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Biotechnology entrepreneurial scientists and their collaborations

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Abstract

Inter-institutional scientific collaborations in biotechnology are now known to be the vehicle that drives the industry forward. Since networks of collaborations become crucial for biotechnology research, academic and industrial scientists act as entrepreneurs by expressing dedication to the potential commercial value of their intellectual capital. This paper focuses on the new scientific entrepreneurial spirit in the universities and the industry, and explores possible statistical and descriptive features of entrepreneurial scientists. The core analysis explores the relations between existing scientific collaborations and the scientific and intellectual capital of the scientists as well as the impact of the characteristics of the institution by which they are employed. Some analytical distinctions between various forms of scientific-entrepreneurship are suggested toward the end of the paper.

Keywords: Biotechnology; University scientists; Scientific entrepreneurship; Collaborations; Intellectual capital

1. Introduction

Biotechnology can now be characterized as the industry in which scientific and product development processes are collaborative. Every single organizational, sociological or science policy research that has focused on this industry has shown how collaborations (of any kind and form) are crucial to the maintenance, development, and survival of the industry, of organizations within the industry, and of different scientists working in the industry and in related fields in universities (Liebeskind et al., 1996; Oliver, 2001; Owen-Smith et al., 2002; Powell and Brantley, 1992; Powell et al., 1996, 2002; Weisenfeld et al., 2001; Zucker et al., 2002 to name only a few).

In order to have a full understanding of the arena of scientific technological innovation in general and in biotechnology in particular, we have to place the role of basic research conducted in universities in context. Recent literature on national systems of innovation depicts intensive scientific collaborations between universities, industrial organizations and government agencies (Etzkowitz and Leydesdorff, 2000; Etzkowitz et al., 2000), and argue that university research may increasingly function as a locus of national knowledge intensive networks. In addition, Hicks and Katz (1997) found that research in general is becoming more interdisciplinary and that research is increasingly conducted more in networks, both domestic and international.

At the same time, research on structural and procedural changes within universities, raises the issue of the "second revolution" of universities: "The first academic revolution was the transformation of universities from institutions of cultural preservation to institutions for the creation of new knowledge.

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Putting that knowledge into use followed soon after. The second academic revolution was the translation of research into products and into new enterprises (Etzkowitz et al., 1998).” This “second revolution” is based on large funding from the pharmaceutical industry, or smaller but more extensive pre-competitive and contract research collaboration that industry and academia share.

These inter-institutional collaborations are coupled with the growth of commercialization of academic science and the translation of research findings into intellectual property (patents)—a marketable commodity (Djerassi, 1993; Etzkowitz and Webster, 1998; Etzkowitz, 1998; Kleinman, 1998; Lee, 1996; Packer and Webster, 1996). Along with the comodification of intellectual property rights, university cultures were claimed to be changing to resemble the private sector due to increased dependence on resources from the private sector (Hackett, 1990). The increase in the commercialization of academic science is associated with the related, respective individual level phenomena of entrepreneurial scientists, in which academic scientists participate in various ways in the commercialization of their scientific inventions.

Some internal features of the scientific work associated with biotechnology are of significance in providing the contextual framework for the study of biotechnology related scientific entrepreneurship. In the classification of science based innovations (Pisano, 1994; Senker and Faulkner, 1992), the distinction between developed and developing science refers to the level of ‘maturity’ of the scientific knowledge. Biotechnology is defined as a developing science, in which the R&D process is based on tacit knowledge with little a priori understanding, and the process is exploratory and based on ‘learning by doing,’ tightly coupled and reciprocal research process which is heavily based on integrated teams of interdisciplinary experts (Cardinal et al., 2001; Pisano, 1994). This nature of the R&D process in biotechnology related fields which is significantly different from developed sciences, such as chemistry, can also be related to the characteristics of scientific entrepreneurs who function within an exploratory, tacit and limited knowledge base. This study will explore these complexities as embedded within the inherent conflict between entrepreneurship as an individualized behavior and biotechnology research as a collaborative process.

1.1. Biotechnology in Israel

Israel’s biotechnology scientists provide the grounds for an interesting case study. According to Watzman and Avitzour (2001), Israel’s academia produces 1700 graduates a year, in all levels within the life sciences, and it boasts one of the highest per-capita rate of publications in the world. Similar to patterns found in the US biotech industry (Zucker et al., 1998), the biotechnology industry in Israel was initially founded primarily by academic scientists. In 1990, Israel boasted only 30 biotechnology companies, employing 600 employees, but by 2000 there were 160 companies employing more than 4000 employees. In order to ease the commercialization of academic research, the government set three initiatives in the 1990s. These included: the creation of incubator units for fledgling companies, the supply of high-tech resources for academic and start-up companies, and the creation of links between academia and industry. The survey used in this study was one of the government’s initiatives.

