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ABSTRACT

How and Why Does Knowledge Spill Over? The Case of Biotechnology*

This paper sheds light on the questions, Why does knowledge spill over? and How does knowledge spill over? The answer to these questions lies in the incentives confronting scientists to appropriate the expected value of their knowledge considered in the context of their path-dependent career trajectories. In particular, we focus on the ability of scientists to appropriate the value of their knowledge embedded in their human capital along with the incentive structure influencing it and how scientists choose to commercialize their knowledge. We use a hazard model to estimate the duration over a scientist's career to starting a new biotechnology firm. We conclude that the spillover of knowledge from the source creating it, such as a university, research institute, or industrial corporation, to a new-firm start-up facilitates the appropriation of knowledge for the individual scientist(s) but not necessarily for the organization creating that knowledge.

JEL Classification: L00, O10, O30
Keywords: knowledge spillovers, biotechnology, science, start-ups, entrepreneurship

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NON-TECHNICAL SUMMARY

The starting point for most theories of innovation is the firm. In such theories the firm is assumed to be exogenous and its performance in generating technological change is endogenous. For example, in the most prevalent model in the literature of technological change, the *knowledge production function*, formalized by Zvi Griliches, the firm exists exogenously and then engages in the pursuit of new knowledge as an input into the process of generating innovative activity. The most important source of new knowledge is generally considered to be R&D. The recent wave of studies (revealing that small enterprises serve as the engine of innovative activity in certain industries) is particularly startling, however, because the bulk of industrial R&D is undertaken in the largest corporations - small enterprises account for only a minor share of R&D inputs. The more recent evidence identifying the role of small firms as a source of innovative activity raises the question: "*Where do new and small firms get the innovation producing inputs, that is, the knowledge?*".

One suggested answer is that although the model of the knowledge production function may certainly be valid, the implicitly assumed unit of observation which links the knowledge inputs with the innovative outputs – at the level of the establishment or firm – may be less valid. Instead, a new literature suggests that knowledge spills over from the firm or research institute producing it to a different firm commercializing that knowledge. This view is supported by theoretical models which have focused on the role that spillovers of knowledge across firms play in generating increasing returns and ultimately economic growth.

The creation of a new firm, especially in a high-technology, science-based industry, such as biotechnology, produces an event that leaves traces for studying the knowledge production function. One of the most striking features of firms making Initial Public Offerings (IPOs) in biotechnology is that they are typically able to raise millions of dollars in the absence of having a viable product at the time when they go public. Indeed, new firms are founded and receive financing on the prospects of transforming technological knowledge created at another source into economic knowledge at a new firm through the development and introduction of an innovative product. Thus, the establishment of a new firm in a knowledge-based industry such as biotechnology provides an opportunity for examining properties of the knowledge production function, and especially the links between the creation of knowledge and its commercialization.

The purpose of this paper is to shed some light on the questions: "*Why does knowledge spill over?*" and "*How does knowledge spill over?*". We suggest

that the answer to these questions lies in the incentives confronting scientists to appropriate the expected value of their knowledge considered in the context of their path-dependent career trajectories. In the metaphor provided by Albert O Hirschman in 1970, if voice proves to be ineffective within incumbent organizations, and loyalty is sufficiently weak, scientists will resort to exit from a corporation or a university to form a new biotechnology company.

This paper attempts to penetrate the black box of the knowledge production function. In addressing the questions how and why knowledge spills over, an assumption implicit to the model of the knowledge production function is challenged – that firms exist *exogenously* and then *endogenously* seek out and apply knowledge inputs to generate innovative output. Although this may be valid some, if not most of the time, the evidence from biotechnology suggests that, at least in some cases, it is the knowledge in the possession of economic agents that is *exogenous*. In an effort to appropriate the returns from that knowledge, the scientist then *endogenously* creates a new firm. Thus, the spillover of knowledge from the source creating it, such as a university, research institute, or industrial corporation, to a new-firm start-up facilitates the appropriation of knowledge for the individual scientist(s) but not necessarily for the organization creating that new knowledge in the first place.

