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Abstract

This paper examines gender differences in the participation of university life science faculty in commercial science. In part based on interviews, we develop hypotheses regarding how scientists' career achievements—their productivity, co-authorship networks, and institutional affiliations—have different effects on whether male and female faculty will become "academic entrepreneurs". We then statistically examine this framework in a case cohort dataset containing the career histories of 6,000 life scientists. We find that participation in for-profit ventures, which we measure as the hazard of joining the scientific advisory board (SAB) of a biotechnology firm, is a new arena in which gender differences are sharp: compared to men, women life scientists are far less likely to receive compensated advisory roles at for-profit biotechnology companies. Moreover, the gap in participation rates persists after conditioning on numerous measures of human and social capital. We also find that this gender difference is contoured by a number of factors, such as co-authorship network structure and the level of institutional support for commercial science. Surprisingly, we find that the (conditional) gender gap is largest among scientists employed at high prestige institutions.

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ABSTRACT

This paper examines gender differences in the participation of university life science faculty in commercial science. In part based on interviews, we develop hypotheses regarding how scientists' career achievements—their productivity, co-authorship networks, and institutional affiliations—have different effects on whether male and female faculty will become "academic entrepreneurs". We then statistically examine this framework in a case cohort dataset containing the career histories of 6,000 life scientists. We find that participation in for-profit ventures, which we measure as the hazard of joining the scientific advisory board (SAB) of a biotechnology firm, is a new arena in which gender differences are sharp: compared to men, women life scientists are far less likely to receive compensated advisory roles at for-profit biotechnology companies. Moreover, the gap in participation rates persists after conditioning on numerous measures of human and social capital. We also find that this gender difference is contoured by a number of factors, such as co-authorship network structure and the level of institutional support for commercial science. Surprisingly, we find that the (conditional) gender gap is largest among scientists employed at high prestige institutions.

I. Introduction

The relationship between gender and wage attainment, advancement paths, and other aspects of scientific careers has been a topic of keen sociological interest (Cole 1979; Long and Fox 1995). Much of the empirical work in this area has examined sex 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 underlying mechanisms that determine 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 in science (Haberfeld and Shenhav 1990; Long and Fox 1995; Fox 2001).

Fortunately, recent evidence suggests that the gender gap in performance in scientific careers is beginning to close (Xie and Shauman 1998), especially in the life sciences (Sonnert and Holton 1996; CSPT 1996; Xie and Shauman 2003). Belying progress toward gender parity in pay and promotions in academic careers in the biological sciences, our paper describes a new arena in which ascriptive characteristics appear to (dramatically) shape scientific careers: participation rates of university faculty members in commercial science, or what we label "academic entrepreneurship." During the past 25 years, the scope of academic careers has expanded to encompass different aspects of commercial science, including patenting, the founding of for-profit companies, scientific advisory board membership, consulting, and other forms of compensated work with industry. Indeed, academic scientists themselves have started and advised thousands of for-profit companies, a great many of which were explicitly established to capitalize academic research (e.g., Etzkowitz 1998; Zucker, Darby, and Brewer 1998; Owen-Smith and Powell 2001; AUTM 2001).

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's 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 admittedly small, because universities share royalties from industrially licensed discoveries with faculty inventors, commercial science has become a source of income for a growing number of scientists. Therefore, opportunities for extramural work now meaningfully influence wealth differences among scientists. Yet, earnings from these sources do not appear in the wage data typically examined in studies of attainment differences in academic science. Similarly, the non-pecuniary benefits scientists may gain from associating with companies, such as exposure to (unpublished) research in corporate labs, access to state-of-the-art laboratory equipment, and job leads for graduate students, are also unaccounted for in current analyses of career differences.

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 analysis we undertake draws in equal parts from qualitative and quantitative data. We join insights from theory with in-depth interviews to derive propositions that we then test in an archival analysis. Because of the dearth of literature on the influence of demographic characteristics on rates of participation in "academic entrepreneurship," the qualitative component of our analysis proved to be an essential complement to the existing literature in guiding our formulation of hypotheses to test in the large-sample analysis.