1.2. Entrepreneurial scientists

“Scientific entrepreneurship” or “entrepreneurial scientists” are conceptualizations that have not been commonly used in either the scientific literature or the entrepreneurship literature. An early reference to the phenomenon was made by the sociologist of science, Ben David (1971), in his historical analysis of the changes in American universities that led to the “professionalization” of scientists, and the development of scientific entrepreneurs (p. 159). Ben David’s historical accounts show that the onset of professional training in American universities occurred around 1900 and the function of the universities was to train students to perform and apply research of the highest standards. Thus, they required the most up-to-dated research laboratories in order to train the graduate students as well as facilitate professors’ research. According to the German model, the role of a research worker was not a central element of the German science organizations. Moreover, research that was directly paid for was not considered research “because it had none of the metaphysical pathos of the deepest expression of creative spirit" (1971, p. 156). However, in the new American model, academic scientists enjoy autonomy in research, and act as members of the professional community and professional associations. Under this view, there is no contradiction between creative accomplishment in research and the organization of research. As a result, organized and standardized research (including paid for research) became normative in American universities, and led directly to the increase of entrepreneurial scientists and administrators (1971, pp. 158–159). Thus, according to Ben David, the initial concept of "scientific entrepreneurship" refers to academic scientists, who conduct professional, large-scale research with graduate students, under professional administration, including "paid for" research (e.g. invited research by and with the industry).

More recent literature introduces new accounts of "entrepreneurial scientists." In this context, we witness research on academic scientists who establish knowledge firms (Antonelli, 1999), or on university "star" scientists who work collaboratively with firm scientists (Zucker et al., 2002). Even though Zucker et al. did not refer to the "star" scientists as entrepreneurs, such stars can be classified as entrepreneurs since the study found an interesting link between scientific publications of star scientists and firm success. The joint publication these scientists had with firm scientists increased the number and citation rate for firm patents and contribute to firms' success. Another study (Zucker and Darby, 1997) found that "star" bioscientists had a central role in determining when and where New Biotechnology Firms were formed and the degree of their success.

An alternative account of scientific entrepreneurship (Oliver and Ramati, 2003), refers to scientists who acknowledge the commercial value of their academic scientific research, act in various ways to economically legitimize it and commoditize it, and facilitate in its commercialization. Accordingly, modern processes that aims to capture the value of intellectual property rights is the process of claiming patents over scientific inventions in order to license the rights to future use of these inventions by interested parties (Oliver and Liebeskind, 2003). Claiming for patents rights over academic research can serve as another feature of entrepreneurial scientists. Historically, for the past 25 years, there has been a steep increase in patenting activity by US universities and publicly funded research institutes (Eisenberg, 1996; Eisenberg and Nelson, 2002; Henderson et al., 1998; Mowery et al., 2001, 2002). This trend has been stimulated mainly by the passage of the Bayh-Dole Act in 1980 and the Federal Technology Transfer Act in 1986, which devolved the right to patent the fruits of federally-funded research from the federal government to recipient institutions. European countries follow the same pattern. A recent study found that the share of public research organizations (universities and public research laboratories) in patent application has been increasing from 1975 to 1998 (Nesta and Mangematin, 2002). These changes are also evident in Israeli academic institutions, and we have increasing numbers of patents' claims assigned to universities.[1]

1.3. Scientific collaborations in biotechnology

Biotechnology is considered an industry that is clearly science based (Meyer-Krahmer and Schmoch, 1998). As a result, academic scientists are highly involved in collaborative work with the industry (Liebeskind et al., 1996). These collaborations are added to the traditional normative scientific collaborations that exist between scientists working in academia (Crane, 1969, 1972; Friedkin, 1978; Merton, 1968).

Due to the multidisciplinary nature of biotechnology research, coupled with a need for various kinds of resources (i.e. funding, equipment, technological know-how and materials), scientific collaborations in biotechnology require collaborations across various institutional settings and disciplines—including between scientists within the same university, between scientists in different universities, and between academic and industrial scientists (for some examples, see Hagedoorn, 2002; Liebeskind et al., 1996; Liebesking and Oliver, 1998; Oliver and Liebeskind, 1998; Oliver, 2001; Powell and Brantley, 1992; Powell et al., 1996, 1999; Zucker and Darby, 1997; Zucker et al., 2002). These scientific collaborations are perceived as "learning intensive" opportunities and can be derived from network centrality (Powell et al., 1996) or

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[1] For example, the Hebrew University has increasing numbers of patents listed in the US patent data base and is well compatible to major US universities. In 1998, the university had 58 patents per year and the number increased to 71 in 2001. For comparison, Stanford University had 98 patents in 2000.

location in crowded technological segments (Stuart, 1998), but are also a factor of the scientist's characteristics (Zucker et al., 2002). Since biotechnology is characterized as a developing science in where knowledge is not yet well defined (Cardinal et al., 2001; Pisano, 1994), these collaborations allow for codifying and internalizing complementary knowledge, and for its transformation into new knowledge. Therefore, scientific collaborations add to scientific capability building of the scientists in a relatively economic fashion. This scientific capability building results not only from the explicit learning opportunities in every kind of collaboration, but is also impelled by the interdisciplinary structure of biotechnology collaborations. The advantage of interdisciplinary collaborations lies in their ability to enhance the interplay between tacit and explicit knowledge (Nonaka, 1994), from various scientific areas that is considered a central feature and requirement in individual and organizational learning processes.

Due to the "newness" of the topics covered in this study, the nature of the research is exploratory. One inquiry relates to the relations between intellectual property rights (in the form of patents over scientific inventions) and various forms of scientific collaborations. Merton (1968) refers to the "Mathew effect" that claims that "those who have more get more." This hypothesis was corroborated in various studies of social processes within which science and scientists develop. For example, Foschi (1991) found that high status scientists were judged more successful than lower status scientists, even if their findings were exactly the same. In the context of this study, the question is: "Would those who have more protected intellectual property rights (patents) participate also in more scientific collaborations?"