This paper also sheds light on the question that has plagued economists for decades: "*Where do new industries come from?*". The answer, at least in the case of biotechnology, appears to have something to do with new knowledge created with perhaps one purpose in mind, but is, in fact, valuable in a very different context. We observe that the participants in the biotechnology industry come from a broad range of diverse backgrounds. Because no biotechnology industry has traditionally existed, no set career paths have been established. Rather, the participants in an emerging industry choose to leave what otherwise would be established career trajectories in more traditional industries. Through the flow of scientists into this new industry knowledge, which was generated with a more traditional context in mind, spills over by becoming applied in the process of creating a new industry.

> *The late twentieth century has witnessed a scientific gold rush of astonishing proportions: the headlong and furious haste to commercialize genetic engineering. This enterprise has proceeded so rapidly – with so little outside commentary -- that its dimensions and implications are hardly understood at all.*
> Michael Crichton, Introduction to *Jurassic Park*

1. Introduction

The starting point for most theories of innovation is the firm. In such theories the firm is assumed to be exogenous and its performance in generating technological change is endogenous (Arrow, 1962). For example, in the most prevalent model in the literature of technological change, the *knowledge production function*, formalized by Zvi Griliches (1979), the firm exists exogenously and then engages in the pursuit of new knowledge as an input into the process of generating innovative activity. The most important source of new knowledge is generally considered to be R&D. Certainly a large body of empirical work has found a strong and positive relationship between knowledge inputs, such as R&D, and innovative outputs (Griliches, 1984).

However, the recent wave of studies revealing that small enterprises serve as the engine of innovative activity in certain industries (Audretsch, 1995; Acs and Audretsch, 1988 and 1990) is particularly startling, because the bulk of industrial R&D is undertaken in the largest corporations; small enterprises account for only a minor share of R&D inputs (Scherer, 1992; and Cohen and Klepper, 1992). Thus, the model of the knowledge production function seemingly implies that innovative activity favors those organizations with access to knowledge-producing inputs – large organizations. The more recent evidence identifying the role of small firms as a source of innovative activity raises the question, *Where do new and small firms get the innovation producing inputs, that is the knowledge?*

One suggested answer is that although the model of the knowledge production function may certainly be valid, the implicitly assumed unit of observation which links the knowledge inputs with the innovative outputs – at the level of the establishment or firm – may be less valid. Instead, a new literature suggests that knowledge spills over from the firm or research institute producing it to a different firm commercializing that knowledge (Griliches, 1992). This view is supported by theoretical models which have focused on the role that spillovers of knowledge across firms play in generating increasing returns and ultimately economic growth (Romer, 1994, 1990 and 1986; Krugman; 1991a and 1991b; and Grossman and Helpman, 1991).

An important theoretical development is that geography may provide a relevant unit of observation within which knowledge spillovers occur. The theory of localization suggests that because geographic proximity is needed to transmit knowledge and especially tacit knowledge, knowledge spillovers tend to be localized within a geographic region. The importance of geographic proximity for knowledge spillovers has been supported in a wave of recent empirical studies by Jaffe (1989), Jaffe, Trajtenberg and Henderson (1993), Acs, Audretsch and Feldman (1992 and 1994), Audretsch and Feldman (1996) and Audretsch and Stephan (1996).

While this literature has identified the important role that knowledge spillovers play, they provide little insight into the questions of why knowledge spills over and how it spills over. What happens within the black box of the knowledge production is vague and ambiguous at best. The exact links between knowledge sources and the resulting innovative output remain invisible and unknown. This has moved Paul Krugman (1991a, p. 53) to argue that economists should abandon any attempts at measuring knowledge spillovers because "...knowledge flows are invisible, they leave no paper trail by which they may be measured and tracked."