The outcome we examine is the likelihood that scientists will become members of scientific advisory boards (SABs). A distinguishing feature of these boards is that new members must be invited to join; for all but the company founder, an individual's involvement hinges on an invitation to participate. This characteristic accounts for our decision to focus on SAB membership, as it helps us to overcome one of the challenges in understanding the nature of the relationship between ascriptive characteristics and discretionary employment outcomes; namely, in generating group differences in participation rates, biases may be exposed when participation hinges on receiving invitations to join a company. We return to the thorny issue of causal mechanisms at much greater length in a later section (and we cannot claim that we have fully succeeded in parsing the sources of the gender gap). Here, we simply note that SABs represent a strategic research site for revealing the root causes of gender differences. Moreover, because the process of forming an advisory board for a new organization is fundamentally a relational one, we consider it to

be a very promising domain for sociological inquiry. In particular, invitations to join a SAB typically arise from close social ties and referrals, and as we describe below, a primary consideration in the construction of the board is its symbolic significance for the public image of the firm.

We find systematic qualitative and quantitative evidence that women are less likely to join the Scientific Advisory Boards of biotechnology firms. In a case-cohort data archive containing career histories of 6,000 university-employed life scientists, we find that male scientists are more than twice as likely as women to become formal scientific advisors to companies. This result is particularly strong at elite universities, where the gender gap is of greater magnitude than among those employed at less prestigious institutions. Our qualitative evidence together with suggestive statistical results indicate that this gap arises 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: first, unambiguous signals of scientific success such as running a productive lab increases the likelihood of SAB participation for women more than for men; second, direct social ties to co-authors who serve on SABs are also differentially more important in increasing female participation; third, working at a university that has institutionalized sources of support for commercial science is of greater benefit to women faculty.

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 Careers – Academic Science and Entrepreneurship

The number of university scientists involved in for-profit companies has grown precipitously since the late 1970s (Eisenberg 1987; Blumenthal et al. 1996; Slaughter and Leslie 1997; Etzkowitz 1998). This trend is most notable in the life sciences disciplines, which have become the primary locus of

university technology transfer (Owen-Smith and Powell 2003; AUTM, all years; Azoulay, Ding and Stuart 2006; Evans 2006). Commercial science opportunities include patenting, consulting, joining scientific advisory and corporate boards, and even founding entrepreneurial biotech firms (Murray 2004; Ding 2006). In fact, university-employed scientists have been the founders of about 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 risen precipitously (Azoulay, Ding, and Stuart 2006); and a study of faculty authors in 14 biomedical journals found, remarkably, that 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 et al. 1998; Owen-Smith and Powell 2003; Murray and Stern 2005; Evans 2006).

There is very little systematic research of which we are aware relating a university scientist's gender to his or her likelihood of participating in commercial science (for two recent exceptions, see Rosa and Dawson 2006; Ding, Murray and Stuart 2006). However, gender patterns in academic entrepreneurship may be informed by insights from related literatures. For instance, the question of whether the reward system in science is universalistic has animated much of the empirical literature on career outcomes in the sociology of science. This body of work has generally concluded that attainment is not blind to ascriptive characteristics (Cole 1992; Zuckerman 1988). Researchers have found that women are under-represented in scientific and engineering occupations (Cole and Cole 1973; Zuckerman and Cole 1975; CPST, all years); 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 found at elite institutions (Long and Fox 1995); they advance ranks at a slower rate than do 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 separates women from men (Haberfeld and Shenhav 1990; NSF 2005).

The biological sciences, however, are now recognized as an exception to the overall patterns of pronounced gender differences 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 well-documented, 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 appears to increase 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 academic scientists wishing to capitalize their research. 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.

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—

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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. That said, in a separate analysis of *all* venture capital funded healthcare companies started after 2001, we find 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.

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, neither the existence, magnitude nor moderators of the gender gap have been revealed. In the following sections, we first describe the role of scientific advisory boards 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 ten contributors of biotechnology SAB members and company founders.[2] This institution has a long 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 a total of 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 very 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 understand faculty interest in SABs, the sources of the

[2] Our large sample data (described in detail below) on academic patenters, firm founders, and SAB members suggest that academic entrepreneurs 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.

invitations they had received to join SABs, and whether and why these opportunities had been pursued. In addition, for the six scientists who were highly experienced in SAB formation, 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 comparison with Table 3 subsequently will make clear, the interview sample is an exceptionally accomplished group of individuals. Compared to the general population, the men and women we interviewed were prolific both in terms of the quantity and impact of their academic output, as well as in the extensiveness of their participation in academic entrepreneurship. Thus, 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 Scientific Advisory Boards. 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 these boards 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, scientists assess and critique experiments designed by the firm's internal researchers and debate the direction of the next series of experiments. For example, one faculty member commented that he was invited to join a company's SAB when they in-licensed a portfolio of 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 a combination of deep scientific expertise and a basic understanding of business issues are an ideal combination for SAB members. For example, commenting

on one of his colleague, an individual reported to us: "*X is who I would want on my SAB – he is a real academic at heart, not a business man, he is one of the smartest people I know, but he also seems to have a great sense of the business side – he knows what is going on…of course he also holds that very valuable patent for drug A.*"

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 is thought to aid firms in the process of attracting resources (Stuart, Hoang, and Hybels 1999; Higgins and Gulati 2003). 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 (Murray 2004).

