for women in general), we would take this as evidence against a willingness-to-supply-effort-based explanation for the gender gap.

This analysis appears in the final model (8) in Table 4, in which we add to the full model an interaction between female and inventor on one or more patents. Although the estimated coefficient for the interaction effect is positive, which does suggest that the negative effect of being female is partially offset for women with patents, the coefficient is nowhere near statistical

significance.[12] This result indicates that the gender gap in SAB participation persists even among faculty members that are highly likely to be interested in commercial science.

The data archive also permits us to examine whether there are notable gender differences in the *content* of scientists' research programs. It is naturally the case that certain areas of scientific research have greater commercial value than do others. If women scientists on average are less interested than men in working with companies, we might expect to observe a division of scientific effort: men will migrate some of their research toward questions of commercial interest, while women will not. To assess whether this has occurred, we have generated a (admittedly coarse) measure of the extent of "commercial content" of research: following Lim (2004), we constructed a per-paper average Journal Commercial Score (JCS), which is computed by weighting each *paper* by the proportion of corporate authors that have published in the corresponding *journal*. For example, 95% of the authors in the prestigious journal *Cell* in 1997 had not-for-profit affiliations; hence it receives a JCS of 0.05 for that year. In comparison, Chemical Engineering has a JCS of 0.85 for the year because just 15% of its authors reported academic or government affiliations. The result of the comparison suggests very minor gender differences. The male and female means and standard deviations of the JCS are, respectively, 0.076 (0.056) and 0.074 (0.052). While the mean JCS for men is statistically higher than that for women (t=3.14), the magnitude of the difference—0.002—is extremely modest (less than 3 percent of the mean). Based on this measure at least, we conclude that there is no notable gender difference in the commercial content of research.[13]

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[12] In an unreported estimation, the interaction effect between female and patent status remains insignificant even if we exclude all other interaction terms in model 8.

[13] We have also generated an additional measure of the commercial leaning of scientists' research based on more fine-grained bibliometric information. Specifically, we constructed time-changing "research patentability" scores to measure the patentability of scientists' research by comparing the title words of their articles to those of papers that have been used as the basis for previously issued patents. The (unreported) comparison of means in this measure shows no significant gender gap (details of this measure and the analysis are available from the authors upon request). In addition, we performed (unreported) fractional logit regressions of scientists' (i) research patentability score, and (ii) per-paper JCS. In these models, we included variables such as calendar year and career stage dummies, publication and citation counts, and employer characteristics, along with gender. A scientist's gender has no effect on either of these measures of the commercial content of research.

In conclusion, the combination of qualitative and quantitative evidence we have examined leads us to consider that the gender difference we observe is largely rooted in the opportunity structure at the university-industry interface.

VIII. Conclusions

The scholarly discourse on university-industry relations has proclaimed the arrival of the "entrepreneurial university" (Etzkowitz, 2003) and an era of "academic capitalism" (Slaughter and Leslie, 1997). Particularly in science-intensive industries such as biotechnology and pharmaceuticals, university faculty have played an increasingly important role in shaping firms' scientific trajectories and even their culture and management practices. For this reason, it is important to understand how opportunities to participate in commercial science vary across the ascriptive groups and social positions of academic scientists. Moreover, such knowledge is necessary to fully understand stratification processes in the 21st century scientific labor force.

Our archival analyses show that women scientists are less likely than men to join the advisory boards of for-profit biomedical companies. We have also demonstrated some of the conditions under which the gender gap in commercial science participation rates varies. Our results indicate that the gap is lower among the most accomplished and best-networked scientists. An unexpected finding is that employment in a high-ranking academic department increases the rate of academic entrepreneurship for men more than it does for women, thus creating a larger gender gap in the highest status departments. And we find that the gender gap is more modest in universities that have formal technology transfer offices. This latter result and our fieldwork have policy implications: perhaps because of their more limited social networks and their lack of experience in the private sector, formal institutional support for technology transfer activities is important to assist women faculty in overcoming the obstacles to entry into commercial science.

