Characterizing MIT's Serial Scientist-Entrepreneurs in Life Sciences

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ABSTRACT

Since the Bayh-Dole Act of 1980, the commercialization of ideas generated in academia has driven significant startup activity and expansion in the life sciences. This commercial transformation has been shown by others to be concentrated among a relatively small number of elite academic institutions. However, within these institutions, we find that a small number of prestigious scientists are disproportionately responsible for entrepreneurial and commercial activity. To date, limited research has been conducted which aims to understand the characteristics of such serial scientist-entrepreneurs or their significance in early commercial ventures. This study identifies and characterizes 18 serial scientist-entrepreneurs (defined as faculty who have founded or served on the board of directors of 3 or more startups) on the basis of academic impact, patenting, and social network centrality, as compared to their first-time entrepreneur (i.e., faculty who founded or directed 1-2 companies) and noncommercial peers. These individuals constitute a subset of 66 scientist-entrepreneurs from a population of the 493 scientists who served as faculty in life sciences-related departments at MIT, during the period of 1981 to 2005 (representing the primary commercialization period for biotechnology).

The thesis highlights three key findings. First, the subset of 18 serial scientist-entrepreneurs founded or directed two-thirds of all startup ventures associated with the entire population thus underscoring the significant "skew" in commercial activities. Furthermore, empirical analyses revealed that these serial scientist-entrepreneurs had significantly higher academic impact (i.e., "academic prestige"), as measured by citations to their work, as compared to first-time entrepreneurs and noncommercial scientists. Perhaps not surprisingly, they also had significantly higher numbers of issued U.S. patents, compared to first-time entrepreneurs. Second, the serial scientist-entrepreneurs developed robust relationships with a small group of venture capital investors, who have repeatedly funded their companies. Several of these serial scientist-entrepreneurs retained central positions in the social network of faculty entrepreneurs, potentially brokering and accelerating entrepreneurial activity, including scientific advisory board membership, within the community. These findings suggest that serial scientist-entrepreneurs play a vital role in contributing reputation, deep technical insight, access to intellectual property, and relationship networks to startup life sciences ventures. It remains for additional research to determine whether the active involvement of serial scientist-entrepreneurs has resulted in enhanced startup value or performance.

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1. Introduction

The biotechnology industry has burgeoned in the past 25 years, largely on the basis of ideas generated in academia and commercialized "from bench to bedside." The passage of the landmark Bayh-Dole Act in 1980, together with growth in NIH funding and strengthening US intellectual property rights, led to an explosion in university patenting and licensing (Mowery 2002). From 1979 to 1984, the number of university-issued patents doubled; they doubled again between 1984 and 1989, and nearly doubled during the 1990s, while license revenues grew from $220MM in 1991 to nearly $700MM in 1997 (Colvyas, 2002). This blossoming of university intellectual property and technology transfer activity has translated to robust startup activity to commercialize these inventions, with universities becoming a fount of new, high-tech enterprises through the efforts of faculty, students, postdocs and academic collaborators (Roberts 1991).

Since 1980, U.S. universities, hospitals, and research institutes have spawned 4,543 companies through technology licensing, of which two-thirds continue operating (Stevens et al., 2005). The academic-industry interface and university start-up activity can provide enormous value (Lerner 2005), including:

- for universities, institutional revenues in the form of licensing royalties and equity, prestige and recognition to attract and retain faculty and students, and local economic benefits
- for faculty, sources of wealth and career fulfillment, as well as prestige, funding, and collaborations, and
- for venture investors, sources of investment ideas and investment opportunities

The commercial transformation of academia, however, has centered on a relatively small number of institutions, which represent a significant proportion of licensing income, technology transfer, and entrepreneurial activities. The top 25 universities have accounted for over 50% of all academic patents during the past two decades, and licensing income "is highly concentrated among a few universities and blockbuster patents" (National Science Board, 2006).

Just as a small number of institutions are responsible for a significant portion of university commercialization activities, Thursby and Thursby (2003) have also found that only a small portion of faculty engage in licensing activities – drawing on data with over 3,300 researchers from 6 universities they found that 80% of faculty in their sample "never disclosed or disclosed only once in the seventeen year period." A significant body of work, including research by Agrawal and Henderson (2002), Azoulay et al (2004), Stephan et al (2004), and Markiewicz and Diminin (2004), has concluded that faculty invention disclosure, patenting and licensing activity does not reduce academic productivity, in the form of publishing, and, in fact, patenting is highly concentrated among more productive scientists.

There is "mounting evidence that faculty involvement in the commercialization of university-based technologies is important for success," (Toole, 2005) including work by Zucker et al. (1996, 1998) on "star" scientists in biotechnology. Additional research in this area has been conducted by Thursby et al. (2001), Lowe (2001), and Murray (2004) on the role of faculty-inventors on commercialization and commercial development, and by Lowe and Gonzalez-Brambila (2004) on the research characteristics and productivity of faculty entrepreneurs. Academic principal investigators at leading institutions such as MIT can contribute significant value to entrepreneurial ventures, in the form of "specialized knowledge, network contacts, or reputations," which may positively impact their performance.

To date, however, no research has been conducted on serial scientist-entrepreneurs (i.e., faculty entrepreneurs with multiple entrepreneurial experiences) and, more broadly, there has been limited research conducted on serial entrepreneurs (MacMillan, 1986). While Shane and Khurana (2000) have more recently conducted a study demonstrating that MIT inventors with prior founding experience are more likely to commercialize patents by founding a new company, their research is focused only on the mode of commercialization for an MIT invention and does not extend to studying characteristics of the serial scientist-entrepreneurs, *as primary drivers of entrepreneurial activity.* This is a significant gap as it is possible that the commercialization and entrepreneurial activity within the top-tier academic research institutions is not simply skewed to a small number of faculty but furthermore revolves around an even smaller subset of elite faculty. From the standpoint of university administers interested in spawning academic entrepreneurial 'hubs,' it is critical to understand the significance and characteristics of serial scientist-entrepreneurs toward creating such an environment. Early-stage venture investors may also have deep interest in such a study if it hones the point that serial scientist-entrepreneurs are, in fact, central relationships toward commercializing university inventions via new company formation.

This study extends the prior research on faculty entrepreneurs by identifying MIT-related serial scientist-entrepreneurs – and then by characterizing them in terms of their academic productivity, patenting, and entrepreneurial networks. I have defined *serial scientist-entrepreneurs* as principal scientific investigators (i.e. academic faculty members) who have demonstrated a disproportionate involvement (i.e., 3 or more companies) in startup activity, through founding or serving as board directors. This study identifies these serial scientist-entrepreneurs from a population of 493 life sciences faculty who served at MIT from between 1981 and 2005. In particular, this study investigates the following three questions:

1) What is the significance of serial scientist-entrepreneurs in the commercialization and entrepreneurial activity?
2) What are the characteristics of serial scientist-entrepreneurs (how does their productivity, either in publishing or patenting, compare to their colleagues, and are certain fields more conducive to academic commercial involvement)?
3) Have serial scientist-entrepreneurs established repeated connections with the financing community (i.e., venture capitalists), as evidenced by funding of their startups?
4) Do these serial scientist-entrepreneurs serve as "brokers" of academic commercialization activity within this network of MIT-related faculty or do they simply act as repeated commercializers of research coming from their own laboratories?

I have focused on MIT, in particular, as a leader in university entrepreneurship and technology transfer. According to the MIT Entrepreneurship Center, over 5,000 MIT-related companies today (founded at a rate of 150 per year) employ over 1 million individuals (MIT Entrepreneurship Center 2006). Moreover, MIT inventions have resulted in the founding of 171 companies (venture capitalized and/or with minimum of $500K of other funding) from 1997 to 2005, at a rate of nearly 20 funded startups per year (MIT Technology Licensing Office website). MIT scientific faculty can typically draw upon plentiful resources to facilitate the commercialization of their inventions via new startups and the culture of the university is typically encouraging faculty involvement with industry startups. One such resource is the Deshpande Center for Technological Innovation, which funds novel early-stage research and connects MIT innovators with venture capitalists and entrepreneurial companies.

Experienced "habitual" entrepreneurs (i.e., serial entrepreneurs) identify more business opportunities, pursue more of them, and are associated with more innovative opportunities (Ucbasaran et al., 2006). As Hsu (2005) found, experienced founders are also able to raise the visibility and valuation of their current ventures, as well as reduce the time to obtain initial financing. Audretsch et al. (2006) argue that "scientist entrepreneurship may prove to be the sleeping giant of university commercialization," extending beyond the commercialization activities of technology transfer offices. If so, the social and intellectual capital of serial scientist-entrepreneurs may enable them to be the central conduits for venture investors and startup firms to access knowledge spillovers from university research.