The SAB members we met volunteered that, in addition to the potential for remuneration, they garnered non-pecuniary professional and personal 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 intractable 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 scientific advisory board? Relying on the previous description of SABs, insights from our interviews, and the sociological 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.

IV.A 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 high-prestige 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 and experienced 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: <u>women academic scientists will be less likely than men to transition to commercial science</u>.

Assuming the existence of a (conditional) 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 hope that knowledge of these will illuminate the mechanisms that underlie ascriptive group differences in commercial science participation. 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?

IV.B 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 criteria for identifying SAB members become more ambiguous.

One factor underscored in the interviews is the premium placed on perceived legitimacy within the scientific community. From existing literature, we understand that success in the resource mobilization process for new ventures hinges on the contacts and legitimacy of the entrepreneurs attempting to attract resources (e.g., Aldrich, 1999; Shane and Stuart 2002). One veteran SAB member and company founder commented that when venture capitalists make determinations about investments in early-stage biotech firms, they often rely upon the guidance of individuals on their own roster of scientific advisors. According to this individual, when the scientific founder and the SAB members are known to the venture capitalist's advisors, the due diligence process is much easier. There is no doubt that credibility is a critical asset for an entrepreneur, especially one seeking external investors.

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—sex-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).

The women we interviewed echoed these ideas, believing that they were not serious contenders for work with industry. One woman described how a close male colleague was always approached at

conferences by industry scientists to give his opinion on topics more central to her area of expertise: "*[Fred] is considered an expert and I have been with him at meetings when they come up and talk to him about XYZ—a subject I know more about … even people who know me talk to him instead. I know what he does and doesn't know in this field and that is hard because when you are with him you feel invisible.*" In other fields of professional work, research supports the notion that women may be viewed with skepticism (Ibarra 1992). Ibarra (1997), for instance, found that women in high-ranking positions in a professional services firm were often perceived to lack credibility, especially when their work required interacting with external constituents.

In describing the flow of opportunities to join SABs, however, a few female faculty commented on the impact of particularly visible accomplishments in 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 women 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 – its 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 capital 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: 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. In fact, evidence consistent with this expectation has been reported in the context of scientific careers: Long et al. (1993) found that an increase in the number of publications of a scientist has a greater effect on the probability of promotion for women scientists than it does for male scientists.

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 women 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 women 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 a few similar stories from 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 an association with a prestigious employer.

We expect: 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.

IV.C Social Networks. The selection of SAB members is a highly relational process unfolding across the social circles comprising the invisible colleges of 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 (academic) 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 expertise) to incorporate commercially-oriented networks formed through commercial science, including SAB participation. Consistent with previous research on the role of social networks in facilitating matches between workers and jobs (Granovetter 1973; Fernandez *et al*. 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 were 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 1999).

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 women and so that would never happen to me…I am not bitter about it…it never happens to any of my female colleagues…its 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, they 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 she had developed a close friendship with 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 being 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 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' likelihoods.

IV.D 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 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 technology transfer offices (TTOs). 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 notorious 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 the commentary is 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: <u>the presence of a formal technology transfer office will have a greater effect on women faculty members' likelihoods of joining a SAB than it will on the male scientist rate.</u>

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 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.

V.A Case Cohort Sampling. 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 typically deemed "failures") to generate reasonably precise parameter estimates. 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. This procedure has been demonstrated to result in very little loss of efficiency.

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 S1, SB2, or S-18) with the U.S. Securities and Exchange Commission.[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.

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[3] All privately owned companies must file an IPO prospectus with the SEC before selling stock to the public. The S-1 is the basic securities registration form. An SB-2 form may be filed in lieu of an S-1 by small businesses meeting certain conditions (e.g., annual revenues less than $25 million). Form S-18 had been the form for small business issuers from 1982 until 1992, when it was replaced with the SB-2.

A total of 533 dedicated biotechnology firms headquartered in the US 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.[4] 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 that they started or joined the biotech company. We have identified 715 unique members of scientific advisory boards. The transition to *first* SAB membership of these university faculty members constitute the events we analyze (the "failure set").