The statistical analysis we have presented cannot provide a definitive answer to questions of individuals' underlying motivations. However, when interpreted in the light of findings from our interviews and with supplemental empirical analyses reported in section VII, we believe that the conditions under which the gender gap arises are more compatible with a constraint-based explanation, albeit one that may be tempered by some differences in intrinsic interest in commercial science on the part of female faculty. We believe that two insights from our analyses reinforce this claim. First, the finding that measures of professional achievement most strongly

impact women faculty members' commercial participation is suggestive of external constraints on commercial science imposed by perceptions of the illegitimacy of out-group members. Likewise, the result that women are more likely to be aided in their transition to commercial science when they coauthor with someone already serving on a SAB also suggests that close relationships to commercially oriented actors overcomes traditional out-group biases. Second, the result that formal institutional support from a technology transfer office acts only on the transition rate for women scientists is consistent with the comments of female faculty that suggest they are hampered by a lack of contacts. Once structures are in place to overcome their relative lack of commercial experience and broker their scientific expertise, women begin to participate in the commercial process. These findings are underscored by the fact that very few women we interviewed had turned down SAB opportunities. If the limitation on their involvement in commercial science was purely based on a different appetite for commercial-sector work, we would expect to have been told of many declined invitations among women scientists.

The analyses have a number of other limitations. One issue is the limited scope of our fieldwork, which is not representative of the archival sample. We chose to interview scientists at an elite institution because faculty at high prestige institutions hold a disproportionate share of SAB memberships. Still, our qualitative insights are doubtlessly shaped by the distinctive characteristics of the institution we examined. One concern in particular is that women faculty at our interview site tend to be exceptionally career-oriented. In consequence, it would not be surprising if their eagerness to participate in commercial science overshoots the population-wide mean.

Another concern is that we were able to obtain background information on the scientific advisors only for relatively successful biomedical companies. The inability to acquire data on firms that fail at an early age is a perennial problem in research on small firms, and it is one that hampers our study. It is possible that the implicit selection on the performance level of new companies elevates the magnitude of the gender coefficient in the regressions. Indeed our interviews also indicated that the preponderance of SAB invitations received by female scientists were from small startups with limited financial backing rather than the high profile companies founded by serial academic founders with high status venture capital investors.

Nevertheless, for the one university where we conducted our fieldwork, the magnitude of the gender gap remained substantial even when these unsuccessful firms were counted. Obviously, we are unable to directly address this issue on a large scale. Although we think it important, we note that the basic conclusion that there is a significant gender gap in academic scientists' attainment of supplemental income in the commercial sector would remain substantively unchanged. Since the majority of the compensation from participating in early stage companies comes in the form of stock ownership, the payouts from new ventures that fail before reaching public status are likely to be negligible.

We conclude by suggesting one area of research that merits further investigation as a possible source of gender differences in access to commercial science opportunities. There are a relatively small number of prominent (male) university scientists who are hubs in both the biomedical industry and in the academic co-authorship network. These individuals, a few of whom have started or advised more than ten companies, likely play a prominent role in assisting students and co-authors in the transition to commercial science. In fact, a number of these men are both prodigious participants in commercial science and extraordinarily active graduate student and postdoctoral advisors. There is some evidence as well in our data pointing toward the emergence of gender homophily in the co-authorship network. When coupling these bits of evidence with Long (1990), which documents that female Ph.D. students have less productive and less prestigious mentors than do male students, it is possible that gender differences in the connectedness of thesis and post doctoral advisors and coauthors account for some of the gender gap observed in our analysis. We believe that fine-grained, longitudinal investigations of the role of mentoring and the transmission of advisor contacts to favored students may be a promising area of inquiry for understanding group differences in opportunities for commercial science.

References

Agrawal, A., and R. Henderson
2006   "Putting Patents in Context." Management Science, 48(1): 44-60.

Azoulay, P., W. W. Ding, and T. E. Stuart
2007   "The Determinants of Faculty Patenting Behavior: Demographics or Opportunities?" Journal of Economic Behavior and Organization, 63: 599-623.

Azoulay, P, W. W. Ding, and T. E. Stuart
2009   "The Impact of Academic Patenting on the Rate, Quality and Direction of (Public) Research Output." Journal of Industrial Economics 57(4): 637-676.

Aldrich, H. E., and M. Ruef
2006   Organizations Evolving. London: Sage.

Alford, R. D.
1988   Naming and Identity. New Haven, CT: HRAF Press.

Audretsch, D. B., and P. E. Stephan
1996   "Company-Scientist Locational Links: The Case of Biotechnology." The American Economic Review, 86: 641-52.

Barlow, W. E.
1994   "Robust Variance Estimation for the Case Cohort Design." Biometrics, 50: 1064-72.

Barlow, W. E., L. Ichikawa, D. Rosner, and S. Izumi
1999   "Analysis of Case Cohort Designs." Journal of Clinical Epidemiology, 52:1165-1172.