While Krugman's (1991a) observation is undeniably true, the creation of a new firm, especially in a high-technology, science-based industry, such as biotechnology, produces an event that leaves traces for studying the knowledge production function. One of the most striking features of firms making Initial Public Offerings (IPOs) in biotechnology is that they are typically able to raise millions of dollars in the absence of having a viable product at the time when they go public. Indeed, new firms are founded and receive financing on the prospects of transforming technological knowledge created at another source into economic knowledge at a new firm through the development and introduction of an innovative product. Thus, the establishment of a new firm in a knowledge-based industry such as biotechnology provides an opportunity for examining properties of the knowledge production function, and especially the links between the creation of knowledge and its commercialization.

The purpose of this paper is to shed some light on the questions, *Why does knowledge spill over?* and *How does knowledge spill over?* We suggest that the answer to these questions lies in the incentives confronting scientists to appropriate the expected value of their knowledge considered in the context of their path-dependent career trajectories. In the metaphor provided by Albert O. Hirschman (1970), if voice proves to be ineffective within incumbent organizations, and loyalty is sufficiently weak, scientists will resort to exit from a corporation or a university to form a new biotechnology company.

2. Appropriability and Incentives

A large literature has emerged focusing on what has become known as the appropriability problem. The underlying issue revolves around how firms which invest in the creation of new knowledge can best appropriate the economic returns from that knowledge (Arrow, 1962). Audretsch (1995) proposes shifting the unit of observation away from exogeonously assumed firms to individuals – agents with endowments of new economic knowledge. When the lens is shifted away from the firm to the individual as the relevant unit of observation, the appropriability issue remains, but the question becomes, *How can economic agents with a given endowment of new knowledge best appropriate the returns from that knowledge?* Stephan (1996) and Levin and Stephan (1991) suggest that the answer is, *It depends* --it depends on the career trajectory of the individual scientist and whether (s)he is coming from an academic or an industrial background.

Stephan and Levin (1992) analyze how different work contexts have different incentive structures. The academic sector encourages and rewards the production of new scientific knowledge. Thus, the goal of the scientist in the university context is to establish *priority*. This is done most efficiently through publication in scientific journals (Stephan, 1996). By contrast, in the industrial sector, scientists are rewarded for the production of new economic knowledge but not necessarily new scientific knowledge *per se*. In fact, scientists working in industry are often discouraged from sharing knowledge externally with the scientific community through publication. As a result of these differential incentive structures, industrial and academic scientists develop distinct career trajectories.

The appropriability question confronting academic scientists can be considered in the context of the human capital model. Life-cycle models of scientists suggest that early in their careers scientists invest heavily in human capital in order to build a reputation (Levin and Stephan, 1992). In the later stages of their career, scientists' trade or *cash in* this reputation for economic return. Thus, early in their careers, scientists invest in the creation of knowledge in order to establish a reputation that signals the value of that knowledge to the scientific community. With maturity, scientists seek ways to appropriate the economic value of the new knowledge. But how should a scientist best appropriate the value of her/his human capital? Alternatives abound, such as working full-time or part time with an incumbent firm, licensing the knowledge to an incumbent firm, or starting or joining a new firm.

Scientists working in the private sector are arguably more fully compensated for the economic value of their knowledge. This will not be the case for academic scientists unless they *cash out*, in terms of Dasgupta and David (1994), by selling their knowledge to a private firm. This suggests that academic scientists seek affiliation with a commercial venture in a life-cycle context. By contrast, industrial scientists consider leaving the incumbent firm when a disparity arises between the firm and the individual concerning the expected value of their knowledge. In the former situation, age is a good predictor of when the scientist establishes ties with industry. In the latter case, factors other than age are expected to play a more important role in determining when the scientist leaves the incumbent firm.