Based on the empirical evidence developed in this study, I show that that at least in the case of MIT, serial scientist-entrepreneurs founded or directed two-thirds of all startup ventures associated with the entire population. In line with prior work on faculty patenting at MIT (Agrawal and Henderson 2002) they were characterized as having significantly higher academic impact (i.e., "academic prestige"), as measured by citations to their work, and higher numbers of issued U.S. patents. They also developed robust ties with a small group of preferred venture capital investors, who provided an avenue of venture financing for their startup companies and may access the serial scientist-entrepreneurs as board members for their technical expertise and scientific networks. Finally, I find that several of these serial scientist-entrepreneurs retained central positions in the social network of faculty entrepreneurs, demonstrating their high degree of entrepreneurial collaboration within this network. Given that these serial scientist-entrepreneurs are frequently founders, board members or SAB members on companies together with other scientists in the network, the data suggest the serial scientist-entrepreneurs may serve a role in brokering and accelerating entrepreneurial activity, including scientific advisory board membership. As experienced entrepreneurs, they can support first-time faculty entrepreneurs in new company formation by introducing them to preferred venture investors, advising them on commercially oriented research plans, and familiarizing them with the university startup process. These findings suggest that serial scientist-entrepreneurs play a vital role in contributing reputation, deep technical insight, access to intellectual property, and relationship networks to startup life sciences ventures. Additional research can be conducted to determine whether the active involvement of serial scientist-entrepreneurs has resulted in enhanced startup value or performance.

The findings of this study may impact our understanding of how academic institutions should manage commercialization activities and resources. From an early-stage venture investor standpoint, the findings also point toward the identification of the serial scientist-entrepreneur as the center of future commercial innovation and academic-industry collaboration although of course their valuable role may be costly and competitive to acquire. The results may also help aspiring scientist-entrepreneurs recognize the value of collaborating with experienced scientist-entrepreneurs in starting new ventures.

2. Hypotheses

Zucker and Darby (1996) suggest that star scientists (defined by them as those with more than 40 genetic sequence discoveries or 20 or more articles reporting genetic sequence discoveries by 1990) and their university-firm ties greatly facilitated scientific commercialization. In particular, they observed higher scientific productivity, as measured by higher annual citation rates, for stars with greater commercial involvement – over 9 times as frequently as peers with no patents or commercial ties (Zucker and Darby, 1996). Similarly, Lowe et al. (2004) found faculty entrepreneurs to be among the leaders in their respective fields.

Leading academic scientists are more likely to be serial entrepreneurs, and vice versa, for several reasons. First, they are more likely to have been associated with (either from their own lab or via their expansive collaborations) key scientific discoveries which have commercial potential. Their academic prestige may attract less-established scientists to seek them out as scientific co-founders or as board members, to lend credibility, guidance, and experience to the new venture (Murray 2004). They may also retain the "intellectual human capital" enabling them to have insight into potential commercial opportunities from scientific discoveries and then to be indispensable toward the commercialization of this research.

Since Bayh-Dole, important university research results are now increasingly protected by patents. Therefore, the number of issued U.S. patents becomes another measure of scientist productivity, in addition to a measure of their commercial orientation. Especially in life sciences, where intellectual property rights are at the core of building enterprise value, these patents may also form the basis of a new venture, or they may have been issued within the context of the private venture itself (rather than from within the environs of the university).

Therefore, I hypothesize the following:

- *Hypothesis 1. Serial scientist-entrepreneurs have had success in academia and are translating that success to commercialization.*
    - *Hypothesis 1a. A significantly higher proportion of serial scientist-entrepreneurs will be represented in the 'highly cited researchers' list than their peers.*
    - *Hypothesis 1b. Serial scientist-entrepreneurs will also demonstrate a higher rate of patenting activity vs. their peers.*

Given the focus of "applied sciences" on solving practical problems, rather than pursuing the fundamental advancement of knowledge, commercialization opportunities may be more prevalent within applied science departments. As a result, leading scientists with access to those opportunities may have greater opportunities to become involved with multiple startups (hence, becoming serial scientist-entrepreneurs). Faculty in applied science departments may also have greater access to industry relationships. If entrepreneurship were stratified across applied science versus basic science departments, such a finding would further narrow the "risks" and benefits associated with commercialization to a subset of faculty researchers.

- *Hypothesis 2. Serial scientist-entrepreneurs are more likely to be overrepresented in applied fields vs basic science fields. Applied fields are defined as applied biological sciences,* *chemical engineering, and health sciences & technology. The remaining departments are characterized as basic science fields.*

Launching a new scientific enterprise or university spinoff is contingent upon securing financing, often by venture capitalists, and further growth is likewise constrained by venture capital fundraising. Serial scientist-entrepreneurs may be able to access venture capital faster through their social capital / social networks, as well as on the basis of their prior experience. Likewise, venture capital firms may demonstrate a strong interest in a leading faculty member who has "exclusive" access to innovation within the four walls of the university, via their human intellectual capital. The resulting trust-based relationship between the scientific expert and the venture investor may result in a form of commercialization collaboration, which may manifest as founding status or board of director status for startup companies.

Successful serial scientist-entrepreneurs may then be further recruited by less experienced scientists as advisors to their entrepreneurial endeavors and as facilitators toward access to venture capital. Their role model status would serve as a mechanism for accelerating broader faculty entrepreneurship.

There, I hypothesize:

- *Hypothesis 3. Serial scientist-entrepreneurs will demonstrate a repeated connectedness with the same members of the venture capital financing community. One or more VCs will make a repeated showing in VC funding of those startups where serial scientist-entrepreneurs are involved, as evidenced by funding 2 or more of their startups, as compared to a 'random'* *case which would show a distributed funding of serial scientist-entrepreneur affiliated companies (I describe the case in more detail later in this study)*

- *Hypothesis 4. Serial scientist-entrepreneurs will play a central role brokering commercial relationships (i.e., SAB membership, founder status, or board of directors membership) for other scientists. In other words, once scientific advisory board membership has been taken into account, serial scientist-entrepreneurs – more so than first-time entrepreneurs – will retain central status within the MIT scientist social network, based on commercial ties. In particular, this empirical study would demonstrate that serial scientist-entrepreneurs are highly collaborative in their entrepreneurial activity, within the network (as demonstrated by centrality measures). The null hypothesis, in essence, would be that serial scientist-entrepreneurs are isolated in their entrepreneurial activities and do not have strong commercial relationships amongst their peers.*

3. Methods

3.1 Sample and Data Sources

1. Population of scientists

In carrying out the analysis, I first identified a population of 493 current and former MIT life sciences scientific investigators – i.e., scientists who had MIT faculty positions (assistant professor, associate professor, professor) from 1981-2003 in the following departments:

- Applied Biological Sciences
- Biology
- Biological Engineering
- Brain & Cognitive Sciences
- Chemical Engineering
- Chemistry
- Health Sciences & Technology
- Toxicology

These individuals were identified through the departmental listings in the annual MIT course catalogs. Each scientist was given a unique identification code, *SID*, consisting of his/her first and last names. The resulting database included the scientists and departmental affiliation(s). Scientist positions (i.e., assistant professor, associate professor, professor, or professor emeritus) and year(s) of MIT affiliation were also recorded, but these are not used in the later analyses. This population is defined as the *MIT scientist* population.

2. Population of commercial affiliations and companies

Scientist-firm involvement was conducted at two levels. First, zoominfo, google, and Internet searches were used to identify publicly available involvement of the population of scientists as founders, board members, or scientific advisory board members with firms. Second, a search of each individual was conducted using VentureSource and VentureXpert to identify board of director/executive involvement in venture-funded companies. Only affiliations were with companies which were private at the time of the affiliation were included (i.e., pre-IPO affiliations are included, as these were affiliations with then-private companies, but post-IPO affiliations with public companies were excluded).

Because of the deep and active involvement of founders and board directors in companies, I identified a population of 134 companies with individuals from the *MIT scientist* population as founders or board directors. These companies were characterized using VentureSource, VentureXpert, and publicly available information via Internet searches by: status, stage, number of employees, $ raised, value at last financing or exit, and year founded. Additionally, a list of venture capital firms investing in the companies was collected.

3. Populations of commercial scientists and serial scientist-entrepreneurs

The *commercial scientist* subset of the *MIT scientist* population was defined as the 66 individuals from the *MIT scientist* population were identified who served as founders or board directors of 1 or more private companies. The subset of individuals affiliated with 1-2 companies is identified as the *first-time entrepreneur* population. A subset of 18 individuals, who served as founders or board directors of 3 or more private companies, was defined as *serial scientist-entrepreneurs*.