Baron, J. N., M. T. Hannan, G. Hsu, and O. Kocak
2001   "Gender and the Organization-Building Process in Young, High-Tech Firms." in M. F. Guillén, R. Collins, P. England, and M. Meyer (eds.), Economic Sociology at the Millennium. New York, NY: Russell Sage Foundations Press.

Bercovitz, J., and M. Feldman
2008   "Academic Entrepreneurs: Organizational Change at Individual Level." Organization Science, 19(1): 69-89.

Berger, J., B. P. Cohen, and M. Zelditch, Jr.
1972   "Status Characteristics and Social Interaction." American Sociological Review, 37: 241-255.

Blum, T. C., D. L. Fields, and J. S. Goodman
1994   "Organizational Level Determinants of Women in Management." Academy of Management Journal, 37(2): 241-268.

Blumenthal, D., E. G. Campbell, N. Causino, and K. S. Louis
1996   "Participation of Life-Science Faculty in Research Relationships with Industry." New England Journal of Medicine, 335: 1734-39.

Breslow, N. E., J. H. Lubin, P. Marek, and B. Langholz

1983   "Multiplicative Models and Cohort Analysis." Journal of the American Statistical Association, 78: 1-12.

Brush, C. G., N. M. Carter, E. J. Gatewood, P. G. Greene, and M. Hart
2001   "The Diana Project: Women Small Business Owners and Equity Capital-Myths Dispelled." Kauffman Center for Entrepreneurial Leadership, Kansas City, MO.

Cole, J. R., and H. Zuckerman
1984   "The Productivity Puzzle: Persistence and Change in Patterns of Publication among Men and Women Scientists." in P. Maehr, and M.W. Steinkamp (eds.), Advances in Motivation and Achievement: 217-56. Greenwich, CT: JAI.

Cole, J. R., and S. Cole
1973   Social Stratification in Science. Chicago, IL: University of Chicago Press.

Cole, S.
1992   Making Science: Between Nature and Society. Cambridge, MA: Harvard University Press.

Commission on Professionals in Science and Technology (CPST)
1975-2002   Professional Women and Minorities. Washington, D.C.

Cox, D. R.
1972   "Regression Models and Life Tables." Journal of the Royal Statistical Society Series B, 34: 187-220.

Devine, T. J.
1994   "Changes in Wage-and-Salary Returns to Skill and the Recent Rise in Female Self-Employment." The American Economic Review, 84: 108-113.

Ding, W. W., and E. Choi
2010   "Divergent Paths or Stepping Stones: A Comparison of Scientists' Advising and Founding Activities." Research Policy. Forthcoming.

Ding, W. W., F. Murray, and T. E. Stuart
2006   "Gender Differences in Patenting in the Academic Life Sciences." Science, 313: 665-667.

Edwards, M., F. Murray, and R. Yu
2006   "Gold in the Ivory Tower: Equity Rewards of Outlicensing." Nature Biotechnology, 24: 509-515.

Etzkowitz, H.
1998   "The Norms of Entrepreneurial Science: Cognitive Effects of the New University-Industry Linkages." Research Policy, 27: 823-33.

Etzkowitz, H.
2003   "Research Groups as 'Quasi-Firms': the Invention of the Entrepreneurial University." Research Policy, 32: 109-121.

Evans, J.
2006   "Industry Collaboration and Discipline of Academic Science: The Case of *Arabidopsis* Research, 1974-2003." Working paper.

Farber, S.
1977   "The Earnings and Promotion of Women Faculty: Comment." American Economic Review, 67: 199-206.

Fernandez, R. M., E. J. Castilla, and P. Moore
2000   "Social capital at work: Networks and employment at a phone center." American Journal of Sociology, 105:1288-1356.

Festinger, L.
1954   "An Experimental Investigation of the Effect of Unstable Interpersonal Relations in a Group." Journal of Abnormal and Social Psychology, 49: 513-522.

Fiske, S. T., and S. E. Taylor.
1984   Social Cognition. Reading, MA: Addison-Wesley.

Fox, M. F.
2001   "Women, Science, and Academia - Graduate Education and Careers." Gender and Society, 15: 654-666.

Granovetter, M. S.
1973   "The Strength of Weak Ties." American Journal of Sociology, 78: 1360-1380.

Haberfeld, Y., and Y. Shenhav
1990   "Are Women and Blacks Closing the Gap? Salary Discrimination in American Science during the 1970s and 1980s." Industrial and Labor Relations Review, 44: 68-82.

Hochschild, A. R., and A. Maschung
1989   The Second Shift: Working Parents and the Revolution at Home. New York: Viking.