Having identified the population of individual scientists experiencing events, 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 13,564 doctoral degree holders listed in the UMI Proquest Digital Dissertation database, which reports the name, discipline, date, and degree-granting university of all U.S. Ph.D. program graduates. The sub-cohort was constructed so that its disciplinary composition and Ph.D. year distribution matched those of the failure set (e.g., 15 percent of biotechnology company advisors are biochemistry Ph.D.s, 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 then prospectively followed from the time they earned a Ph.D. degree.

Published statistics suggest that fewer than half of new Ph.D.s in the life sciences find employment in academia. Therefore, to construct a random sample of scientists in universities at risk of engaging in commercial science, we must identify who among the Ph.D. degree recipients obtained

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[4] For companies that filed papers to go public after 1995, IPO prospectuses are available on the web from the SEC's EDGAR database (http://www.sec.gov/edgar.shtml). We acquired pre-1995 prospectuses from the SEC's main office in Washington, D.C., where these documents can be paged from an offsite warehouse. Not every prospectus provided detailed information about scientific advisors; we were able to obtain complete information for 70% of the companies.

faculty positions. To determine this, we created publication histories for all scientists in our database. Specifically, we queried the ISI's "Web of Science" database for all publications by authors with names that matched those appearing in our data archive.[5] 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 13,564-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 assumed that, (i) all Ph.D. holders who exclusively publish under corporate affiliations, and (ii) those that have zero publications for a period of five consecutive years, have exited academia. In the regressions we report below, the employment spells of publication-dormant individuals are censored in the transition-to-commercial science regressions at the point in time their publication records stop.[6] After we deleted very early exits (those who stopped publishing five years after Ph.D. grant are likely holding only 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).

V.B Statistical Method. 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

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[5] We automated most of this otherwise very laborious process; the complete list of publications contains 636,113 entries. We undertook a number of steps to eliminate duplicate name matches: we excluded all papers from journals outside of scientists' subject areas; we match merged using surnames, first and middle initials; and in instances in which we appeared to have multiple individuals with the same name, we manually made corrections.

[6] Assumption (ii) is made to accommodate the fact that many individuals exit from university employment because they fail to earn tenure or choose to pursue professional opportunities outside of the academy. 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 different censoring criterion, which is to be expected given that the individuals experiencing events contribute most of the information in hazard rate models (King and Zeng 2000). One limitation of the ISI data is that for most individuals in the control sample who obtained their doctorate degrees prior to 1970, we were unable to obtain early-career employment information due to the fact that the Web of Science provides addresses only for post-1972 publications. In cases for which pre-1973 affiliations were unavailable from other sources, we used an individual's1973 affiliation for the years between the Ph.D. grant and 1972. Such episodes constitute a small percentage of the employment spells in the overall database.

the later of: (i) the time that he or she is issued a Ph.D. degree, or (ii) the year 1961, when the first ever biotechnology company was established.[7] All individuals who are known to be in academia and have yet to engage in commercial science are right-censored at: (i) the end of January 2002, or (ii) the (assumed) age of 65.[8]

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:

$$\lambda_i(t; Z_i) = \lambda_0(t)\, r_i(t) \tag{1}$$

where

$$r_i(t) = \exp[\, \beta' Z_i(t)\,] \tag{2}$$

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:

$$\prod_t \frac{Y_i(t)\exp[\beta' Z_i(t)]}{\sum_{k=1}^{n} Y_k(t)\exp[\beta' Z_k(t)]} \tag{3}$$

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 (3), 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

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[7] 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.

[8] 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.

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:

$$\prod_{t} \frac{Y_i(t)\exp[\beta' Z_i(t)]}{Y_i(t)w_i(t)\exp[\beta' Z_i(t)] + \sum_{\substack{k\neq i \\ k\in S}} Y_k(t)w_k(t)\exp[\beta' Z_k(t)]} \qquad (4)$$

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. 4) is equivalent to that of the partial likelihood (eq. 3). The first term in the denominator of equation (4) 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.[9]

V.C 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.

V.C.1 Individual Level Variables. 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

[9] 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.

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 well-documented 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 et al. 1998; Shane and Khurana 2003), and we expect to reach the same conclusion. 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. 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.[10]

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[10] 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.