The paper asks the general question namely 'What are the relations between scientists' background characteristics, the existence of scientific collaborations of various kinds and protected scientific inventions in the form of patents?' More specifically, the study aims at understanding the impact of scientific capital (various ranges of specializations), intellectual capital (patents), academic tenure, research settings (institutional affiliation), and valorization of human capital (laboratory size) on the accumulation of learning enhancing collaborations of various kinds. Or, in a hypothesis format: the number of scientific specializations, technologies used, areas of interest, laboratory size, and patents play a role in the propensity of the laboratory to valorize.

Another direction of exploration in the paper focuses on identifying classifying variables that introduce significant differences between various subgroups among the sample of entrepreneurial scientists. Finally, the paper introduces some descriptive features of the top inventors among the entrepreneurial scientists, and suggests three general compositions for this phenomenon.

2. Data and variables

2.1. Data

The study concentrates on biotechnology related scientists that are actively searching for new collaborations. These scientists from academic and non-academic settings in Israel have replied to a survey that was conducted by a national committee in order to compile a database for national and international collaboration searches by biotechnology firms. In this respect, all scientists in the sample can be considered "entrepreneurial scientists" as they expressed an active interest in enlarging the scope and the exposure of their research into commercial domains through collaborations by responding to the survey. These scientists also become potential 'technology-transfer' agents since the survey aimed at providing information to biotechnology and pharmaceutical firms on the research interests and activities of biotechnology related scientists in Israel, and thus generate potential for university-industry technology transfer.

The data were collected in 1994 through mail questionnaires that were sent to all scientists in Israel who were interested in biotechnology related research. The data-collecting agency was a private research firm employed by the 'National Biotechnology Committee.' This committee was nominated by the Ministry of Industry and Trade, and was mandated to explore the potential of the biotechnology industry and to enhance biotechnology R&D in universities and industry. This particular scientists' database was finally compiled in 1998 in order to allow Israeli and international industrial interested parties to search for information regarding relevant collaborators. The database became available to interested Israeli and international parties. The data were in text format, and were coded, entered and analyzed in order to correspond to the research focus.

The secondary use of the data results in non-optimal variables and scope of measurement. On the other hand, the data have several advantages. Firstly, since the data were not collected as a designed research but rather as an instrumental tool for interested scientists, the response of the scientists was based on strong self-interest. In addition, the self-interest assumption led me to expect more accurate and reliable data since no researcher, knowing his responses are about to be used as public data, will risk partial or false information.

The database included originally 306 scientists in universities, industry and governmental research centers in Israel, out of which 291 cases were used in the final analyses due to missing data. No information could be obtained regarding the response rate and sample biases. However, due to the instrumental nature of the data, and the "selection effect" in the response to the survey, it is reasonable to assume that all respondents that were seeking industrial collaborations can be considered 'entrepreneurial scientists' at various levels.

Additional patents information was added to each scientist in the survey. Due to the availability of such searches on line, and the listing of the scientists' names in the database, it was possible to compile these data and merge them with the survey used in the study. In the regressions, the sheer number of patents listed was used.

2.2. Variables

Five continuous dependent variables are used as proxies for various forms of innovation and technology transfer: the number of academic collaborations the scientist currently has, the number of industrial collaborations the scientist already has, the number of local collaborations in Israel (both with academia or with the industry), the number of current international collaborations (both with academia and with the industry), and the number of total collaborations (composed of all kinds of collaborations).

The independent variables in the study include:

1. Laboratory size: This was based on the combined number of students in the researcher's laboratory (master, doctoral, and post-doctoral students). This variable was used first as an aggregated variable, but due to strong explanatory power of this measure, a distinction between the numbers of students in each of the three categories was made at later analyses.
2. Number of areas of interest specified by the scientist: The list ranges up to six areas of interest and the variable is a count variable.
3. Number of scientific specializations specified by the scientist: These include medicine, molecular biology, immunology, biochemistry, neurobiology, agriculture, ecology, marine biology, food, bioinformatics to name a few out of the 25 areas specified in the study and the variable is a count variable.
4. Number of technologies used by the scientist: These include 24 technologies including molecular biology, genetic engineering, classic agriculture genetics, cell culture, ecology, immunological systems, computerized systems, and others. The variable is a count variable.
5. Number of biological systems studied by the scientist: These include 12 systems among which are humans, mammals, fish, plants, fungus, viruses and bacteria and the variable is a count variable.
6. Academic age: This is based on the number of years since the scientist was awarded his/her highest degree (95.4% of the sample have either Ph.D. or M.D. degrees).
7. Number of patents on which the scientist is one of the inventors: This variable was compiled from an external source—through searches in the US patent database, and added to the database. Further, some dummy variables were constructed based on the count variable (see bellow in Section 2.3).
8. Institutional affiliation: A dummy variable in which academic scientists are 1 ($n = 152$) and non-academic scientists are 0 ($n = 139$).

2.3. Dummy variables

Additional dummy variables were constructed for exploratory comparisons of averages between subgroups in the sample and were later used for *t*-test comparisons of significance in equality of means. In general, and as expected the patent distribution is skewed, as the number of patents assigned to the scientists in the sample (until 2001) ranged from 0 to 26 (with a mean of 1.79 and an S.D. of 4.2, while till 1994, the mean was 1.06 with an S.D. of 2.8). Therefore, I have constructed a set of dummy variables based on the patent data.