Hsu, D.H., E. B. Roberts, and C. E. Eesley
2007   "Entrepreneurs from technology-based companies: evidence from MIT." Research Policy, 36(5): 768-788.

Ibarra, H.
1992   "Homophily and Differential Returns: Sex Differences in Network Structure and Access in an Advertising Firm." Administrative Science Quarterly, 37:422-47.

Jacobs, J. A., and S. E. Winslow
2004   "The Academic Life Course, Time Pressures and Gender Inequality." Community, Work and Family, 7: 143-161.

Jain, S., G. George, and M. Maltarich
2009   "Academic Entrepreneurs: Investigating Role Identity Modification of University Scientists Involved in Commercial Activity." Research Policy, 38(6): 922-935.

Kanter, R. M.
1977   Men and women of the corporation. New York: Basic Books.

Kempers, R. D.
2002   "Ethical Issues in Biomedical Publications." Fertility and Sterility, 77: 883-888.

Krimsky, S, L., S. Rothenberg, P. Stott, and G. Kyle
1998   "Scientific Journals and Their Authors' Financial Interests: A Pilot Study." Psychotherapy and Psychosomatics, 67: 194-201.

Lieberson, S., and E. O. Bell
1992   "Children's First Names: An Empirical Study of Social Taste." American Journal of Sociology, 98: 511-554.

Lim, K.
2004   "The Relationship between Research and Innovation in the Semiconductor and Pharmaceutical Industries (1981-1997)." Research Policy, 33: 287-321.

Long, J. S.
1990   "The Origins of Sex Differences in Science." Social Forces, 68: 1297-1316.

Long, J. S., and M. F. Fox
1995   "Scientific Careers: Universalism and Particularism." Annual Review of Sociology, 21: 45-71.

Long, J. S., P. D. Allison, and R. McGinnis
1993   "Rank Advancement in Academic Careers: Sex Differences and the Effects of Productivity." American Sociological Review, 58: 703-22.

Louis, K.S., D. Blumenthal, M.E. Gluck, and M.A. Stoto.
1989   "Entrepreneurs in Academy: An Exploration of Behaviors among Life Scientists" *Administrative Science Quarterly* 34(1): 110-131.

Murray, F.
2004   "The Role of Inventors in Knowledge Transfer: Sharing in the Laboratory Life." *Research Policy,* Vol 33, Issue 4, pp. 643-659.

Murray, F., and S. Stern
2005   "Do formal Intellectual Property Rights Hinder the Free Flow of Scientific Knowledge? An Empirical Test of the anti-Commons Hypothesis," NBER Working Paper, 11465.

National Science Foundation
1996   Women, Minority, and Persons with Disabilities in Science and Engineering: 1996. Arlington, VA. (NSF 96-311).

National Science Foundation
2005   Survey of Earned Doctorates (SED). [MRDF]. Arlington, VA: National Science Foundation.

Owen-Smith, J., and W. W. Powell
2001   "Careers and Contradictions: Faculty Responses to the Transformation of Knowledge and Its Uses in the Life Sciences." Research in Sociology and Work, 10: 109-140.

Prentice, R. L.
1986   "A Case-Cohort Design for Epidemiologic Cohort Studies and Disease Prevention Trials." Biometrika, 73:1-11.

Preston, A. E.

1994   "Why Have All the Women Gone? A Study of Exit of Women from the Science and Engineering Professions." American Economic Review, 84:1446-62.

Redner, S.
1998   "How Popular is Your Paper? An Empirical Study of the Citation Distribution." The European Physical Journal B, 4: 131-134.

Renzulli, L A., H. Aldrich, and J. Moody
2000   "Family Matters: Gender, Networks, and Entrepreneurial Outcomes." Social Forces, 79:523-546.

Reskin, B. F.
1978   "Scientific Productivity, Sex, and Location in the Institution of Science (in Research Notes)." American Journal of Sociology, 83:1235-43.

Ridgeway, C. L., and L. Smith-Lovin
1999   "The Gender System and Interaction." Annual Review of Sociology, 25: 191-216.

Ridgeway, C. L., and K.G. Erickson
2000   "Creating and Spreading Status Beliefs." American Journal of Sociology, 106(3): 579-615.

Robinson, J. P.
1996   "Time, Housework and the Rest of Life." Journal of Family and Economic Issues, 17: 213-229.

Rosa, P., and A. Dawson
2006   "Gender and the Commercialization of University Science: Academic Founders of Spinout Companies." Entrepreneurship and Regional Development, 18: 341-366.