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 head of a research group occupies the position of last author on papers published by the group. Studies of authorship order in biomedical research conclude that last authors' intellectual contributions to joint research are sometimes less than those of first authors, but last authors provide crucial resources (e.g., laboratory access) to collaborative endeavors (Shapiro, Wenger, and Shapiro 1994; Kempers 2002). Scientists with a high frequency of 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 highly visible, 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. In most cases, patents for scientific findings produced in university facilities are assigned to individuals' employers, but list contributing scientists as inventors. We sorted all U.S. patents issued since 1963 by inventor name to identify individuals in our career history data file, and then used information on scientists' affiliations to delete extraneous matches. 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.

V.C.2 Co-Authorship Networks. Having downloaded 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 can utilize these data to derive proxies for the amount of information about commercial sector opportunities available to scientists. Although the co-authorship network admittedly provides an incomplete image 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 distill two measures from the co-authorship network. The first is an author's degree score, or the total number of unique coauthors with whom a scientist has collaborated. 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 coauthorship 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.

V.C.3 Work Context Variables. 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.

V.C.4 Additional Controls. 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. This was a watershed year for the development of the biotech industry. Specifically, a landmark Supreme Court decision (*Diamond* v. *Chakrabarty*) established the patentability of bioengineered life forms and a biotechnology firm founded only four years earlier, Genentech, had an attention-grabbing initial public offering that set a record for the fastest increase in stock price for an IPO, from $35 at offering to $89 in only 20 minutes. These events considerably augmented the investment community's interest in sponsoring biotechnology firms, and a significant number of firm foundings ensued in subsequent years. Thus, there were many more opportunities to join SABs in the post-1980 period. 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.

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 one fifth of the matched sample is female. With numbers so disproportionate, it is unsurprising that a log-rank test shows 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 increased significantly over time. Before 1975, 14.8 percent of the members of the random sample were women; between 1976 and 2002, women received 25.8 percent of the Ph.D. degrees granted in our sample[11]. Although not broken out in the table, however, when we disaggregate the data to examine gender composition at the level of individual disciplines, we observe considerable variation in gender composition across the subfields represented in our dataset. For example, in the decade from the middle 1980s to the middle 1990s, 39.8 percent of the Ph.D.s granted in immunology and 34.2 percent of those awarded in microbiology were to women; by contrast, only 17.8 percent of the Ph.D.s in biophysics and 9.4 percent of those in chemical engineering were earned by women.

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 only focusing on the members of the random sample.[12] In examining these data, it is important to keep in mind that all of the reported means condition on a scientist's publication count being greater than zero (because of our reliance on bibliometric data to determine which Ph.D. graduates obtain academic appointments). Although it is unlikely that there are many scientists at research universities with zero publications, there are scientists in teaching positions who have not published. To the extent that teaching positions are disproportionately held by women, the mean scores for the performance measures of female scientists will be biased upward in Table 3.

The univariate statistics in Table 3 are consistent with the findings of past studies: women scientists exhibit enduringly lower levels of productivity than men. First, women publish fewer papers

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

[12] 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 Table 2 shows, most of the scientific advisors are men and, as we will demonstrate shortly, outstanding professional achievement is highly predictive of the transition to commercial science. Therefore, it is obvious that the gender imbalance in performance metrics would increase substantially if we were to include the event set in the data used to generate the statistics in Table 4. To facilitate comparisons to other studies, we report the Table 3 statistics for the random sample only.

than men; the female-to-male ratio of cumulative publication counts is near 0.8 at each tenure cross section. Similarly, women scientists receive fewer overall citations than do men. Our data also include a number of measures that have not been extensively examined in the past, and on a few of these dimensions too, women scientists appear to differ from men. Among these, the most significant disparity is in patenting: women scientists are far less likely than men to be listed as inventors on patents. There is also a significant gender gap in the proportion of last-authored papers: male scientists' are considerably more likely to be listed as the last contributor on their papers. Women also accrue fewer co-authors throughout their careers, although the gender difference on this variable is slight.

There are two covariates for which there is parity across gender. First, the number of co-authorship ties to scientists who have previously started or advised for-profit biomedical companies shows no consistent gender difference across the five tenure cross sections. Second, when citations are examined as a per-paper average instead of a total count, there is little difference between the two sexes.

Multivariate results are presented in Table 4. Following the earlier discussion, 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. The parameters on the "Prior to 1980" dummy variable and "Year of Ph.D." (model 2) have the expected, negative signs. The time-changing human capital variables, number of papers published, number of citations received, and the dummy indicating whether or not the scientist is an inventor on one or more patents are all strong, positive predictors of the likelihood of joining a SAB.