The protection of scientific inventions through patents is an indication of interest in commercialization of the scientific invention, thus listed patents can serve as indicators of entrepreneurial aspirations. Four dummy variables are various measures of entrepreneurship, and were generated based on classifications of the patent invention information (through searching the US patent database for all listed scientists) as follows:

1. *Entrepreneurs*: The first variable is a dummy variable that refers to scientists that are listed in the patent database as having at least one patent invention until 1994 ($n = 102$), compared to scientists with no patents invention.
2. *Continuous entrepreneurs*: The second variable refers to all scientists that are listed in the patent database as having at least one patent invention since the survey was done in 1994, compared to other scientists who do not have any patents inventions since that time. This measure refers to scientists that have declared an interest in collaborations with the industry by answering the survey and have continued to claim rights to patents since the survey was conducted, thus they are classified as continuous entrepreneurs ($n = 74$ versus others $n = 217$).
3. *High scope entrepreneurs*: A measures for high invention scope and intense intellectual capital is introduced by using a dummy variable that refers to scientists that are inventors of at least 3 patents ($n = 52$, about 18% of the sample), compared to scientists who do not have more than two patents.
4. *Entrepreneurial university affiliation*: In order to explore the possible effect of the scientists' academic affiliation (entrepreneurial university effects), and explore the option that some universities enhance more scientific entrepreneurship, a dummy variable was constructed for comparisons between scientists affiliated with the two universities in which most patents were invented (The Hebrew University and the Weizmann Institute—combined $n = 90$) with the other four academic institutions in the survey (Technion, Tel Aviv University, Bar Ilan University, and Beer Sheva University—combined $n = 49$).

The following two variables were designed to distinguish between scientists from different scientific sectors, and between scientists with and without post-doctoral students.

5. *Academic institutional affiliation*: The sector affiliation of the scientist is a dummy variable that differentiates between scientists who are affiliated with academic institutions ($n = 152$) and scientists who work in biotech firms, hospitals or in government research centers.
6. *Post-doctoral students*: The presence of post-doctoral students in the scientist's laboratory can serve as an indicator for advanced and frontier research. Therefore, a dummy variable that classifies the scientists in the sample as having at least one post-doctoral student working with them ($n = 102$) versus not having any post-doctoral students ($n = 189$) was constructed.

3. Results

3.1. Descriptive statistics

Table 1 provides some descriptive statistics of the variables in the study including means, standard deviation and a correlation matrix. From this table, we can learn that scientists in the study have relatively high tenure (measured by number of years since being awarded the highest degree—mainly Ph.D.s—average of 19.7), and have on the average one patent in which they are listed as inventors. The averages of the various kinds of collaborations show that most existing collaborations listed by the scientists in the survey are academic and international.

Four major points are worth highlighting:

(1) Laboratory size is positively and significantly correlated with areas of interest (0.23), number of academic collaborations (0.44), local (0.26), international (0.40), and total (0.45) collaborations and with academic tenure (0.24).
(2) The number of area interests of the scientist is positively and significantly correlated with the number of technologies used by the scientist (0.32).

Table 1
Correlation matrix of the variables in the study

Variables	1	2	3	4	5	6	7	8	9	10	11	12
All collaborations	2.0 (1.85)	0.97**	0.24**	0.69**	0.78**	0.45**	−0.03	0.25**	0.00	0.02	0.19**	0.14*
Academic collaborations	1.86 (1.79)	X	−0.05	0.68**	0.75**	0.44**	−0.02	0.24**	−0.02	−0.00	0.19**	0.15*
Industrial collaborations	0.14 (0.45)		X	0.13*	0.22**	0.10	−0.03	0.07	0.09	0.08	0.05	−0.06
Local collaborations	0.91 (1.16)			X	0.09	0.26**	−0.02	0.10	−0.00	−0.04	0.04	0.11
International collaborations	1.09 (1.34)				X	0.40**	−0.02	0.26**	0.01	0.06	0.23**	0.09
Laboratory size	2.91 (3.42)					X	0.13**	0.23**	0.01	−0.12*	0.16**	0.24**
Number of patents	1.06 (2.8)						X	0.09	−0.01	−0.03	0.12*	0.16**
Number of areas of interest	3.64 (1.24)							X	0.17**	0.12*	0.32**	0.08
Number of specializations	4.24 (1.36)								X	0.29**	0.27**	−0.07
Number of biological systems	2.99 (1.53)									X	0.31**	−0.17**
Number of technologies used	9.88 (5.08)										X	−0.05
Academic age	19.7 (8.61)											X

The numbers, on the first column are of means and standard deviations of each variable. The number of responses used in the analyses is 291 due to missing data in some of the cases.

* $P < 05$.

** $P < 0.01$.

(3) The number of specializations of the scientist is correlated with the number of biological systems used by the scientist (0.29) and the number of technologies used in the scientists' laboratory (0.27).
(4) The number of biological systems used by the scientist is positively correlated with the number of technologies used (0.31).

Some indications for the association between being a generalist or specialist in science and the ability to provide complementary knowledge assets in collaborations appear in the correlations. While being a generalist-scientist in technological specialization and interests is associated with collaborations, being a generalist-scientist in specializations and biological systems is not. This finding leads to the conclusion that not all facets of generalist-scientists are associated with collaborations.