Self, S. G., and R. L. Prentice
1988   "Asymptotic Distribution Theory and Efficiency Results for Case Cohort Studies." The Annals of Statistics, 16: 64-81.

Shane, S., and R. Khurana
2003   "Bringing Individuals Back In: The Effect of Career experience on New Firm Founding." Industrial and Corporate Change, 12: 519-543.

Shane, S., and T.E. Stuart
2002   "Organizational Endowments and the Performance of University Start-Ups." Management Science, 48: 154-70.

Shapiro, D. W., N. S. Wenger, and M. F. Shapiro
1994   "The Contributions of Authors to Multiauthored Biomedical Research Papers." The Journal of the American Medical Association, 271: 438-442.

Sine, W. D., S. Shane, and D. Di Gregorio
2002   "The Halo Effect and Technology Licensing: The Influence of Institutional Prestige on the Licensing of University Inventions." Research Policy, forthcoming.

Slaughter, S., and L. L. Leslie
1997   Academic Capitalism: Politics, Policies, and the Entrepreneurial University. Baltimore: Johns Hopkins University Press.

Smith-Doerr, L.
2004   Women's Work: Gender equality versus hierarchy in the life sciences. Boulder: Lynne Reinner Publishers.

Sonnert, G., and G. Holton
1996   "Career Patterns of Women and Men in the Sciences." American Scientist, 84:63-71.

Spencer, J. W.
2001   "How Relevant Is University-Based Scientific Research to Private High-Technology Firms? A United States-Japan Comparison." Academy of Management Journal, 44 (2): 432-440.

Stuart, T. E., H. Hoang, and R. C. Hybels
1999   "Interorganizational Endorsements and the Performance of Entrepreneurial Ventures." Administrative Science Quarterly, 44: 315-349.

Stuart, T. E., and W. W. Ding
2006   "The Social Structural Determinants of Academic Entrepreneurship: An Analysis of University Scientists' Participation in Commercial Ventures." American Journal of Sociology, 112:97-144.

The Association of University Technology Managers
1991-2001   A Survey Summary of Technology Licensing (and Related) Performance for U.S. and Canadian Academic and Nonprofit Institutions, and Patent Management Firm. Northbrook, IL.

Therneau, T. M., and H. Li
1999   "Computing the Cox Model for Case Cohort Designs." Lifetime Data Analysis, 5: 99-112.

Tsui, A.S. and C.A. O'Reilly
1989   "Beyond Simple Demographic Effects: The Importance of Relational Demography in Superior- Subordinate Dyads." Academy of Management Journal, 32(2): 402-423.

US Small Business Association
2001   Women in Business, 2001. US Small Business Association, Office of Advocacy.

Wenneras, C., and A. Wold
1997   "Nepotism and sexism in peer-review." Nature, 387: 341-343.

Xie, Y., and K. A. Shauman
1998   "Sex Differences in Research Productivity: New Evidence about an Old Puzzle." American Sociological Review, 63: 847-870.

Xie, Y. and K. Shauman
2003   Women in Science. Boston: Harvard University Press.

Zucker, L. G., M. R. Darby, and M. B. Brewer
1998   "Intellectual Human Capital and the Birth of US Biotechnology Enterprises." American Economic Review, 88: 290-306.

Zuckerman, H., and J. R. Cole
1975   "Women in American Science." Minerva, 13: 82-102.

Zuckerman, H.

1988   "The Sociology of Science." in Neil J. Smelser (ed), Handbook of Sociology: 511-74. Newbury Park, CA: Sage.

Table 1 Descriptive Statistics for Interview Sample – Means by Gender

	Male (n=22)	Female (n=22)
PhD Year	1985.3	1986.5
Publication Count	91.45	55.45
Publication Count per Year	4.05	2.61
Citation Count	3431.73	2673.18
Citation Count per Paper	36.75	40.91
Number of Co-authors	131.77	90.45
Number of Collaborating Institutions	32.77	22.82
Pct. Joint Industry Publications	17.30%	5.68%
Number of Industry Collaborators	5.05	2.00
% Faculty with Patents	72.73%	22.73%
Patent Count	7.05	1.32
Patent Count (patenting faculty only)	9.69	5.80