4. Publication productivity

The Institute of Scientific Information's "Highly Cited Researchers" list at http://www.isihighlycited.com identifies the top 250 individual researches in 21 subject categories who have demonstrated great influence in their field as measured by citations to their work. A search was performed on the 493 individuals in the *MIT scientist* population to determine their status on the "highly cited researchers" list, as a measure of their scientific productivity.

5. Patenting activity

The number of issued U.S. patents was determined for each individual in the *commercial scientist* subset through searches on the USPTO website and on http://www.freepatentsonline.com.

3.2 Dependent Variables

A set of variables are measures of the entrepreneurial activity, as defined by the number of company affiliations, of the individuals within the *MIT scientist* population.

1. Serial scientist-entrepreneur

The variable, *serial scientist-entrepreneur*, is a dummy = 1 if the individual is a member of the *serial scientist-entrepreneur* subset, defined as founders or board directors of 3 or more private companies.

2. Company count

The variable, *company count*, is a count of the number of private and public company affiliations (identified via publicly available sources) at the founder or board directorship level, made with private companies or, in the case of public companies, during the pre-IPO time period.

3.3 Independent Variables

1. *Highly cited researcher*

The variable, *highly cited researcher*, is a dummy = 1 if the scientist is listed in ISI's "Highly Cited Researcher" database online (mean = 0.104) and is a measure of the academic impact of the scientist's work.

2. *Patent count*

Patent count, which ranges from 0 to 183, is a count of the number of issued U.S. patents for which the scientist is listed as an inventor (mean = 14.646 and median = 9, for the *commercial scientist* population). Patent count is a measure of the degree of commercial interest by a scientist.

3. *Applied vs. basic*

Applied vs. basic is a dummy variable for the category of departmental affiliation for the scientist. It is = 1 if the scientist's departmental affiliation is an applied sciences department, = -1 if the scientist's departmental affiliation is in basic sciences, and = 0 if the scientist is affiliated with both basic and applied sciences departments (mean = 0.100). The applied science departments were identified as:

- Applied Biological Sciences
- Biological Engineering
- Chemical Engineering
- Health Sciences & Technology
- Toxicology

Three departments were identified as basic sciences:

- Biology
- Brain & Cognitive Sciences
- Chemistry

Applied vs. basic is a measure of the degree to which the individual conducts research that has potential commercial application, versus basic science research for knowledge development.

3.4 Control Variables

PhD age (mean = 31.271) is a measure of the number of years the scientist has been an active scientific investigator. It is calculated by the year 2005 minus the PhD graduation year of the scientist. The PhD graduation year was available for 59 of the 66 individuals in the *commercial scientist* population. PhD age was used as a control variable for company count and patent count by determining the rate of company formation (i.e., *companies/year*) and patenting rate (i.e., *patents/year*).

3.5 Statistical Analysis

Microsoft Excel was used to conduct statistical analyses, such as t-tests and correlations.

3.6 Social Network Analysis

UCINet 6 for Windows and NetDraw 2.34 were used to calculate social network centrality measures and to draw network maps of the *MIT scientist* population, with the scientists (and venture capital investors) as nodes and company affiliations (founder, board of directors, or scientific advisory board membership) as ties. Scientific advisory board membership for the *MIT scientist* population was determined via publicly available information via zoominfo and Google searches.

4. Results and Empirical Analyses

Descriptive statistics of MIT scientists, commercial scientists, and serial scientist-entrepreneurs

From the total *MIT scientist* population (n = 493), 66 scientists were identified to be in the *commercial scientist* cohort – i.e., they founded or served on the board of directors of at least one private life sciences company – and represent only 13.6% of the *MIT scientist* population. 18 scientists, comprising the *serial scientist-entrepreneurs* subset and representing 3.7% of the *MIT scientist* population, founded or served on the board of directors of 3 or more private companies.

The 66 scientists in the *commercial scientist* population were affiliated as founders or board directors of 134 private, life sciences companies. Within this *commercial scientist* population (n=66), the average number of private companies founded/directed is 2.47 (standard deviation = 3.06), and of the *serial scientist entrepreneurs* (n=18), the average number of private companies founded/directed is 5.94 (standard deviation = 4.24), with the highest being 20 (See Figure 1.)

Of the 134 companies founded or directed by the *commercial scientist* population, 89 companies are affiliated with *serial scientist entrepreneurs*. Thus, *serial scientist entrepreneurs* – 3.7% of the total population – are responsible for two-thirds (66.4%) of entrepreneurial activity. The top 8 serial scientist-entrepreneurs (who have each founded/directed 5 or more companies) are responsible for 65 companies, or nearly half (48.5%) of the 134 companies studied (see Figure 2).

Serial scientist-entrepreneurs are more likely to be top academic scientists

An analysis of the ISI highly cited list reveals that 51 of the *MIT scientists* are represented as one of the top 250 scientists in their subject area (as measured by citations of their work). Of these 51, 19 have founded/directed at least 1 company, and 9 of the 19 are *serial scientist-entrepreneurs*. 7.5% of noncommercial scientists are highly cited, 21.3% of first-time entrepreneurs are highly cited, and 50% of serial scientist-entrepreneurs are highly cited. A correlation analysis of the variable *companycount* with the variable *highlycited* yields a fairly low 27.3% correlation; however, the difference in means for the variable *highlycited* between *serial scientist-entrepreneurs* and *first-time entrepreneurs* is statistically significant (P=0.022), based on a t-test analysis (see Figure 3).

This result allows the rejection of the null hypothesis:

> H_0: MIT *serial scientist-entrepreneurs* are equally likely or less likely than *first-time entrepreneurs* to be listed on ISI's highly cited list

Serial scientist-entrepreneurs have higher numbers of issued US patents

A comparison of patenting activity (i.e., number of issued US patents) between *serial scientist-entrepreneurs* and *first-time entrepreneurs* reveals that serial scientist-entrepreneurs have significantly higher numbers of issued U.S. patents (mean = 29.39 for *serial scientist-entrepreneurs,* compared to mean = 8.81 for *first-time entrepreneurs*) (see Figure 4)

Because the top scientist-entrepreneur is an outlier in number of issued patents (183 patents), I have also conducted a t-test excluding this individual. The resulting analysis confirms that *serial* *scientist-entrepreneurs* have a mean number of issued patents that is statistically significantly greater than the mean issued patents for *first-time* entrepreneurs (see Figure 5)

Although the correlation statistic for the variable *companycount* and the variable *patent count* is relatively high at 0.754, once the top serial scientist-entrepreneur is excluded from the analysis to avoid skewing the result, the correlation between *companycount* and *patent count* drops to a much lower 0.389.

Additionally, controlling for PhD age of the scientists[1] (available for 59 of the 66 scientists in the *commercial scientist* population) a comparison of the rate of company formation (*companies/year)* with patenting rate (*patents/year*) yields similar results. Initial analysis suggests a high correlation statistic of 0.757 between the two variables, but excluding the top outlier (0.65 companies/year and 5.90 companies/year) results in a much lower correlation statistic of only 0.279. However, a two-sample t-test excluding the top outlier still confirms the rejection of the null hypothesis, at a 95% confidence level (see Figure 6):

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[1] 13 of the 18 scientists forming >0.10 companies/year are in the *serial scientist-entrepreneur* subset, while 5 of the remaining individuals in the *serial scientist-entrepreneur* were included in the group with lower company formation rates, forming companies at a rate as low as 0.07 companies/year.

H_0: *Scientist-entrepreneurs with high rates of company formation (0.10 – 0.29 companies/year)* have patenting rates equal to or lower than those with *lower rates of company formation (0.02 – 0.09 companies/year).*

Serial scientist-entrepreneurs are not more likely to have appointments in applied science departments

The cohorts of *serial scientist-entrepreneurs*, *first-time entrepreneurs*, and *noncommercial scientists* were analyzed to observe whether, empirically, serial scientist-entrepreneurs are more likely to have appointments in applied science departments, versus basic science fields. Among the aggregate *MIT scientist* population, there is a nearly 50-50 distribution between applied vs. basic science department appointments, with a slight weight toward applied appointments (see Figure 7).

Examination of the serial scientist-entrepreneurs, however, reveals that basic science departments are slightly more represented. A one-tail, two-sample t-test comparing the means for the *applied vs. basic* dummy variable shows there is not a significant difference between *serial scientist-entrepreneurs* and *first-time entrepreneurs* (see Figure 8).

Moreover, differences between the means for the *applied vs. basic* variable are also not significant between *serial scientist-entrepreneurs* and *noncommercial scientists* (see Figure 9).