3.2. Regressions

Some of the exploratory questions were tested with multiple regressions. Table 2 shows the results of multiple regressions of the number of various types of collaborations on the structural, personal, and scientific characteristics of the scientists in the sample. Since, the variable 'laboratory size,' which is a composite variable based on the total number of M.A., Ph.D., and post-doctoral students working with the scientist, was one of the most significant variables in the regressions presented in Table 2, I have decided to sort the effects of number of students in each category on the dependent variables. Therefore, Table 3 shows the results of multiple regressions of the number of various forms of collaborations on the personal, structural, and scientific characteristics of the scientists—with the distinctive number of students in each category.

The multiple regressions presented in Tables 2 and 3 reveal a number of interesting findings that should be highlighted and discussed. First, the highest significant contribution to the explanation of the variance of the dependent variable (for all five dependent variables) in Table 2 is the laboratory size of the scientist. The larger the laboratory size, the more total, academic, international local and industrial collaboration the scientist has (significant beta values of 0.41, 0.40, 0.36, 0.24, and 0.12, respectively). Out of all the scientific scope variables (e.g. areas of interest, of specialization, and numbers of technologies and biological systems), only the number of technologies used by the scientist has a low but significant effect on the number of academic and international collaborations, but not on the number of industrial or local collaborations. In addition, scope of interest has a significant low impact on the number of academic and international collaborations. The final finding, that the number of patents has a low negative effect on the

Table 2
Multiple regressions of the number of various forms of collaborations on structural, personal, and scientific characteristics of scientists

Independent variables	Dependent variables				
	Number of academic collaborations	Number of industrial collaborations	Number of local collaborations	Number of international collaborations	Number of total collaborations
Constant	0.32	0.00	0.44	−0.12	1.016
Laboratory size	0.40***	0.12*	0.24***	0.36***	0.41***
Number of areas of interest	0.13**	0.04	0.05	0.15**	0.14**
Number of specializations	−0.08	0.06	−0.01	−0.08	−0.06
Number of technologies used	0.11*	−0.02	0.00	0.13**	0.10*
Number of biological systems used	0.03	0.06	−0.01	0.06	0.04
Academic age	0.07	−0.07	0.06	0.02	0.05
Number of patents	−0.11**	−0.04	−0.07	−0.10*	−0.12**
Adjusted R^2	0.222	0.007	0.052	0.203	0.234

$N = 291$.
* $P < 0.10$.
** $P < 0.05$.
*** $P < 0.01$.

Table 3
Multiple regressions of the number of various forms of collaborations on structural, personal, and scientific characteristics of the scientists—with distinctive number of students in each category

Independent variables	Dependent variables				
	Number of academic collaborations	Number of industrial collaborations	Number of local collaborations	Number of international collaborations	Number of total collaborations
Constant	0.12	0.00	0.35	−0.27	0.00
Number of MA students	0.12*	0.03	0.07	0.11*	0.12**
Number of PhD students	0.07	0.01	0.03	0.06	0.07
Number of Post Docs	0.26***	0.08	0.19**	0.20***	0.27***
Number of areas of interest	0.14**	0.05	0.05	0.16**	0.14**
Number of specializations	−0.07	0.07	0.00	−0.06	−0.05
Number of technologies used	0.10*	0.07	0.01	0.12**	0.10
Number of biological systems used	0.05	−0.02	0.00	0.08	0.06
Academic age	0.05	−0.08	0.06	−0.01	0.03
Academician	0.13*	0.06	0.02	0.17*	0.14**
Number of patents	−0.10*	−0.03	−0.06	−0.09*	−0.11*
Adjusted R^2	0.229	0.00	0.049	0.213	0.244

$N = 291$.

* $P < 0.10$.

** $P < 0.05$.

*** $P < 0.01$.

number of academic and international collaboration calls for further investigation and analyses.

Table 3 breaks the number of students working in the scientist's laboratory into all three categories, and enters them as distinct variables, and controls for whether the scientist works in the academic or the non-academic sector. The results show that the number of post-doctoral students in the scientist laboratory has the most significant effect on the number of academic, local, international, and total collaborations the scientist has (significant positive beta values of 0.26, 0.19, 0.20, and 0.27, respectively). In addition, academic scientists have significantly more (although with low correlation, and a significant level of 0.10), academic and international collaborations. Other than these effects, the other effects in Table 3 are similar to these presented in Table 2.

3.3. *Difference between subgroups*

In order to further explore possible distinctive classifications of entrepreneurial scientists, *t*-test analyses were conducted to compare the significance of the differences of the averages of scientists in various subgroups. The comparisons are based on a set of dummy variables constructed through the data (as defined and described in Section 3.2). Below, I report on the most significant differences that are of interest, for each of the six dummy variables constructed to reflect the possible context of entrepreneurial scientists.

Findings show that:

(a) *Entrepreneurs*: Scientists that have invented at least one patent until 1994 ($n = 102$) in comparison with scientists who have no patents, have significantly more international collaborations (average of 1.23 versus 1.04); more doctoral students (average of 1.74 versus 1.13 for scientists with no patents); they have higher academic tenure (average of 21.69 versus 18.97); and specify more areas of interest (average of 3.9 versus 3.5) as well as use of technologies in their laboratory (average of 11.23 versus 9.39). All other variables did not show significant differences between the two groups.