Table 2 Ph.D.s Granted in the Random Matched Sample

Ph.D. Grant Period	Female		Male	
1941-1945	4	(9.1%)	40	(90.9%)
1946-1950	6	(10.9%)	49	(89.1%)
1951-1955	14	(10.0%)	126	(90.0%)
1956-1960	30	(16.3%)	154	(83.7%)
1961-1965	47	(11.2%)	374	(88.8%)
1966-1970	121	(15.0%)	683	(85.0%)
1971-1975	185	(16.8%)	916	(83.2%)
1976-1980	203	(19.5%)	839	(80.5%)
1981-1985	154	(28.3%)	390	(71.7%)
1986-1990	176	(30.5%)	401	(69.5%)
1991-1995	89	(35.7%)	160	(64.3%)

Table 3: Mean Values of Human and Social Capital Covariates at Five Professional Tenure Cross-Sections, by Gender

	5th Year		10th Year		15th Year		20th Year		25th Year	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Publication Count	4.620	3.791	10.975	8.632	17.716	13.671	22.380	18.388	25.803	20.777
Citation Count	45.90	38.76	173.73	139.06	353.33	270.59	513.16	400.78	629.44	468.25
Citation Count per Paper	8.285	8.222	13.368	13.576	16.111	16.361	17.717	18.069	18.276	18.170
Pct. Last-authored Publication	0.123	0.094	0.194	0.141	0.242	0.178	0.275	0.203	0.295	0.213
Patent Count	0.116	0.021	0.323	0.050	0.587	0.066	0.740	0.082	0.820	0.100
Count of Co-authors	9.091	8.598	12.709	11.623	15.498	14.175	16.380	15.751	16.961	15.758
Count of Ties to Academic Entrepreneurs	0.038	0.047	0.086	0.085	0.119	0.135	0.134	0.175	0.161	0.127
N	4131	1029	4031	971	3744	835	3332	670	2751	488

Legend: Reports the mean values for the human and social capital variables for scientists in our random, matched cohort, reported at five different levels of professional tenure (5, 10, 15, 20, and 25 years since Ph.D.), and broken out by scientists' gender.

Table 4: Case-Cohort-Adjusted Cox Regression Models of Transition to SAB

	(1)	(2)	(3)	(4)
Trend Controls				
Year is prior to 1980 (=1)	-4.158 (0.509)**	-4.780 (0.542)**	-4.849 (0.547)**	-4.902 (0.546)**
Individual Level Variables				
Gender (female = 1)	-0.865 (0.221)**	-0.703 (0.228)**	-0.643 (0.230)**	-0.594 (0.207)**
Ph.D. degree year		-0.042 (0.009)**	-0.048 (0.009)**	-0.054 (0.009)**
Total publication count		0.009 (0.001)**	0.001 (0.001)	-0.0003 (0.001)
Total citation count		0.015 (0.002)**	0.015 (0.002)**	0.015 (0.002)**
Inventor on one or more patents		1.310 (0.151)**	1.393 (0.151)**	1.333 (0.157)**
Pct last-authored publication		2.286 (0.272)**	2.450 (0.261)**	2.482 (0.254)**
Network Variables				
Count of co-authors			0.004 (0.001)**	0.004 (0.001)**
Count of primordial co-authorship tie to academic Entrepreneurs			0.906 (0.252)**	0.909 (0.239)**
Institutional Level Variables				
Employer prestige (=1 if top 20 department)				0.871 (0.128)**
University has technology transfer office				0.260 (0.135)†
Log-Likelihood	-8779.6	-8254.0	-8134.3	-8066.5
χ^2	80.69	385.23	497.04	556.88
d.f.	2	7	9	11
		(Continued on next page)		