It is important to note that the top *serial scientist-entrepreneurs* have deep experience across both biology and chemistry. Chemistry-related fields (i.e., chemistry, chemical engineering, and chemical biology / biological chemistry) are dominant among the top 5 serial scientist-entrepreneurs: 4 of the top 5 had MIT appointments in chemistry or chemical engineering, while the other scientist is currently a professor of chemical biology (he had a historical appointment in the MIT Biology Department). On the other hand, 4 of the top 5 have also had MIT appointments in biology or applied biological sciences/biological engineering, and the other scientist (distinct from the scientist mentioned in the prior example) leads a laboratory conducting research in chemical biology and biochemistry, in addition to chemistry. Thus, it is likely that the *applied* vs. *basic* designations, based on department, are not the most accurate representations of the applied nature of the scientists' research, and that broadly applicable, interdisciplinary research may be a more important driver of serial faculty entrepreneurship.

Serial scientist-entrepreneurs develop preferred repeated VC funding relationships

Venture funding information was publicly available for 82 of the 89 companies founded/directed by the *serial scientist-entrepreneurs*. Of the 404 investors across these 82 companies, 108 invested in more than one company and 27 invested in 5 or more companies (see list in the Appendix).

Of the 18 *serial scientist-entrepreneurs*, 15 (83%) worked with the same venture capital firm across two or more companies. The most preferred venture capital firm (i.e., the VC firm funding the largest number of companies founded or directed by a given scientist) for each *serial scientist-entrepreneur* was selected as a funding source nearly half of the time (mean = 47.4%), which is statistically significantly higher than the proportion if a given VC firm funded only one of the *serial scientist-entrepreneurs'* companies (mean = 23.9%) (See Figure 10). This comparison is stricter than comparing to the likelihood of any given VC funding a firm, if randomly drawn from the sample of 404 investment firms (1/404 = 0.25%) or even from the sample of 27 firms investing in 5 or more companies (1/27 = 3.7%). However, this paired analysis (i.e., pairing of *serial scientist-entrepreneurs* with their preferred VC) is more accurate, as the same VC is not necessarily preferred across all 18 *serial scientist-entrepreneurs*. In other words, excluding the first instance of venture funding with a preferred VC, *serial scientist-entrepreneurs* work with a preferred VC more than 30% of the time (i.e., calculated by AVERAGE (*[n-1] / [T – 1]*), where n = # of companies funded by the preferred VC for any given *serial scientist-entrepreneur* and T = total # of venture-funded companies founded/directed by the same *serial scientist-entrepreneur*). While the optimal analysis would examine whether a preferred VC is selected again as an investor, *after* a serial scientist-entrepreneur has worked with them once (i.e., conditional on having worked with the preferred VC, how frequently does the scientist-entrepreneur work with the VC again), I did not have the time-series information necessary for such an examination.

A social network analysis of the 18 *serial scientist-entrepreneurs* and the 404 investors of their associated ventures was conducted, with the individuals and firms as nodes and the company relationships as ties. In particular, UCINet was utilized to calculate two different types of centrality measures: degree centrality and betweenness centrality. Degree centrality is a measure of the number of ties, or connections, a given node, also known as an "actor" (i.e., scientist-entrepreneur or a venture investor) has with other actors in the network (Hanneman, 2005). UCINet's degree counts are calculated as normalized Freeman degree centralities – i.e., "expressed as percentages of the number of actors in the network, less one (ego)" (Hanneman, 2005). Higher degree centrality enables any given actor to have greater access to the network's resources and may also broker relationships among others in the network. Betweenness centrality is a measure of the extent to which an actor is between, or falls on the geodesic path(s) between, other actors in the network (Hanneman, 2005). In essence, a high betweenness centrality statistic can be interpreted as associated with an actor that may have greater power as an intermediary for information or access between other actors in the network.

Within the social network of the 18 serial scientist-entrepreneurs and their associated venture investors, the top venture firms as measured by degree centrality (mean = 4.558, standard deviation = 4.102) had significantly more network power (greater than 3 standard deviations), as compared to the general population. The top 5 VCs by this measure were: 1. Venrock Associates (29.691), 2. New Enterprise Associates (26.841), 3. CW Group (19.715), 4. Transamerica Technology Finance (18.527), and 5. Domain Associates (18.29). The VC groups were also highly skewed in significance, as measured by betweenness centrality (mean = 0.363, standard deviation = 1.20), where the top 5 VCs were: 1. Venrock Associates (8.604), 2. New Enterprise Associates (6.814), 3. MPM Capital (4.644), 4. Domain Associates (4.632), and 5. BancBoston Ventures (4.298). It is interesting to note that there is not necessarily a 1-to-1 correlation between the venture firms' ranking by total number of serial scientist-entrepreneur companies funded and their ranking by degree centrality or betweenness centrality. For example, the 3rd and 4th highest venture firms, ranked by total number of serial scientist-entrepreneur companies funded – Polaris Ventures (funded 10 serial scientist-entrepreneur companies) and Abingworth Management (funded 8 serial scientist-entrepreneur companies) – are not top-ranked by degree centrality or by betweenness centrality, because as early-stage investors, they did not invest in some of the companies with multiple rounds and many different investors (e.g., Anadys Pharmaceuticals [26 investors/scientists], ACLARA BioSciences [21 investors/scientists], and Idec Pharmaceuticals [21 investors/scientists]). These results are important as they not only demonstrate how these *serial scientist-entrepreneurs* may draw upon preferred early-stage investors, but they also suggest later-round venture investors may continue to work with these scientists as founders and/or board members.

Serial scientist-entrepreneurs have high centrality within the entrepreneurial network of MIT scientists

Social network analysis of the *MIT scientist* population, with the scientists as nodes and company affiliations (via relationships as founder, board director, or scientific advisory board membership) as ties, demonstrates the highly skewed centrality of *serial scientist-entrepreneurs* within the academic, entrepreneurial community.

The network map of the interconnectedness of the *serial scientist-entrepreneurs* shows several individuals hold significant positions within the social network. When the 18 serial scientist-entrepreneurs are mapped with connections determined by common company affiliations (which include SAB membership) (see Figure 11), it is evident that there is, in fact, a high degree of collaboration among just the group of *serial scientist-entrepreneurs*. The network centrality measures are significantly more skewed for betweenness centrality (for the network, range [6.67 - 53.333], mean = 8.810, standard deviation = 13.651), where the standard deviation is greater than the mean, than for degree centrality (for the network, range [0 - 46.03], mean = 24.167, standard deviation = 12.444) (see Appendix, Table 2). In particular, three individuals hold high-centrality positions within the network, as measured by degree centrality and betweenness centrality, and are also 3 of the top 4 serial scientist-entrepreneurs, as measured by experience as founder and board of directorships (i.e., companycount).

Unique scientist ID (*Companycount.counter*)	**Degree**	**Betweenness**
9.002	53.33	46.03
20.001	40.00	34.44
10.001	40.00	24.92

(Note: Each scientist is labeled by a unique code, with the number of companies founded/directed (excluding SAB membership counts) to the left of the decimal and a "counter" number to the right of the decimal (i.e., 9.001 = 1st scientist with 9 companies; 9.002 = 2nd scientist with 9 companies, etc.).

The 4th top entrepreneur, (scientist ID = 9.001), had significantly lower degree centrality (13.33) and betweenness centrality (5.87), as this individual is largely an "affiliate entrepreneur" of scientist ID 20.001. For example, scientist ID 9.001 has relatively lower company affiliations once SAB memberships are included (n=10), as compared to 9.002 (n=16), and 6 of these 10 affiliations are linked to scientist ID 20.001, with only one additional tie to scientist ID 4.003.

A number of additional observations can be made about the *serial scientist-entrepreneurs* and their position within the network. Both scientist 20.001 and scientist 9.002 appear to have multiple repeated collaborations with the same *serial scientist-entrepreneurs*. For example, 9.002 has 3 companies each in common with 20.001, 3.005, 8.001, and 4.004. On the other hand, scientist 20.001 has 3+ companies in common with 4 of 6 connected scientists. This confirms that these scientists are infrequently "lone rangers" in their entrepreneurial activity.

It is also interesting to note the "star" formed by scientists 4.002, 3.001, 9.002, 4.004, and 8.001, which represents the formation of a significant early biotechnology company in the Boston area involving multiple MIT scientists as co-founders. Scientist 9.002's high degree centrality and betweenness centrality, primarily due to board of director and SAB memberships across a wide variety of therapeutic companies, may be linked to this individual's diverse and deep experience in chemistry, biology, and medicine at MIT and a leading medical school. Finally, while scientists 5.001 and 3.002 are renowned biologists who founded/directed 5 companies and 3 companies, respectively, their entrepreneurial activity remains disconnected from this network. In aggregate, the social network analysis describes a group of collaborative scientist-entrepreneurs, with multiple company collaborations between the same scientists.