(b) *Continuous entrepreneurs*: Scientists who have invented additional patents after 1994 or have patented inventions only after the survey was conducted (in 1994) were classified as recent entrepreneurs. The comparison between the recent entrepreneurs (those who had invented patents after 1994) and those who did not invent any patents after 1994 (but may or may not have invented patents prior to 1994), shows some interesting results. The significant differences found for this classification of subgroups are in the number of industrial collaborations (the recent entrepreneurs have a significant higher average of industrial collaborations—average 0.216 versus 0.115); have more post-doctoral, doctoral and MA students (0.96 versus 0.48; 2.15 versus 1.00; 1.69 versus 0.82, respectively); and expressed significantly more areas of interest in the survey (an average of 3.97 versus 3.52). All other variables did not show significant differences between the two groups.

(c) *High scope entrepreneurs*: Scientists who have invented more than two patents have significantly more post-doctoral students (average of 0.98 versus average of 0.52); have more doctoral students (average of 2.10 versus average of 1.12); and more MA students (average of 1.5 versus average of 0.94). In addition, they have a higher tenure (average of 22.25 versus average of 19.14); and listed more areas of interest (average of 4.02 versus average of 3.55). All other variables did not show significant differences between the two groups.

(d) *Entrepreneurial university affiliation*: Among the academic scientists subsample, I distinguished between scientists affiliated with the two more entrepreneurial academic institutions in Israel (in terms of the total number of patents listed per institutions—The Hebrew University and the Weizmann Institute, $n = 90$) and compared them to scientists from all other four academic institutions in the sample ($n = 62$). The findings show that significant differences are found between scientists from the entrepreneurial universities and scientists from the other universities. Scientists from the Hebrew university and the Weizmann institute have more international collaborations (average of 1.7 versus average of 1.24); have more post-doctoral students (1.11 versus 0.65) and more doctoral students (2.34 versus 1.8); and have a higher academic tenure (23.62 versus 20.51). All other variables did not show significant differences between the two groups.

(e) *Academic institutional affiliation*: In the comparison between scientists working in academic institutions versus scientists in government research centers, in industry or in hospitals, significant differences in where the academic scientists had higher averages were found for the total number of collaboration, a significant higher average of 2.57 versus 1.38; significantly more academic collaborations—average of 2.41 versus 1.27; and more international collaborations, having a significant higher average of 1.48 versus 0.66. In addition, it was found that scientists working in academic institutions have higher tenure (defined as number of years since acquiring the highest degree) (22.7 versus 16.4 on the average); and have listed less biological systems with which they were working (3.24 for industrial and government scientists versus 2.76 for scientists in academic institutions). All other variables did not show significant differences between the two groups.

(f) *Post-doctoral students*: The highest number of significant differences was found between scientists who had post-doctoral students working with them and those who did not have post-doctoral students working with them. These scientists were assigned as inventors on significantly higher number of patents (an average of 2.64 versus an average of 1.33); had significantly more total collaborations (an average of 2.97 versus 1.48); had more academic, international, and local collaborations (average of 2.80 versus 1.36; 1.75 versus 0.74; 1.22 versus 0.75, respectively); had more doctoral and MA students (an average of 2.61 versus 0.58 and 1.87 versus 0.59, respectively). In addition, they had higher academic tenure and classified themselves as working with significantly more technologies (averages of 22.09 versus 18.4 and 11.18 versus 9.19, respectively). All other variables did not show significant differences between the two groups.

4. Characteristics of top entrepreneurial scientists

The study has focused on an effort to explore general features of entrepreneurial scientists and their relations to other variables. In addition to the statistical analysis, I wish to discuss some qualitative insights on the characteristics of entrepreneurial scientists. Table 4 introduces accounts of the distribution of characteristics of the “top patents inventors” focusing on

Table 4
Top Entrepreneurial Scientists (Inventing Above 10 Patents by 2002) and their Major Characteristics