	(5)	(6)	(7)	(8)
Trend Controls				
Year is prior to 1980 (=1)	-4.909 (0.546)**	-4.938 (0.549)**	-4.937 (0.548)**	-4.934 (0.547)**
Individual Level Variables				
Gender (female = 1)	-1.227 (0.357)**	-1.596 (0.508)**	-2.266 (0.628)**	-2.296 (0.631)**
Ph.D. degree year	-0.054 (0.009)**	-0.054 (0.009)**	-0.055 (0.009)**	-0.054 (0.009)**
Total publication count	-0.0004 (0.002)	0.0001 (0.001)	0.0004 (0.001)	0.0004 (0.001)
Total citation count	0.015 (0.002)**	0.015 (0.002)**	0.015 (0.002)**	0.015 (0.002)**
Inventor on one or more patents	1.334 (0.156)**	1.325 (0.155)**	1.331 (0.155)**	1.311 (0.161)**
Pct last-authored publication	2.389 (0.264)**	2.483 (0.254)**	2.367 (0.263)**	2.371 (0.262)**
Network Variables				
Count of co-authors	0.004 (0.001)**	0.004 (0.001)**	0.004 (0.001)**	0.004 (0.001)**
Count of primordial co-authorship tie to academic entrepreneurs	0.920 (0.239)**	0.816 (0.246)**	0.841 (0.246)**	0.811 (0.245)*
Institutional Level Variables				
Employer prestige (=1 if top 20 department)	0.865 (0.128)**	0.910 (0.135)**	0.904 (0.134)**	0.905 (0.134)**
University has technology transfer office	0.258 (0.134)†	0.206 (0.140)	0.205 (0.139)	0.207 (0.139)
Gender Interactions				
Female × Total publication count	0.002 (0.003)		-0.005 (0.004)	-0.007 (0.004)
Female × Pct last-authored publication	1.513 (0.654)*		2.091 (0.722)**	2.090 (0.721)**
Female × Count of co-authors		0.002 (0.001)**	0.003 (0.001)**	0.003 (0.001)**
Female × Count of primordial co-authorship tie to academic entrepreneurs		2.183 (0.674)**	2.704 (0.720)**	2.671 (0.735)**
Female × Employer prestige		-0.694 (0.400)†	-0.706 (0.408)†	-0.644 (0.418)
Female × TTO		1.276 (0.520)*	1.311 (0.530)*	1.268 (0.525)*
Female × Inventor on one or more patents				0.452 (0.552)
Log-Likelihood	-8063.0	-8048.2	-8042.5	-8042.0
χ^2	561.03	1069.21	933.74	923.57
d.f.	13	15	17	18

Notes: (1) Time at risk = 110,383; number of subjects = 5,944; number of events = 715. (2) Robust standard errors in parentheses: † significant at 10%; * significant at 5%; ** significant at 1% confidence level.

Table 5: Summary of Main Qualitative Findings

Question	Female	Male	Notes
Do you believe there is gender-based exclusion from commercial science?	13 of 22	NA	Male scientists not asked this question
Do you have an interest in commercial science?	16 of 22	17 of 22	3 of the 16 women qualified their interest with an explicit expression of one or more reservations
Scientist received one or more invitations to join a SAB?	7 of 22	13 of 22	
Scientist declined one or more invitations to join a SAB?	3 of 7	8 of 13	1 woman declined for lack of interest; 2 for conflicts of interest. 1 man declined for lack of interest; 7 because of other, more interesting opportunities.
Have you served on a SAB?	6 of 22	12 of 22	

Legend: Summarizes the responses of 22 female faculty and 22 male faculty to basic attitudinal and behavioral questions about SAB membership and interest in commercial science. Responses limited to the interview sample at a single, elite university.

Table 6: Tenure at First SAB Transition

Years since Ph.D.	Male	Female
1-5 years	23	1
6-10 years	86	6
11-15 years	126	9
16-20 years	155	13
21-25 years	132	11
25-30 years	74	7
31-35 years	51	2
35-40 years	24	0

Legend: reports number of scientists joining SAB for the first time. A two-sample Kolmogorov-Smirnov test for equality of the tenure distribution across gender indicates statistical equivalence.

Appendix 1: Proportional Hazard Model with Adjustment for Case Cohort Sampling

We use a modification of Cox's (1972) proportional hazards model that adjusts for the case-cohort sampling design. Specifically, let $Z_i(t)$ be a vector of covariates for individual i at time t. Individual i's hazard can be written:

$$\lambda_i(t; Z_i) = \lambda_0(t)\, r_i(t) \qquad \text{where} \quad r_i(t) = \exp[\,\beta'\, Z_i(t)\,] \tag{1}$$

gives the ith individual's risk score at time t, β is a vector of regression parameters, and $\lambda_0(t)$ is an unspecified baseline hazard function. Estimation of β in a standard Cox model is based on the partial likelihood:

$$\prod_t \frac{Y_i(t)\exp[\beta' Z_i(t)]}{\displaystyle\sum_{k=1}^{n} Y_k(t)\exp[\beta' Z_k(t)]} \tag{2}$$

where $Y_{,k}(t)$ indicates whether person k is at risk at t and $Y_{,i}(t)$ indicates whether person i has experienced an event at t. Equation (2), however, produces biased estimates if applied to case-cohort data. This occurs because including all events in a population and a randomly drawn sub-cohort of (mostly) censored cases causes the proportion of events in the dataset to over-represent the proportion of events in the actual population. This in turn results in an incorrect computation of the failure cases' contribution to the Cox score function.