Upon mapping the 66 MIT *commercial scientists* (i.e., scientist-entrepreneurs who have founded or directed at least 1 company), 41 scientists form the main component of the network map, with 2 additional scientists (1.014 and 1.023) separately connected (see Figure 12). 23 scientists were isolates (i.e., unconnected to any other scientist in the network), so they were excluded from the map. Descriptive statistics for the main network component (n=41) follow:

	Degree	Betweenness
Mean	8.659	5.128
Std Dev	7.389	10.201
Minimum	2.5	0
Maximum	30	49.824

The centrality measures continue to be highly skewed, as determined by degree centrality (standard deviation nearly equal to the mean) and, especially, betweenness centrality (standard deviation at 2x mean). Table 3 in the Appendix list the centrality measures for each scientist in the main network component. *20.001*, *9.002,* and *10.001* continue to have highly central positions in this network (as was in the case for the *serial scientist-entrepreneurs* alone). However, in this network, *8.001* also gains a significant position, largely through SAB memberships on an additional 10 companies beyond the 8 founder/director companies, and becomes critical for several scientists (e.g., *1.016, 1.022, 1.020, 1.029, 1.037*) to access the broader network. *2.006* has a relatively high betweenness centrality, as this scientist is the only point through which *5.001* and *1.033* can access the broader network. *4.004* shows high degree centrality relative to the number of companies founded/directed. This characteristic is likely due to *4.004*'s role as one of the pioneering scientists in the field of molecular biology and founder of several key early biotechnology companies.

A total of 115 scientists from the population of 493 *MIT scientists* have experience as founders, board members, or SAB members across 242 entrepreneurial ventures (i.e., in addition to the 66 MIT *commercial scientists,* 49 of the noncommercial scientists have served as SAB members). When these 115 scientists are mapped and connected via company affiliations, 49 scientists are isolates; 62 scientists comprise the main network component; and 4 scientists are separately connected as pairs. Outside of the ties between specific pairs of *serial scientist-entrepreneurs*, *20.001* with *1.040*, and *8.001* with *1.022*, all the remaining connections between pairs of scientists are limited to collaboration on a single company.

Descriptive statistics for the main network component (n=62) follow:

	Degree	Betweenness
Mean	6.875	3.390
Std Dev	6.550	7.211
Minimum	1.639	0
Maximum	29.508	36.550

While the *serial scientist-entrepreneurs* continue to have high degree centrality and betweenness measures, it is interesting to note the extraordinarily high degree and betweenness centrality of *0.036*, which is due to SAB memberships on two companies with relatively high involvement by the scientists in this network. Across the 242 companies, the mean number of scientists from this network involved as a founder, director, or SAB member is 1.4 scientists per company (standard deviation = 0.883). In comparison, *0.036*'s three SAB memberships are on companies affiliated with 5, 2, and 6 *MIT scientists*.

A few scientists have extraordinarily high involvement on scientific advisory boards, relative to the number of companies founded/directed. In general, the following descriptive statistics were observed for SAB membership, relative number of companies founded/directed:

% SAB only of all company affiliations	**Ratio of # SAB only to # founded/directed**	
29% (27%)	0.72 (0.89)	Mean (standard deviation), 66 MIT *commercial* scientists
31% (21%)	0.65 (0.79)	Mean (standard deviation), 18 *serial scientist-entrepreneurs*

Note: As scientists often serve on SABs for companies they found/direct, SAB only refers to those companies for which they are only on the scientific advisory board and not a founder/board of director.

Within this context, *3.003* is an extreme outlier, as this scientist has a large number (n=10) of SAB memberships, in addition to 3 companies founded/directed. 6 of these company affiliations are identified within the network: 3 in common with *20.001*, and the others with *6.002*, *4.001*, and *0.041* (observed in Figure 13). As a physician/scientist, *3.003* may have significant value as a scientific and/or medical advisor to numerous companies and may wish to pursue entrepreneurial interests primarily through that route. On the other hand, it is also possible that this scientist's active entrepreneurial involvement (i.e., founder/board membership) could also significantly increase.

For the noncommercial scientists with observable SAB involvement (n=49), the mean count of SAB memberships was 1.53, with a standard deviation of 0.79. Among the noncommercial scientists, 6 scientists (*0.001, 0.027, 0.034, 0.036, 0.045, and 0.049*) have participated on 3 scientific advisory boards and 1 scientist (*0.003)* has been a member of 4 SABs. *0.003* may have been sought out as an advisor due to 15 years of industry experience prior to a long and distinguished (30+ years, 20 patents) scientific career at MIT.

In summary, these results suggest that several primary serial scientist-entrepreneurs (*9.002, 20.001,* and *8.001*) are the most influential brokers of faculty entrepreneurship within the MIT commercial scientist network. Other *serial scientist-entrepreneurs* (*4.002* and *10.001*) are also significant, and several of the *serial scientist-entrepreneurs* (especially affiliated with *20.001* and *9.002*) demonstrate repeated collaborations on entrepreneurial ventures. Additionally, the *serial scientist-entrepreneurs*, as evidenced by the main network component in Figure 13, have engaged on entrepreneurial ventures with a significant number of first-time entrepreneurs and noncommercial scientists. In other words, 62 scientists (54% of the 115 scientists with entrepreneurial activity) are connected in the main network component of the social network.

5. Discussion

In this study, I identified and characterized MIT serial scientist-entrepreneurs, measured by academic impact, patenting activity, venture capital relationships, and centrality within the academic entrepreneurial network. The study draws comparisons among serial scientist-entrepreneurs, first-time scientist-entrepreneurs, and noncommercial scientists from a novel dataset spanning MIT life sciences faculty across 25 years, from 1981 to 2005.

These results are the first to suggest that serial scientist-entrepreneurs are the driving force behind a significant majority of startup ventures associated with MIT life sciences faculty. Compared to their first-time entrepreneur or noncommercial peers, these individuals were found to be more preeminent, high-impact researchers, as measured by citations to their work, and more prolific inventors, as measured by number of issued patents. Additionally, these serial scientist-entrepreneurs have built repeated relationships with venture investors. A small number of venture investors have likewise built strong, ongoing relationships with these individuals and therefore claim a central position in repeated financings of their companies. Finally, four serial scientist-entrepreneurs (with company counts of 20, 9, 8, and 4) hold exceptionally central roles in the MIT entrepreneurial network, suggesting roles as brokers of entrepreneurial activity among faculty.

However, two primary data-related limitations should be considered in evaluating the results of this study: (a) representativeness, and (b) completeness of data.

The data for this study covers scientists who have served as faculty members, for at least one year, in specific MIT departments from 1981 to 2005. However, I do not adjust for the timing, length of time, or roles of these faculty members at MIT. In some cases, these individuals have spent significant portions of their career at other academic institutions, or possibly in industry. Moreover, the startup company affiliations are not necessarily related to technologies originating from MIT. However, because of their past or current faculty appointment at a top-tier, academic technology institution, such as MIT, with a strong focus on entrepreneurship and commercialization, these individuals are some of the most 'at-risk' scientists for academic-related startup activity. While this group of scientists represents an important population, the results, however, may not necessarily be representative of MIT, per se, nor should they be generalized to understand commercial activity and faculty experiences at other academic institutions. On the other hand, because of MIT's dominant role in scientific entrepreneurship, university technology transfer, and academic research leadership, the population of life sciences faculty investigated by this study likely account for a significant number of higher profile life sciences startups related to university research.

Additionally, this study is limited to faculty in the specified MIT departments and their associated life sciences startup activity. As a result, it excludes other MIT faculty members who may have started life sciences-related companies (e.g., Joseph Jacobson and Codon Devices) and also excludes faculty involvement in non-life sciences related ventures.

While every effort was made to locate and confirm, via exhaustive Internet searches using Google and ZoomInfo, publicly available information regarding company founder status, board membership (especially, historical board memberships), and scientific advisory board membership (again, especially, historical SAB participation), I recognize that our dataset may not be complete. Founder status was especially difficult to ascertain and may be underrepresented in my dataset. Importantly, public disclosure of information (i.e., descriptive information in biographies) is typically biased toward affiliations with positive outcomes. I have also attempted to correct for company evolution and name changes, while retaining the core information in the datasets. While these limitations should be heeded, the biases are likely not significant due to their likely nonsystematic nature and the large size of the dataset.