ID	PhD-Year and institution	Appointment(s)	Organiz.	Field of activity	Biological systems	Technology Applied	M.S. Stud.	Ph.D Stud.	Post Doc. Stud.	Aca. Coll.	Ind. Coll.	# of patents	# of publications
1	1969 Hebrew Univ. Israel	Professor of Chemistry; Consultant to a firm	Hebrew Univ.	Biocehem; Chemistry; Pharmacology	Human Mammals	Molecular Design; Peptide Tech.; Prot. Engine.	3	5	2	2	1	13	138
8	1968 Hebrew Univ. Israel	Professor	Hebrew Univ.	Agriculture; Ecology; Mol. Biology; Plant Path.	Bacteria; Fungi	Cell Separation; Gene Expres; Transgenic plants	3	6	2	3	1	11	244
11	1961 Columbia University USA	Professor	TA Univ.	Mol. Microbiology; Biotechnology; Nutrition	Bacteria	Cloning; Fermentation; Waste Treatments	2	2	1	3	0	22	141
14	1981 Technion, Israel	Assoc. Prof. Head of Dep.	BG Univ.	Bio-engineering; Biomaterials	Algae; Human	Drug Del. Systems; Fermentation; Hormones	8	2	2	4	0	11	9
16	Weizmann Inst. Israel	Chairman and CEO of a biotech firm		Med. Chemis; Mol. Biology; Pharmacology	Human; Mammals	Cell markers; Drug Delivery; Tissue Cult	–	–	–	0	0	16	81 44 at the university
17	1982 Weizmann Inst. Israel	Senior VP of a biotech firm		Biotechnology; Biochemistry; Cell biology; Immunology	Bacteria; Mammals	Cloning; Fermentation; Growth Fact; rDNA	1	1	0	0	0	21	105
43	1975 Wiezmann Inst. Israel	Professor	Weizmann Inst.	Biochemist; Immunology; Molecular. Bio.; Virology	Bacteria; Cell Cultures; Viruses	Cell culture; Cloning; RDNA	1	2	1	0	2	20	111
51	1974 Hebrew Univ. Israel	Head of Govt. Res. Inst.		Agriculture; Develop Bio; Genetics; Physiology	Higher Plants	Plant Breeding; Tissue Culture	–	–	–	0	9	11	46
67	1976 Weizmann Inst. Israel	Professor and Head of Dept.	Hebrew Univ.	Biochemistry; Cell Biology; Molecular Biology	Bacteria; Human; Mammals; Phage	Cloning; DNA Probes; rDNA; RNA technology	1	5	4	4	0	10	192
69	1954 Hebrew Univ. Israel	Professor	Weizmann Inst.	Biochemistry; Immunology; Molecular Biology	Bacteria; Human; Mammals; Viruses	Cell Separation; Chemotherapy; Cloning; Oncogenes	0	4	4	6	0	14	44
124	1972, MD Hebrew Univ. Israel	Head of Dept. Hospital and The Hebrew University Medical School	Hadassah Hospital	Cell Biology; Hematology; Molecular Biology; Oncology	Cell Cultures; Human; Viruses	Cell markers; Chemotherapy; Cloning; Gene therapy; MAbs	1	2	2	2	2	12	469
149	1966 MD, PhD The Hebrew Univ. Israel	Professor	Technion	Bioengineering; Biophysics; Membrane Biology	Cell Cultures; Mammals; Murine	Biosensors; Cell Cultures; Tissue cultures; Transporters	0	3	0	0	0	18	63
165	1988 TA Univ. Israel	Professor	TA Univ.	Chemistry; Marine Biology; Natural Products	Algae; Higher Plants; Marine Organism	Chemotherapy; NMR	3	3	1	3	1	13	219
176	1971 The Hebrew Univ. Israel	Professor	The Hebrew Univ.	Biochemistry; Biophysics; Drug Delivery	Cell cultures; Mammals	Drug Delivery; Drug targeting; MAbs; Peptide Technology	2	6	4	4	0	26	217
184	1974 The Hebrew Univ. Israel	Professor	Weizmann Inst.	Immunology; Molecular Biology	Bacteria; Cell cultures; Mammals	Cell cultures; Cloning; DNA Probes; MAbs	0	4	2	0	0	25	157
266	1971 Weizmann Inst. Israel	V.P. Biotech firm		Biochemistry; Cell biology; Diagnostics; Immunology	Bacteria; Cell Cultures	Biosensors; Cell markers; MAbs; Tissue culture	0	0	0	0	0	27	N/A
309	1976 TA Univ. Israel	Head of Dept. Biotech firm		Hematology; Molecular Biology; Virology	Bactiria; Human; Viruses; Yeast	Cloning; DNA probes; Drug Delivery systems; rDNA; PCR	0	0	0	0	0	26	N/A

scientists that have more than 10 patents on which they are listed as inventors. With these accounts, one can distinguish between a few "models" of entrepreneurial scientists, as well as some general features of the whole group. As a group, we can see that 12 out of the 17 scientists within this group received their PhD before 1980, and 13 of them received their degree from either The Hebrew University or the Weizmann Institute (only one received his degree in the US). Most top entrepreneurial scientists are males, while only one scientist in this group is a female professor. In addition, all scientists are extensively involved in scientific publications (except for two industrial scientists, for which no data could be obtained through the Science Citation Index, due to the inability to specify their organizational affiliation. For all other scientists searched for, the number of publications used their name and their institutional affiliation as specified in the original database). In addition, all academic scientists have students at various levels working with them, including post-doctoral students. Finally, most of the academic professors have academic collaboration conducted in conjunction with industrial collaborations.

The following profiles of entrepreneurial scientists can be drown based on the distributions in Table 4:

1. The "Inventor-Publisher" entrepreneurial scientist (for example, #1; #8; #67; #176): This profile entails mainly the university scientist, who has a high publication rate as well as a high intellectual property protection rate (in terms of patents' invention), and has been working in academia between 25 and 35 years, has more academic than industrial collaborations, and between 8 and 12 students at various levels working with him/her.
2. The "Inventor-Limited Publisher" entrepreneurial scientist (for example, #16; #149): These scientists can be heavily involved in collaborations with the industry (from personal records, it was evident that the academic progress of one of them was slower than other scientists in the same university due to his heavy involvement with industrial collaborations. The slower academic progress can result from being perceived by the university as conducting limited quality research and thus lending to a slower promotion rate of the scientist. Another barrier to their promotion can result from the fact that findings of contracted research with the industry usually cannot be published without permission from the collaborating or contracting biotechnology firm in Israel. Withholding publications till patent submission or until various testing of the discovery are applied can result in delayed publications or lower rate of related publications. Such instances were disclosed through interviews with academic scientists who had research contractual arrangements with biotechnology firms.
3. The "Fast tracker all in all" entrepreneurial scientists (for example, #165): These scientists are new entrants to the academic world, but have a strong emphasis on entrepreneurial science, focusing on simultaneously heavy publishing and heavy inventing and patenting, and thus acting on both—the "open science" and the "privatized science" fronts (Henderson et al., 1998; Oliver and Liebeskind, 2003).