Considering magnitudes, moving from "0" to "1" on the patent dummy has a very large effect—the estimated multiplier of the baseline hazard rate is approximately 3.7. This covariate probably jointly captures the effect of scientists' levels of interest in commercial work, the extent to which their research has commercial applications, and their visibility in industry circles. Likewise, a standard deviation increase in proportion of last-authored papers also multiplies the hazard 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. It is notable that in models that account for departmental prestige, the dummy variable indicating that a university has a technology transfer office is insignificantly different from zero.

The descriptive statistics in Table 3 show that the women scientists in our dataset 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 conditions on human capital, social capital, and employer characteristics. This translates into a per-unit-time hazard rate for male scientists that is between 1.8 and 2.4 times higher than the transition rate for women.[13]

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 robust,

[13] 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 suggest a possible cumulative disadvantage for women when multiple forms and repeated episodes of commercial participation are considered.

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 assumption 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 slope on the social capital covariate is greater for women scientist. A plausible 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, net of the human capital and social capital controls, formal institutional support for technology transfer has a statistically significant effect on the transition rate to commercial science, *but only for women scientists*. (The hazard ratio in model 6 formed by comparing male scientists at universities with TTOs to those at universities without TTOs is not statistically different from zero.) Model 6 thus shows that women scientists appear to be much more reliant than men on formal, institutional support to garner commercial sector opportunities.

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 male than for female scientists. 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 the coefficients for each of the interaction effects when they are individually added to the model 3 specification.

VII. Alternative Explanations of the Gender Gap

Our archival analysis leads us the conclusion that women scientists are substantially less likely to transition to SAB membership. The results, though, raise the question of the mechanisms of causality: Can the gender difference in SAB participation really be attributed to a paucity of opportunities for women scientists to work with companies? In particular, there are at least two alternative (but closely related) interpretations of the results that require investigation. First, there may be supply-side factors that deter women from pursuing commercial science; it is possible, for example, that women scientists are simply less willing than men to allocate their scarce time to compensated extramural activities such as patenting, consulting, joining SABs, or founding companies. If this is the case, the gender gap may be a manifestation of differences in individuals' desire to participate in commercial science, rather than demand-side factors that shape the allocation of opportunities. Second, it is possible that, net of differences in the volume and impact of scientists' publications, there may yet be gender differences in the *content* of research. If female life scientists develop research streams that are less relevant to questions of interest to commercial enterprises, then the estimated gender gap and the apparent differences in opportunities may be spurious. We consider each of these possible alternative explanations.

Many studies have found that, relative to men, women in the full-time workforce assume greater family responsibilities (e.g., Hochschild and Maschung 1989; Robinson 1996). Specifically in the context of faculty careers, there is direct evidence that having a family deters women from entering the profession (Xie and Shauman 2003) and, among those already in the field, shapes how faculty members allocate time (Bellas and Toutkoushian 1999; Jacobs 2004; Jacobs and Winslow 2004a, b). Analyzing data from the National Study of Postsecondary Faculty (NSOPF), Jacobs (2004) finds that male and female full-time faculty work, respectively, 54.8 and 52.8 hours per week. Although there are documented high rates of non-parenting and non-marriage among women faculty, slightly less than half of the women assistant professors in the NSOPF data do have children, and women faculty (but not men) with children at home report working fewer hours per week than their male peers (Jacobs and Winslow 2004a, Table 6). In addition, a very large fraction of the married female faculty members have spouses with full-time jobs. Therefore, married female faculty are less likely than married men to have a spouse at home, and married

women with children are more likely to have significant family-related time commitments. Put simply, female faculty may have both greater non-professional time commitments and higher household incomes than men.

If most faculty members allot long hours to their primary jobs and if women faculty have income-earning spouses and extensive responsibilities at home, then an alternative explanation for the gender gap we have documented is that women simply are unwilling to devote their scarce time to commercial science. Indeed, the challenge of balancing work and family demands did arise in a few of our faculty interviews; two of the women we met declined opportunities to join advisory boards because they lacked the time. One woman stated, *"a couple of people have approached me and we have chatted ...I am very busy, with administrative work and two little kids …and I try and keep my travel on the limited side. I have done some text book writing and I find that that is the thing I enjoy instead of commercialization".* A second woman recounted, *"I wish I could legitimately devote my time to it [start-up]…I would love to see how this plays out …but for me the timing problem is a combination of the balancing act of family and my administrative role – if I totally got rid of my admin job, or my lab or my family (laughs) then I could do it… perhaps the others [men] manage because "they are far more organized than I am!".*