Despite these limitations, these research findings have significant implications for university administrators, principal scientific investigators, and venture capitalists. Additionally, they may impact further research on university technology transfer and university entrepreneurship. The results suggest the critical role that serial scientist-entrepreneurs may play at the intersection of research/discovery leadership and commercialization/entrepreneurship. As leaders in their respective areas of research, these scientists would not only be sources of innovation but also highly sought-after advisors, providing (in the terms of Zucker and Darby) "human intellectual capital" as a form of competitive advantage to startups. Their prestige and recognition may also lend early-stage ventures additional credibility to facilitate venture fundraising or alliances.

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8. Figures

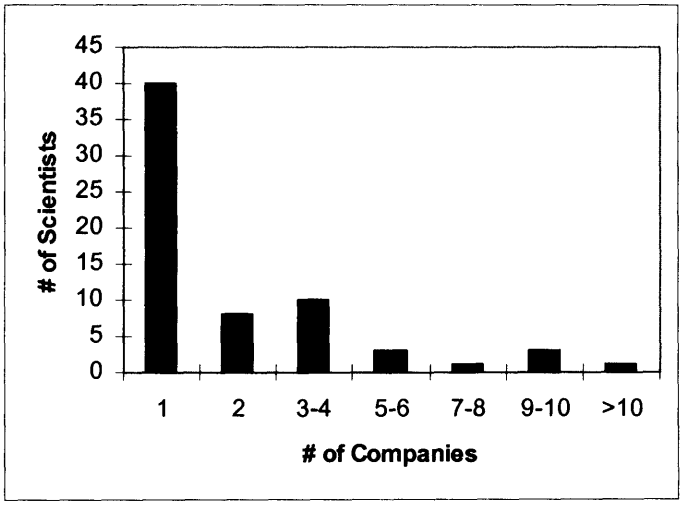

Figure 1. Distribution 66 *MIT scientist-entrepreneurs* based on the number of companies founded/directed.

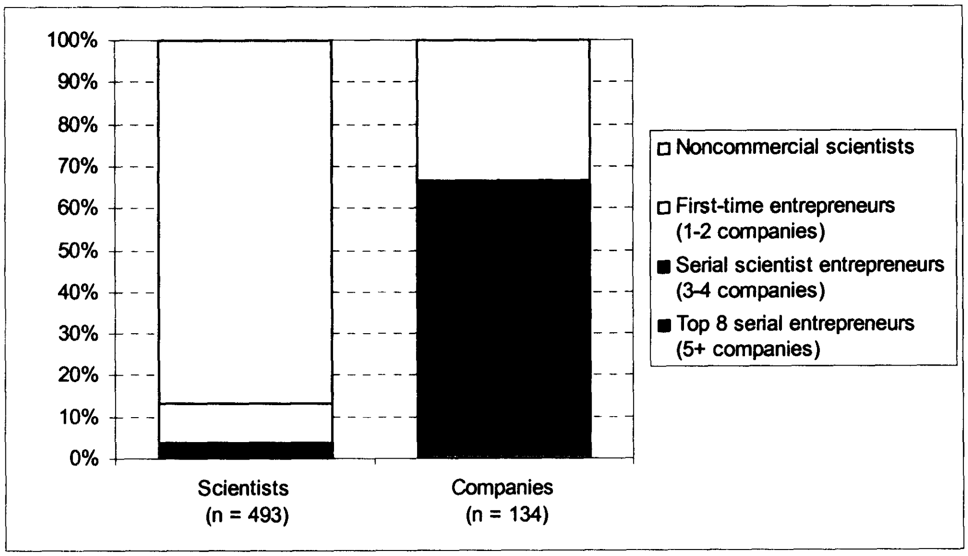

Figure 2. Serial scientist-entrepreneurs founded/directed 2/3 of life sciences companies affiliated with the *MIT scientist* population

t-Test: Two-Sample Assuming Unequal Variances

	serial scientist-entrepreneur	*first-time entrepreneur*
Mean	0.500	0.213
Variance	0.265	0.171
Observations	18	47
Hypothesized Mean Difference	0	
Df	26	
t Stat	2.121	
P(T<=t) one-tail	0.022	
t Critical one-tail	1.706	

Figure 3. Two-sample t-test comparing proportion of *serial scientist-entrepreneurs* vs. *first-time entrepreneurs* represented on the ISI highly cited list

t-Test: Two-Sample Assuming Unequal Variances

	serial	*first-time*
Mean	29.389	8.813
Variance	1724.134	85.432
Observations	18	48
Hypothesized Mean Difference	0	
Df	18	
t Stat	2.083	
P(T<=t) one-tail	0.026	
t Critical one-tail	1.734	

Figure 4. Two-sample t-test comparing issued patents for *serial scientist-entrepreneurs* vs. *first-time entrepreneurs*

Analysis excluding top scientist-entrepreneur

t-Test: Two-Sample Assuming Unequal Variances

	serial	*first-time*
Mean	20.353	8.813
Variance	270.368	85.432
Observations	17	48
Hypothesized Mean Difference	0	
df	20	
t Stat	2.744	
P(T<=t) one-tail	0.006	
t Critical one-tail	1.725	

Figure 5. Two-sample t-test comparing issued patents for *serial scientist-entrepreneurs* (excluding top serial scientist-entrepreneur) vs. *first-time entrepreneurs*

t-Test: Two-Sample Assuming Unequal Variances

	0.10-0.29 companies/yr	*<0.10 companies/yr*
Mean	0.562	0.314
Variance	0.214	0.101
Observations	17	41
Hypothesized Mean Difference	0	
df	23	
t Stat	2.022	
P(T<=t) one-tail	0.027	
t Critical one-tail	1.714	

Figure 6. Two-sample t-test comparing patenting rate (patents/year) for scientist-entrepreneurs with high rates of company formation (excluding top serial scientist-entrepreneur) vs. those with lower rates of company formation (<0.10 companies/year)

	Count	% of total
Applied (dummy = 1)	264	54%
Both Applied and Basic (dummy = 0)	27	5%
Basic (dummy = -1	202	41%
Mean (n=493)	0.13	

Figure 7. Distribution of applied vs. basic department appointments for 493 MIT scientists

	serial (>3)	*(1-2 companies)*
Mean	-0.111	-0.106
Variance	0.693	0.967
Observations	18	47
Hypothesized Mean Difference	0	
df	36	
t Stat	-0.019	
P(T<=t) one-tail	0.492	
t Critical one-tail	1.688	

Figure 8. Two-sample t-test comparing the means of the *applied vs. basic* variable for *serial scientist-entrepreneurs* vs. *first-time entrepreneurs*

	serial	noncommercial
Mean	-0.111	0.161
Variance	0.693	0.932
Observations	18	428
Hypothesized Mean Difference	0	
df	19	
t Stat	-1.350	
P(T<=t) one-tail	0.096	
t Critical one-tail	1.729	

Figure 9. Two-sample t-test comparing the means of the *applied vs. basic* variable for *serial scientist-entrepreneurs* vs. *noncommercial scientists*

t-Test: Two-Sample Assuming Unequal Variances

	Preferred VC firm	Funding 1 company
Mean	0.474	0.239
Variance	0.016	0.009
Observations	18	18
Hypothesized Mean Difference	0	
df	32	
t Stat	6.283	
P(T<=t) one-tail	2.398E-07	
t Critical one-tail	1.694	

Figure 10. Two-sample t-test comparing the proportion of companies funded for the most preferred VC firm compared to a VC firm funding a single company for each *serial scientist-entrepreneur*