3. The Data Base

This paper will use a data base drawn from the prospectuses of 60 firms that made an initial public offering (IPO) in biotechnology during the period March 1990 to November 1992 to examine the sources and incentives for commercializing new knowledge. Prospectuses for the offerings were carefully read in order to identify the scientific founders of the new firms. In cases where it proved difficult to identify founders from the prospectuses, telephone calls were made to the firm. In addition, firm histories were checked and confirmed in *BioScan*. Founders having a Ph.D. or an M.D. were coded as scientific founders for the purposes of this research. In addition, several individuals who did not have a doctorate but were engaged in research were included as scientific founders. All told, we were able to identify 101 scientific founders for 52 firms making an initial public offering during this period.

Biographical information was also collected from the prospectuses and was supplemented by entries from standard reference works such as *American Men and Women of Science*. Four types of job experience were identified – academic experience (which includes positions at hospitals, research foundations and the government); experience with pharmaceutical companies; training experiences (as a student, post-doc, or resident), and "other" experience. This information was used to distinguish among five distinct career trajectories followed prior to the founding of the company:

1. The *academic trajectory* describes scientists who had spent all of their time since completing their training employed in the academic research sector;

2. The *pharmaceutical trajectory* describes those scientists whose careers subsequent to receiving training had been entirely spent working in the drug industry;

3. The *mixed trajectory* describes scientists who had worked in both the pharmaceutical industry and the academic research sector;

4. The *student trajectory* describes individuals who went directly from a training position to founding a biotechnology firm; and

5. The *other trajectory*, which includes scientists who have been employed by non-pharmaceutical firms.

Additional biographical information coded was ascertained concerning date of birth and educational background. Citation counts to first-authored published scientific articles were measured using the 1991 *Science Citation Index* produced by ISI and are used here as an indicator of scientific reputation.

4. Preliminary Results

Summary data, presented in Table 1, show that fifty percent of the scientific founders' careers followed an academic trajectory, slightly more than 25 percent a pharmaceutical trajectory. Half of this latter group had established their careers exclusively with large pharmaceutical companies such as SmithKline and Beckman; half had come from smaller pharmaceutical firms, some of which, like Amgen, were a first generation

Table 1

The Age and Citation Record of Founders

	BIRTH DATE				CITATIONS		
	N	M	SD	N_{known}	M	SD	N_{known}
All Scientific Founders	101	1943.18	10.20	96	92.13	171.05	99
All Academic Founders	50	1940.55	10.06	49	149.32	226.51	49
Part Time	35	1938.79	10.29	34	172.71	259.03	35
Full Time	15	1945.06	8.54	15	72.21	78.70	15
All Drug Founders	28	1945.61	9.20	28	29.71	46.28	28
Small	14	1945.93	9.84	14	30.30	57.40	14
Big	12	1947.00	7.67	12	34.00	34.41	14
Mixed Career	13	1943.80	8.76	13	62.69	57.56	13
Student Career	6	1957.00	3.54	5	58.17	83.72	6
All Full Time	57	1945.64	9.61	57	46.59	60.69	57
All Part Time	40	1939.42	10.03	37	159.30	245.52	37

biotech firm. Table 1 also indicates that approximately an eighth of the founders had a mixed career in the sense that prior to founding the firm they had held positions in both a pharmaceutical company as well as a university or non-profit research organization. A handful of founders moved directly from a training position such as a residency or post-doctorate appointment to the startup firm, thereby short-circuiting the traditional trajectories from pharmaceutical firms and/or academe. The career trajectory of the remaining scientists was either indeterminate or followed another type of path.

The employment status of the founders with the biotechnology company was also determined. We find that 59 of the 101 scientific founders were working full time with the new firm at the time of the public offering, 41 were working part time, and almost all (35) of these had followed an academic trajectory. This means that 70 percent of the academic founders maintain full-time employment with their academic institutions, serving as consultants or members of the Scientific Advisory Boards to the startup firms. Only 15 of the academic founders had moved to full-time employment with the firm by the time the IPO was made. By contrast, all 28 scientists whose careers had been exclusively in the pharmaceutical sector held full-time positions with the firm at the time of the IPO; 9 of the 13 whose careers followed a mixed trajectory were full time.