5. Discussion

The explorative directions of this study included the effort to analytically distinguish some features of scientific entrepreneurship as they were composed through the data base of collaboration-seeking scientists. Within this frame of research, it was important to identify the independent variables—of intellectual capital and institutional characteristics—that could explain the variance within various forms of existing scientific collaborations.

The paper focused on the relations between scientists' background characteristics, the existence of scientific collaborations of various kinds and protected scientific inventions in the form of patents. The structure of these relations can provide partial illumination to the construct of scientific entrepreneurship. The most significant evidence seems to show that among the entrepreneurial scientists in the sample, those who have the higher rate of collaborations seem to have larger laboratories with students of all levels. But the most significant variable within the composition of the laboratory researchers is the number of post-doctoral students. This is an element worthy of additional discussion. Larger academic research laboratories and especially when post-doctoral students are present, they signify the valorization of scientific human capital since they provide a source of 'in-house' learning for the scientist and his/her students. Post-doctoral students who usually arrive at the laboratory from other institutions have the ability of enlarging the pool of 'in house' research capabilities within the laboratory. A larger number of post-doctoral students in a scientist's laboratory also contributes to increased attractiveness and credibility which are associated with his/her scientific prestige. These 'signals' of scientific quality can be generators for potential future collaborations also with the industry as well as for other types of collaborations. To sum-up, evidence showed that the distinction between lower levels of research students and post-doctoral students is important in predicting collaborations (except for industrial collaborations). While MA and doctoral students provide research capabilities, post-doctoral students can bring new knowledge and capability resources to the scientist's laboratory.

Of course, one can argue for the opposite direction in the explanation logic—scientists who have higher scientific prestige, advanced and versatile knowledge, and large research funds tend to have larger laboratories. In Israel, the salaries and fellowships of the students in a scientist's laboratory are paid mostly through the various research grants that the scientist has raised. Thus, Merton's Matthew effect (1968) claiming that those who have more (unmeasured but plausible research funds in this case) will have more (advanced students in this case), and will have even more (collaborations in this case), is nicely validated. An additional corroboration is provided by the finding (presented in Section 3.3 (c)) indicating that 'high scope' entrepreneurs (with more than two patents) have significantly more students at all levels, in addition to a higher tenure and areas of interest, as well as by the finding (from Section 3.3 (f)) showing that having at least one post-doctoral student is associated with significantly more patents.

Another interesting finding is that none of the independent variables in the study contributes to the explanation of industrial collaborations. This evidence shows that at the time of the survey, most scientists in Israel had few or no industrial collaborations, and the intellectual capital and institutional variables were best associated with the normative science of academic collaborations. Since that time, the National Biotechnology Committee in Israel managed to convince the government to invest in biotechnology technology-transfer programs in the form of consortia and incubators, and with no doubt, there are currently more university-industry collaborations. Some indication for this change is indicated (Section 3.3 (b)) by the finding that scientists with significantly more industrial collaborations were those who continued submitting patent applications since the survey was conducted in 1994, in comparison with those having no additional patents between the years 1994 and 2002. Thus, the subcategory of 'recent entrepreneurship' was significantly associated with industrial collaborations as well as with significantly more students in each level and more areas of interest, lending to the observation that recent entrepreneurs tend to form more industrial collaborations.

Another expectation of this study was that diversity or generalization measures of the laboratory would be associated with higher rates of collaborations. This expectation was not met by the findings except for the weak association between number of areas of interest of the scientist and the number of technologies used in the scientist's laboratory. These findings may reflect the fact that the scientists with fewer collaborations tend to develop 'in house' diversified capabilities, and thus have less existing collaborations. Thus, being a generalist may be associated with more independent research. This finding may be in line with the fact that the number of patents assigned to the scientist has a negative (low but statistically significant) impact on the number of academic, international, and total collaborations, while it has no significant association in the bivariate correlation table. The fact that while we control for intellectual property and institutional variables, the zero association turns in three (out of five) regressions to negative and significant correlation, indicates that in regard to patents, Merton's "Mathew effect" does not appear to be valid. These findings may be lending to a few interpretations. They may indicate that the scientists that have experienced the process of securing intellectual property rights through patent protection, tend to collaborate less and promote more secrecy regarding their laboratory research (for example, Arundel, 2001; Liebeskind, 2001). It could also mean that the more secured intellectual property rights the scientists has, the more the gains out of royalties the scientist may receive can allow him/her to be less dependent upon external collaborations. Another option refers to virtues that may be associated with secured intellectual property rights—namely that the more patents a scientist has, the higher his/her ability to secure less, but larger in scope collaboration that can fund the scientists' laboratory expenses.

Finally, an explanation can follow the direction offered by Zucker et al. (2002), and Nesta and Mangematinz (2002) who contend that patenting of biotechnology academic research produces knowledge that encourages firm creation by scientists. Thus, the negative correlation between patenting and collaborations can be explained by an unaccounted for variable—firm formation. Since the separate analysis of only academic scientists, found the same results, it may be the case that scientists with high rates of patents are involved in the founding of new biotechnology firms, and therefore have less collaborations. With the lack of longitudinal data, all the above explanations are plausible, yet only further research using longitudinal data will be able to specify the direction of relations.

The exploration phase also asked whether there are different classifications for scientific entrepreneurship, and if so, what do they represent. The study suggested various classifications based on collaborations, patents, institutional membership and the composition of publications and patents. All these directions seem to be uniquely associated with some characteristics that lend to the expectations of differential forms of scientific entrepreneurship.

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