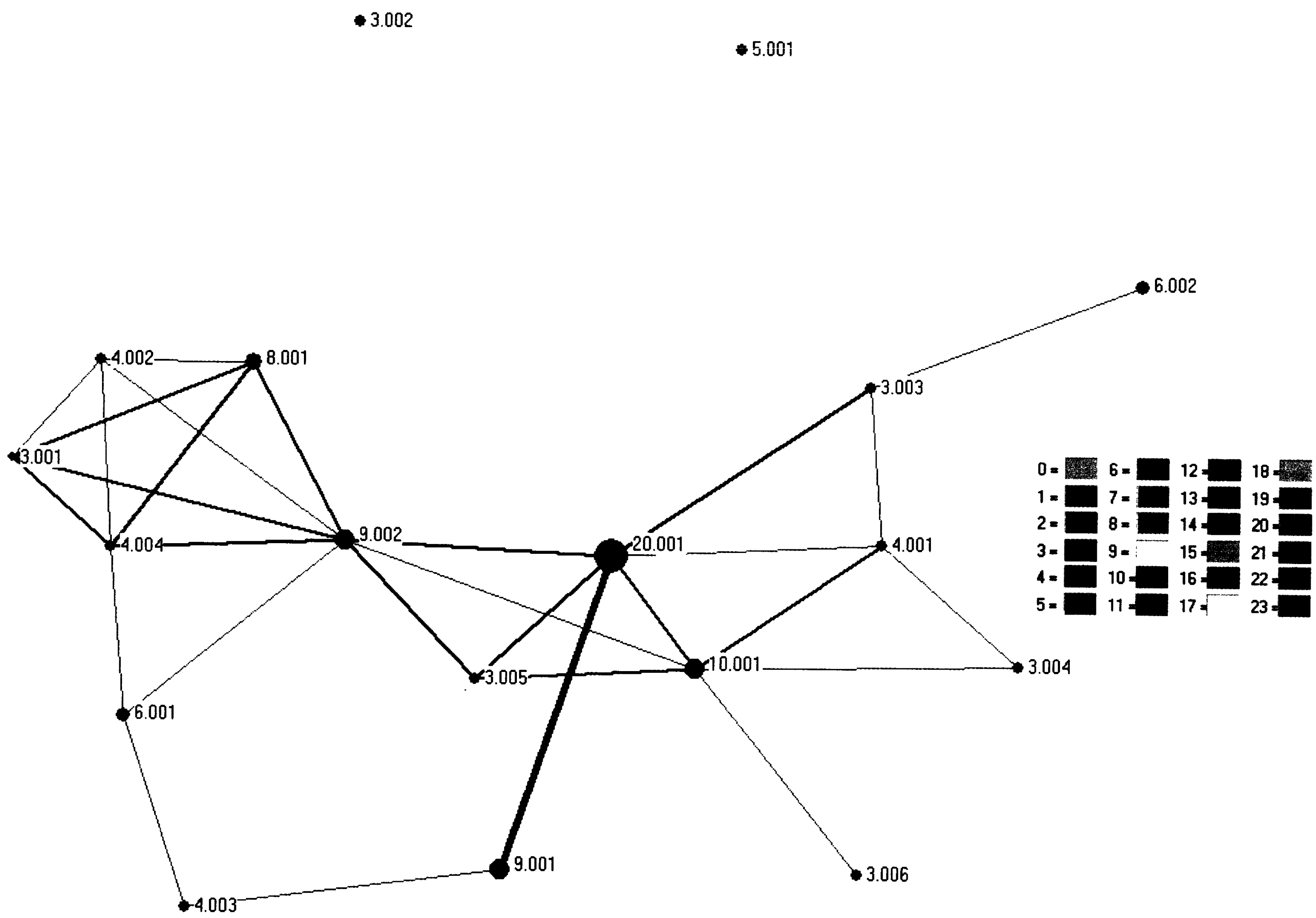

Figure 11. Social network map of the 18 MIT *serial scientist-entrepreneurs*, with company affiliations (founder, board director, or SAB membership) as ties. The color (see legend) and thickness of the connecting lines is a measure of the number of common company connections (i.e., a thicker line means a higher frequency of working together). Each scientist is labeled by a unique code, with the number of companies founded/directed (excludes SAB membership counts) to the left of the decimal and a "counter" number to the right of the decimal (i.e., 9.001 = 1st scientist with 9 companies; 9.002 = 2nd scientist with 9 companies, etc.).

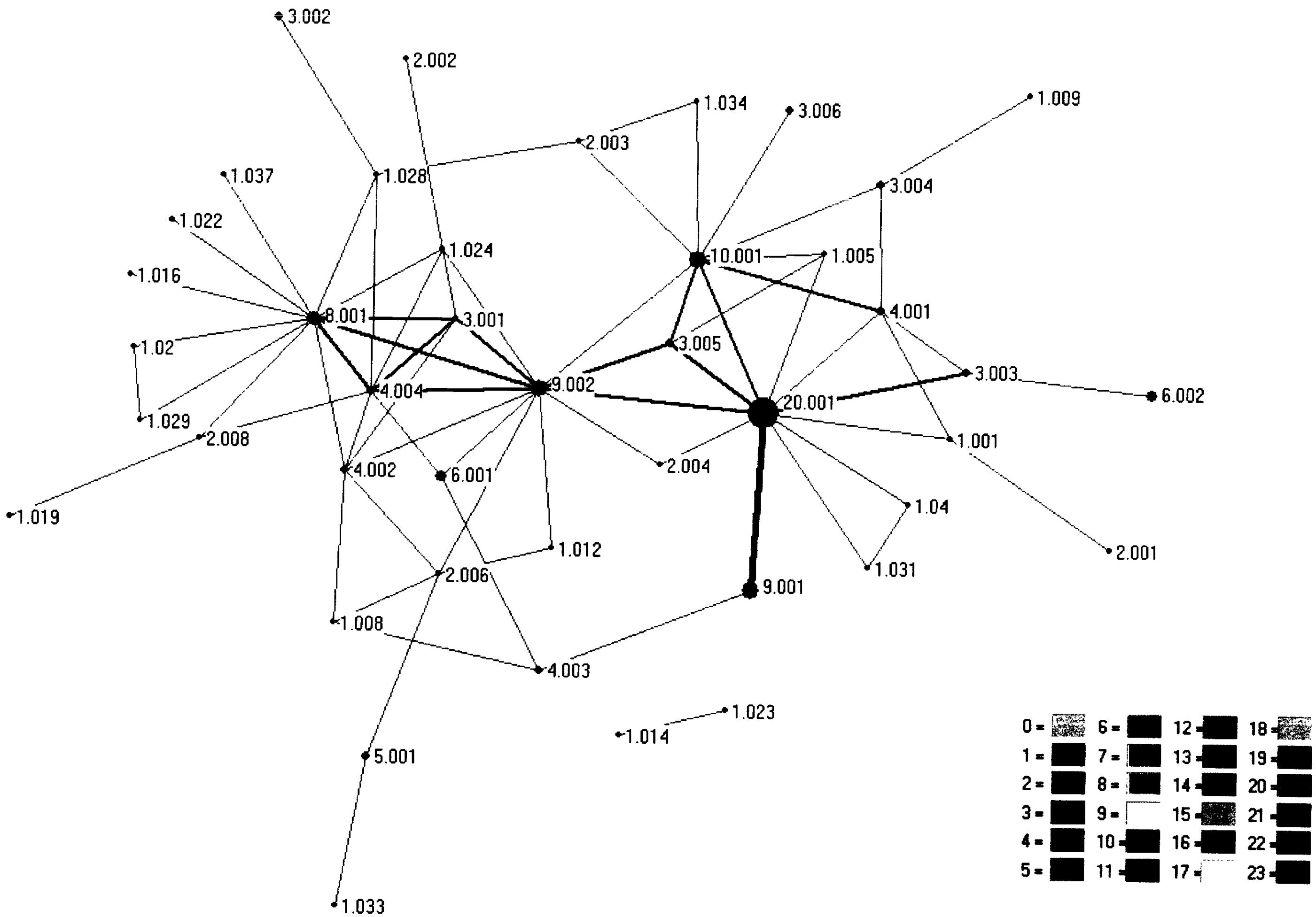

Figure 12. Social network map of 43 of 66 MIT *commercial scientists* (at least 1 founder or board director position), with company affiliations (founder, board director, or SAB membership) as ties. The color (see legend) and thickness of the connecting lines is a measure of the number of common company connections (i.e., a thicker line means a higher frequency of working together). Each scientist is labeled by a unique code, with the number of companies founded/directed (excludes SAB membership counts) to the left of the decimal and a "counter" number to the right of the decimal (i.e., 9.001 = 1st scientist with 9 companies; 9.002 = 2nd scientist with 9 companies, etc.). *Note that 23 isolates have been removed.*