To address this problem, biostatisticians have proposed a pseudo-likelihood estimator. Letting S denote membership in the random draw sub-cohort, the pseudo-likelihood can be written:

$$\prod_t \frac{Y_i(t)\exp[\beta' Z_i(t)]}{Y_i(t)w_i(t)\exp[\beta' Z_i(t)] + \displaystyle\sum_{\substack{k \neq i \\ k \in S}} Y_k(t)w_k(t)\exp[\beta' Z_k(t)]} \tag{3}$$

where the $w_i(t)$ and $w_k(t)$ in the denominator are weights assigned to each observation in the risk set, and all other terms are as defined above. The numerator of the pseudo-likelihood (eq. 3) is equivalent to that of the partial likelihood (eq. 2). The first term in the denominator of equation (3) represents the contribution of the failure cases to the likelihood and the second term represents the contribution of the randomly drawn sub-cohort members in the risk set. We use a modification of the weighting scheme proposed by Barlow (1994). In it, the failure case weight $w_i(t)$ is always "1," and the weights on the members of the sub-cohort, $w_k(t)$, are $1 / p_k$, where p_k is the probability that member k of the matched sample is drawn from the relevant population *and* remains in our data set (see Barlow et al. 1999 for additional details).

The purpose of the sub-cohort weights is to augment the contribution of each of the observations in the random draw so that the proportion of events in the case-cohort sample resembles the proportion of

events in the population overall (or any true random sample thereof). To compute p_k for each random sample member k, we first calculate, for each discipline and degree-year strata, the proportion of the population (all Ph.D.s issued in a given discipline in the focal year) that is included in the random draw, which we denote α_k. If no observations were deleted from the random draw from the UMI database (i.e., if all Ph.D. degree recipients obtained academic appointments), α_k would be the true weight. However, attrition exists because only 40 percent of the members of the original, 13,564-person random sample find positions in academic departments.

Because we possess rudimentary information about all individuals who earn Ph.D. degrees, we can exploit the weighting scheme to adjust for selective entry into the academic profession, conditional on completing a Ph.D. program. Specifically, we know from the existing literature that women Ph.D. recipients are less likely than men to be offered academic positions, engendering selection bias. Using the limited information available from the UMI database for the 13,564 matched sample members, we estimated a probit model yielding the predicted probability that person k is selected into the final matched sample as a function of: gender, degree year, and prestige of Ph.D.-granting institution. We label this probability γ_k. The probit model indicates that male graduates from highly ranked universities are most likely to secure academic positions, thus entering the final, matched sample. With this predicted probability, the conditional probability p_k is then the product of α_k and γ_k. Since the weight $w_k(t)$ applied to each member k is the inverse of his or her probability of reaching the final matched sample, including γ_k augments the leverage of the matched sample members who are most likely to attrite from the dataset; namely, female graduates of lower-ranked universities. With case weights added, a jackknife robust variance estimator based on the estimated effect of deleting each observation from the analysis is used to obtain unbiased standard errors.[14]

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[14] A few different weighting schemes (Prentice 1986; Self and Prentice 1988) and variance estimators have been proposed (Prentice 1986; Therneau and Li 1999) to fit Cox models to case-cohort datasets. Simulation studies using the different weighting schemes and variance estimators have yielded consistent results, particularly when the size of the control sample is large, as it is in our case.

Appendix 2: Computation of Annually Updated Scientist's Citation Count

The Web of Science database supplies the total citation count for each published article at the time we downloaded these data. Thus, we know the total number of cites garnered by all articles in our database between the date of publication and calendar year 2002. However, to compute annually updated citation counts we need to know the total number of citations each article has received up to any given year. We thus must distribute each paper's total citations backward through time. We do so assuming that the arrival of citations follows an exponential distribution with hazard rate (i.e., inverse mean) equal to 0.1. The bibliometric literature suggests that citations accumulate according to an exponential distribution (Redner 1998), and this is true of the typical paper in our database. We identified the specific parameter, 0.1, by manually coding 50 randomly selected papers in each of three publication years: 1970, 1980, and 1990, and then choosing the parameter that yielded the best fit to the actual time path of citations to these randomly chosen papers. We also considered an alternative procedure for distributing 2002 citations backward in time. We regressed the actual annual citations received by the 150 sampled papers on publication year and year-squared. The estimated regression equations were: (i) $0.059 +0.078*pubyear-0.002*pubyear^2$ for papers published in 1970; (ii) $0.02 +0.11*pubyear-0.003*pubyear^2$ for papers published in 1980; and (iii) $0.06 +0.18*pubyear-0.009*pubyear^2$ for papers published in 1990. The two allocation methods yielded highly correlated measures and identical results in the regressions.