What data can be marshaled to adjudicate between supply- and demand-side interpretations of the findings? Although a small minority of the women we interviewed did cite family commitments as one reason for not working with companies, we find that the balance of the evidence rests on the side of exclusionary processes that deny the majority of women compelling opportunities for commercial work. To reach this conclusion, we present three supplemental analyses that shed light on the issue, in addition to the patterns of interaction effects demonstrated in the regressions.[14] First, we compare the professional age distribution of time at SAB transition for men and women; second, we assess whether the magnitude of the gender gaps differ 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. And

[14] Unfortunately, we lack information on faculty members' marital and parenting status except for our qualitative sample. Needless to say, our analyses could be much more direct (and convincing) if we had such data.

because our interpretation of the findings from the archival analyses is heavily influenced by what we learned in our interviews, we conclude this section with some additional details of faculty views of the mechanisms that give rise to the gender difference in academic entrepreneurship.

Unlike the dimensions of attainment examined in much of the literature on gender stratification in scientific careers, 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 5 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 2004a), this suggests that the times of highest risk are between 46 and 56 years of age.

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 most (but not all) women have young children. In addition, if responsibilities at home do interfere with women scientists' participation in SABs, we might expect to observe that, among SAB members, the distribution of ages at failure time for women will be shifted to the right of that for men. However, the data in fact suggest 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 cannot reject the null that male and female scientists join SABs at similar career stages (D = 0.119, p-value = 0.536).[15]

While the similarity of the age distributions is suggestive, it falls well short of being conclusive. In particular, 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

[15] 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.

boards, we would ideally compare the (conditional) hazard rates for male and female scientists that are 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, then 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 included in our risk set will have (unknown to us) self-selected out of consideration for commercial 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 so 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 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.[16] 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.

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

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 labor in scientific effort: male scientists will naturally migrate some of their research toward questions of commercial interest, while women scientists 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 *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.[17]

Finally, for the interview sample we have detailed accounts of faculty members' level of interest in joining SABs and of their self-perceptions of the opportunity structure for working with companies. Before concluding, we present some of the faculty perceptions that led us to consider that the gender difference we have documented is majority rooted in the opportunity structure at the university-industry

[17] 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.

interface. These views are summarized in Table 6, which categorizes the replies of the scientists we interviewed to questions that we consider to be particularly germane to the sources of the gender gap.

Insert Table 6 about Here

Many women described their perceptions of having limited access to commercial opportunities. In truly stark contrast, none of the men were so opined. As Table 6 indicates, over half (13 of 22) the women we interviewed perceived a gender bias in the SAB formation process. Here we convey a few of the beliefs these scientists expressed. We emphasize that these views are representative (and reinforcing), but not exhaustive; we heard similar views from other scientists that are not quoted here. A senior woman in molecular biology stated, "*the [men] who had been my graduate colleagues in the lab did become the founders of the company [with their advisor]…they were there around my time… I remember at the time thinking that's interesting—why didn't he [the advisor] ask me? But I have never asked him why not.*" Another person told us, "*I do suspect that commercialization is a boys club, just like everything else…while men have no explicit gender bias they just tend to look at men and to choose other men.*" Concurring with this opinion, a third reported, *"There's an interesting sort of comfort level… men are doing most of the inviting…there's a comfort level of interacting with men versus women.…"* A fourth woman was particularly direct: "*I have never been asked to consult for a company, and other male faculty I know do this routinely. I think there is plenty of empirical evidence that there is a gender issue here. In general, there is a male-dominated faculty in [my field]. And I know they're all involved with firms… It's not like I've been asked and turned it down. I know that my colleagues here and in other places all consult because they are quite vocal about it*".

Even among the few commercially active women, there was a sentiment that they may represent the exceptions that proved the rule. For example, one particularly successful scientist with some SAB experience stated, *"All the particular individuals I've been working with have been wonderful…I sense no gender issues at all but generally I have just become more aware of these [gender] issues when I visit places … I see few women in these biotechs, and among the faculty I know starting companies only one is a woman–the rest are men. [Interviewer: Why do you think this is?] Well the general perception is that*

women are not entrepreneurial … It's below the surface I think, a natural tendency to go to men. I suppose I think it's a combination of overt prejudice and hidden bias. You know, the stereotype that women are not entrepreneurial and men are tough enough to take it, respectively. There's just no tendency to think of women." And, a few of the men we interviewed reinforced these views. One male scientist who had established several SABs described how certain highly scientifically regarded female colleagues "*simply didn't have the presence that was required…it doesn't matter how accomplished she was she just didn't fit the part.*" Another noted that his female colleagues seemed "*unwilling to express their opinions in spite of their talent especially when it comes to areas slightly beyond their expertise."*