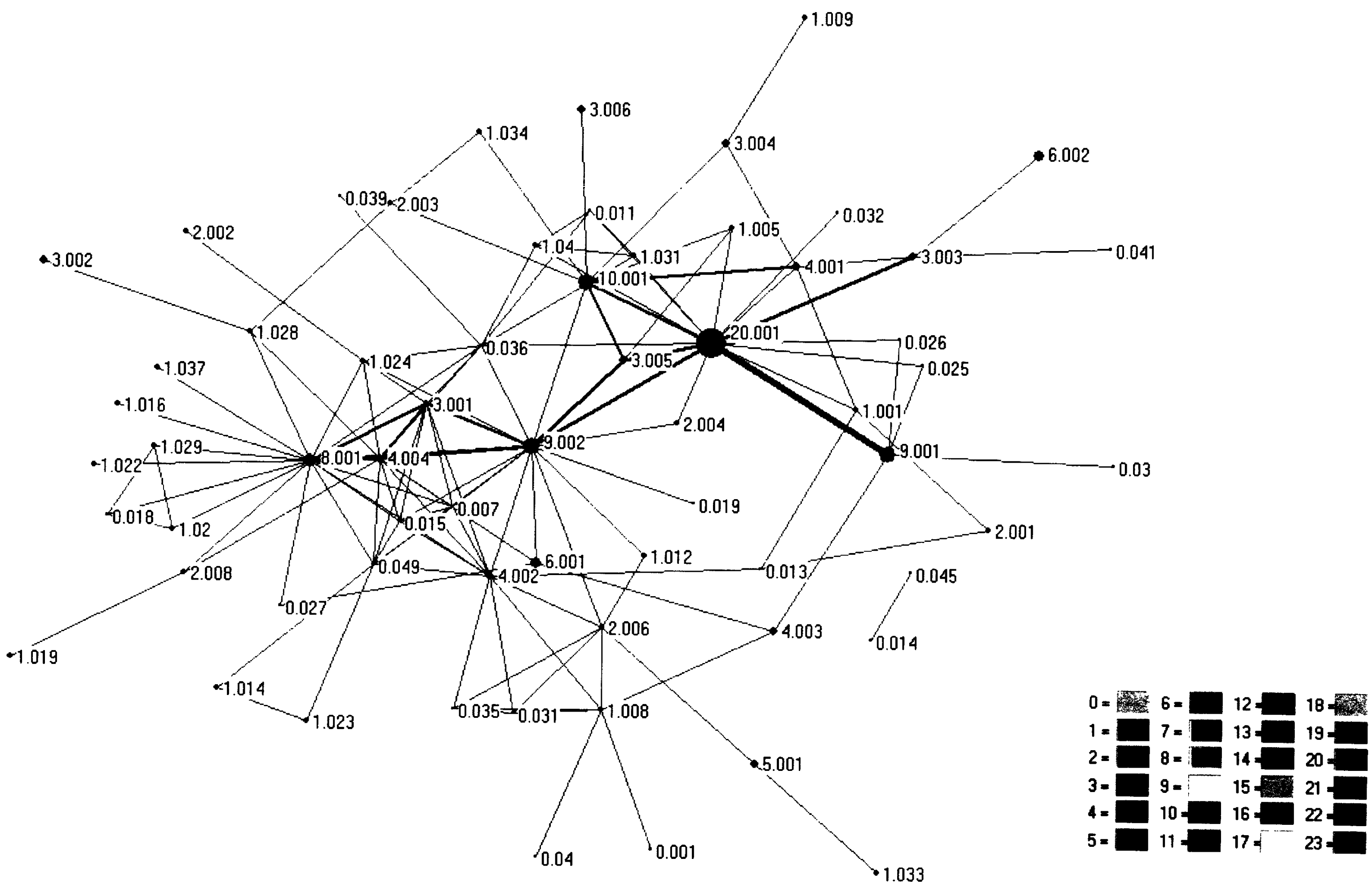

Figure 13. Social network map of 66 of 493 *MIT scientists*, with company affiliations (founder, board director, or SAB membership) as ties. The color (see legend) and thickness of the connecting lines is a measure of the number of common company connections (i.e., a thicker line means a higher frequency of working together). Each scientist is labeled by a unique code, with the number of companies founded/directed (excludes SAB membership counts) to the left of the decimal and a "counter" number to the right of the decimal (i.e., 9.001 = 1st scientist with 9 companies; 9.002 = 2nd scientist with 9 companies, etc.). *Note that 49 isolates have been removed.*

9. Appendix

1. Venture firms funding 5 or more companies founded and/or directed by MIT *serial scientist-entrepreneurs*

Venture firm	Number of companies
Venrock Associates	14
New Enterprise Associates	12
Polaris Venture Partners	10
Abingworth Management	8
CW Group	8
Atlas Venture	7
Bessemer Venture Partners	7
Domain Associates	7
Flagship Ventures	7
HealthCare Ventures	7
MPM Capital	7
BancBoston Ventures	6
Cardinal Partners	6
Institutional Venture Partners	6
Lombard Odier	6
Mayfield Fund	6
S.R. One, Limited	6
Transamerica Technology Finance	6
Advent International	5
Comdisco Ventures	5
H & Q Life Sciences Fund	5
Highland Capital Partners	5
Kleiner Perkins Caufield & Byers	5
Novartis Venture Fund	5
Oxford Bioscience Partners	5
Rothschild Ventures, Inc.	5
SV Life Sciences	5

2. Normalized Centrality Measures for the Main Network Component of Figure 11 (social network analysis of the *serial scientist-entrepreneurs*), ranked by betweenness centrality

Unique scientist ID (*Companycount.counter*)	Degree	Betweenness
9.002	53.33	46.03
20.001	40.00	34.44
10.001	40.00	24.92
3.003	20.00	13.33
6.001	20.00	6.98
9.001	13.33	5.87
4.001	26.67	5.08
4.004	33.33	2.86
4.003	13.33	1.43
4.002	26.67	-
3.001	26.67	-
8.001	26.67	-
3.004	13.33	-
3.005	20.00	-
6.002	6.67	-
3.006	6.67	-

Note: 2 nodes - 3.002 and 5.001 - (i.e., scientists) are excluded because they were isolates.

3. Normalized Centrality Measures for the Main Network Component (n=41) of Figure 12 (social network analysis of MIT *commercial scientists*), ranked by degree centrality

Unique scientist ID (*Companycount.counter*)	Degree	Betweenness
9.002	30	49.824
8.001	30	29.784
20.001	27.5	31.82
10.001	22.5	22.417
4.004	20	8.545
4.002	15	5.365
2.006	12.5	11.002
1.024	12.5	5
4.001	12.5	3.248
3.001	12.5	0.115
1.028	10	7.244
3.005	10	0.849
1.001	7.5	5
2.008	7.5	5
3.003	7.5	5
3.004	7.5	5
2.003	7.5	3.291
6.001	7.5	2.393

4.003	7.5	1.198
1.008	7.5	1.132
1.005	7.5	0
5.001	5	5
9.001	5	2.031
1.012	5	0
1.020	5	0
1.029	5	0
1.031	5	0
1.034	5	0
1.040	5	0
2.004	5	0
1.009	2.5	0
1.016	2.5	0
1.019	2.5	0
1.022	2.5	0
1.033	2.5	0
1.037	2.5	0
2.001	2.5	0
2.002	2.5	0
3.002	2.5	0
3.006	2.5	0
6.002	2.5	0

4. Normalized Centrality Measures for the Main Network Component (n=62) of Figure 13 (social network analysis of 493 MIT *scientists*), ranked by degree centrality

Unique scientist ID (*Companycount.counter*)	**Degree**	**Betweenness**
9.002	27.869	36.550
20.001	26.230	29.969
8.001	29.508	26.598
4.002	19.672	15.165
10.001	14.754	14.424
0.036	16.393	12.211
2.006	11.475	9.424
1.008	11.475	7.682
4.004	19.672	7.224
3.003	6.557	6.503
0.049	14.754	6.448
9.001	8.197	5.176
1.028	6.557	4.758
1.024	9.836	3.279
3.004	4.918	3.279
2.008	4.918	3.279
5.001	3.279	3.279
1.001	6.557	2.616
0.013	4.918	2.613

4.003	4.918	2.242
6.001	6.557	2.220
4.001	8.197	2.219
2.003	4.918	1.353
3.001	14.754	0.919
3.005	6.557	0.513
0.027	3.279	0.223
0.015	11.475	0.000
0.007	11.475	0.000
1.040	6.557	0.000
1.031	6.557	0.000
0.035	6.557	0.000
0.031	6.557	0.000
0.011	6.557	0.000
1.029	4.918	0.000
1.020	4.918	0.000
1.005	4.918	0.000
0.018	4.918	0.000
2.004	3.279	0.000
2.001	3.279	0.000
1.034	3.279	0.000
1.023	3.279	0.000
1.014	3.279	0.000
1.012	3.279	0.000
0.026	3.279	0.000
0.025	3.279	0.000
6.002	1.639	0.000
3.006	1.639	0.000
3.002	1.639	0.000
2.002	1.639	0.000
1.037	1.639	0.000
1.033	1.639	0.000
1.022	1.639	0.000
1.019	1.639	0.000
1.016	1.639	0.000
1.009	1.639	0.000
0.041	1.639	0.000
0.040	1.639	0.000
0.039	1.639	0.000
0.032	1.639	0.000
0.030	1.639	0.000
0.019	1.639	0.000
0.001	1.639	0.000