The evidence from Table 1 supports the hypothesis that the incentive structure varies considerably between the pharmaceutical founders and the academic founders. Those founders coming from universities and non-profit research organizations have the option of eating their cake and having it too, by maintaining formal contacts with their previous employer, often in a full-time position. Even those from the academic sector who are full time with the new firm are often able to maintain some connection with the non-profit sector as adjunct or clinical faculty. By contrast, those scientists who have a career path in pharmaceuticals take full-time positions with the company, at least by the time the company goes public.

There are other differences between those scientists coming from an academic trajectory and those scientists coming from a pharmaceutical trajectory. The most notable is the difference in age at the time the public offering was made. On average, those coming from universities were born approximately five years earlier than those coming from the pharmaceutical sector, a difference which is statistically significant at the 95 percent level of confidence. As would be expected, we also find that those following the academic trajectory have significantly more citations than those coming from a pharmaceutical trajectory.

Of perhaps even greater interest are the differences between the part-time academics and the full-time academics. Academic founders who remain full-time with their institution, working but only part-time for the new firm, were, for example, born more than six years earlier than academic founders who leave their institution to go full time with the firm. The part-timers are not only older; they are also more eminent, having significantly more citations than academics who go full time with the firm. This suggests that eminence gives these scientists the luxury of hedging their bets; both the firm and their research institution welcome a chance to claim them as affiliates. And, although we have not yet measured the incidence, such individuals often serve as directors and members of Scientific Advisory Boards of additional start-up firms. The full-timers, by contrast, have developed sufficient human capital to be recognized as experts but lack the luster to hold "dual" citizenship. In terms of both citation counts and date of birth they are remarkably similar to their fellow founders who followed a pharmaceutical trajectory.

These preliminary observations suggest that the incentive structure depends upon the career trajectory that the scientist has followed as well as upon whether the scientist has established sufficient eminence to be able to sustain multiple roles. Scientists working in incumbent pharmaceutical firms face the well known problem of deciding whether to remain with the incumbent firm or start a new firm. Furthermore, the goal of an incumbent firm to capture their economic knowledge seldom permits a scientist to establish a reputation based solely on publication. Instead, their scientific reputations are typically established in terms of the products they helped to develop and are known primarily to "insiders" in the industry. Scientists in academe, however, face a different incentive structure. They live in a world where publications are essential for the establishment of reputation. Early in their careers they invest heavily in human capital in order to build a reputation. In the later stages of their career, scientists may trade or cash in on this reputation for economic returns. A variety of avenues are available to do this, including the establishment of a new firm.

The data suggest that this *cashing out* pattern is determined in part by eminence. As noted, a number of academic founders have established sufficiently strong reputations as to be able to eat their cake and have it too. They maintain their full-time jobs in academe, while seeking part-time opportunities to gain economically from their knowledge and scientific reputation. The economic returns are tied to the shares they own in the startup companies. A subset of academic scientists, however, go full time with the firm. They, too, hold stock in the firm. But, their rewards are more immediate in terms of the salaries paid to executives in the companies.[1] And, while they have established solid reputations, they are considerably less cited than those academic founders who maintain full-time positions in academe. Although this may be a result of age (they are, after all, about five years younger), it is more likely a characteristic that age cannot alter. Science, as numerous researchers have established, is noteworthy for persistent inequality which age merely amplifies (Stephan, 1996).