Perhaps even more striking was the gender contrast in explanations offered by faculty who were non-participants in commercial science. In the interview sample, 16 of 22 (73%) female and 10 of 22 (45%) male faculty members had never served on a SAB (Table 6). Although women clearly perceived a lack of opportunity, it was, ironically, more common for senior men to attribute their non-participation to a *conscious choice* that was related to the opportunity cost of time. (But, Table 6 shows that all but one male and one female scientist that had received offers to join SABs had accepted them.) While men rarely cited family responsibilities as the basis for their lack of time, many nonetheless attributed their decisions to time constraints. For example, one senior male scientist recounted, "*of course there are people who are really plugged in and I never felt like I was really connected…but in this environment I think the opportunities are definitely there if this was something I would have wanted to have done*" but "*I spend a lot of time with students.*" A second male biologist (with a number of family commitments) stated, "*When I think about starting a company, I think "what would I give up?" after all, I don't even have enough time to do the things I want to do now".*

In summary, although the women faculty we interviewed were slightly more hesitant than men in their expressions of interest in commercial science (16 of 22 women were interested, three with reservations, versus 17 of 22 male faculty), we believe that the interview evidence is most consistent with the existence of biases that work against women who would prefer to do some commercial-sector work.

VII. 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). It is likely that as the traditional norms opposing the privatization of academic science erode and federal funding for university research is further curtailed, the trend toward commercializing university research will gain additional momentum. 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. Such knowledge will be necessary for a thorough understanding of stratification processes in 21st century scientific careers.

Our archival analyses show that women scientists are much 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, and that it is more modest in universities that have formal technology transfer offices. 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 establishing a gender gap that is greatest in high status departments.

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 is tempered by some differences in intrinsic interest in commercial science on the part of female faculty. We believe that three 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. Third, in our interviews, we found strong parallels in the attitude towards commercial science among male and female untenured faculty. With the caveat that few of these faculty have yet to achieve the status that would afford them frequent SAB invitations, this does suggest that young male and female faculty have similar perceptions of the importance of commercial science and do not articulate gender differences that are consistent with an interest-based explanation of the observed gender gap. These findings are underscored by the fact that very few women we interviewed had turned down SAB opportunities. If the limitation on 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.

Despite our beliefs and the evidence that we have been able to assemble, it is a clear limitation of this analysis that we are unable to directly account for supply side explanatory factors in the archival analysis. If we and others are correct in our forecast that university faculty will increasingly wear dual hats as academics and entrepreneurs, it will be quite important for us to develop a richer understanding of the precise mechanisms that give rise to the gender imbalance. Ideally, survey data will become available that include information on family status and indicators of faculty interest in and involvement with commercial science.

The analyses have other limitations as well. One issue is the limited scope of our fieldwork, which is not representative of the archival sample. As we noted early in the paper, our decision to interview scientists at an elite institution was driven by the fact that 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 research institution we examined. One worry in particular is that the women faculty at the interview institution 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 level of interest.

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 thus remains possible that the implicit selection on the performance level of new companies serves to elevate the magnitude of the gender coefficient in the regressions we estimate. Indeed our interviews bear out the fact that at least in one elite school, the preponderance of SAB invitations received by female scientists were from small startups with limited venture backing rather than the high profile companies founded by serial academic founders with high status venture backing.

Nevertheless, for the one school we examined, the magnitude of the gender gap remained substantial even when these unsuccessful firms were included in our analysis. Obviously, we are unable to directly address this issue on a large scale. Although we think it important, however, 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 derived 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 almost certainly small.

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 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.

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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

Legend: Rports the mean values of a range of human and social capital covariates broken our by gender for the interview sample.

Table 2:
Percent Female Ph.D.s in Matched Sample
at Five-year Intervals

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%)

Legend: Rports the gender composition of the randomly drawn matched sample, broken out by 5-year windows of Ph.D. year.

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: Rports 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

Time at risk = 110,383; number of subjects = 5,944; number of events = 715

Robust standard errors in parentheses: † significant at 10%; * significant at 5%; ** significant at 1% confidence level.

Table 5: 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: Distribution by gender of times of transition to first SAB membership. A two-sample Kolmogorov-Smirnov test for equality of the tenure distribution indicates statistical equivalence.

Table 6: 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.