5. A Hazard Model Estimating Biotechnology Start-Ups

What drives a scientist to become a carrier of knowledge in the spillover process? The preliminary evidence presented in the previous section suggests that it is the incentive structure confronting the scientist, which is shaped by the scientist's career trajectory. Other work (Audretsch and Stephan, 1996) suggests that the location of the scientist also plays an important role, through a contagion effect. Those scientists who are exposed to colleagues who have already started a biotechnology firm are more likely to receive vital information reducing the costs and raising the expected value of starting a new firm. This suggests that, *ceteris parabus*, scientists would be expected to start a new firm at a younger age when they are located in the main geographic clusters of biotechnology activity than when they are located outside of biotechnology agglomerations

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[1] Note that our data do not permit us to compare the *full-timers* and *part-timers* to university-based scientists who *do not* found firms. One would expect that this group is younger, and less eminent than either of the other groups.

To address the question, what drives a scientist to start a new biotechnology company, we apply a semi-parametric hazard duration model (Cox, 1972 and 1975; and Kiefer, 1988), where the model is defined in terms of h(t;x), where h is the hazard rate for a scientist subsequent to completion of his Ph.D., and x is a vector of covariates, reflecting the influences described above. The hazard model is given by

$$h(t;x) = h_0(t) * \exp(\beta x') \tag{1}$$

or

$$\ln\left[h(t;x) / h_0(t)\right] = \beta x' \tag{2}$$

where β is a vector of unknown regression coefficients and $h_0(t)$ is an unknown non-negative baseline hazard rate. The second exponential term incorporates the covariates vector x. Estimates of the regression parameters are obtained as follows; let $t_1 \leq t_2 \leq \ldots t_k$ represent distinct times to the start-up of a new biotechnology firm among n observed years. The conditional probability that the ith scientist starts a new biotechnology firm at time t_i^* with a covariate vector x_i, given that a single startup has occurred at t_i, is given as the ratio of the hazards,

$$\exp(\beta x_i') / \sum_{j \in R_i} \exp(\beta x_j'), \tag{3}$$

where $j \in R_i$ corresponds to those scientists that have not started a new firm prior to time t_i. The baseline hazard rate is assumed to be the same for all the observations and hence it cancels out.

The partial likelihood function derived from Cox (1972 and 1975) is obtained by multiplying these probabilities together for each of the k incidences of starting a new firm,

$$PL(\beta, x_1, x_2, \ldots, x_n) = \prod_{j \in R}^{k} \left[\exp(\beta x_i') / \sum \exp(\beta x_i') \right] \tag{4}$$

Maximization of the partial likelihood function yields estimators of β with properties similar to those of usual maximum likelihood estimators, such as asymptotic normality.

The estimated regression coefficient indicates the relationship between the covariate and the hazard function. A positive coefficient increases the value of the hazard function and therefore indicates a positive impact on the likelihood of a scientist starting a new biotechnology firm. A negative coefficient indicates that the particular covariate has a negative impact on the likelihood of the scientist starting a new biotechnology firm.

The specific covariates in equation (4) to be estimated in the hazard model include:

1.The cumulative citations of the scientist

2. The number of other scientists who have started biotechnology firms in the same geographic region where the scientist is located (contagion effect).

3. The number of new biotechnology firms in the same geographic region where the scientist is located (contagion effect).

4. Dummy variable indicating that the scientist was on an *academic trajectory* (employed in the academic sector)

Table 2: Hazard Function Estimates of Duration to Biotechology Start-Up
(standard errors in parentheses)

	Log-Logistic	Normal	Gamma
Academic Trajectory	1.896	1.934	1.879
	(0.36)	(0.36)	(0.28)
Pharmaceutical Trajectory	1.427	1.475	1.341
	(0.39)	(0.37)	(0.32)
Mixed Trajectory	1.606	1.730	1.616
	(0.40)	(0.39)	(0.33)
Citations	0.002	0.002	-0.002
	(0.05)	(0.04)	(0.03)
Firm Density	-0.017	-0.017	-0.006
	(0.04)	(0.05)	(0.04)
Scientist Density	-0.001	0.002	-0.004
	(0.01)	(0.01)	(0.10)
Intercept	0.769	0.844	1.203
	(0.39)	(4.79)	(12.58)
Log-likelihood	-84.760	-290.780	-81.926

Figure 1

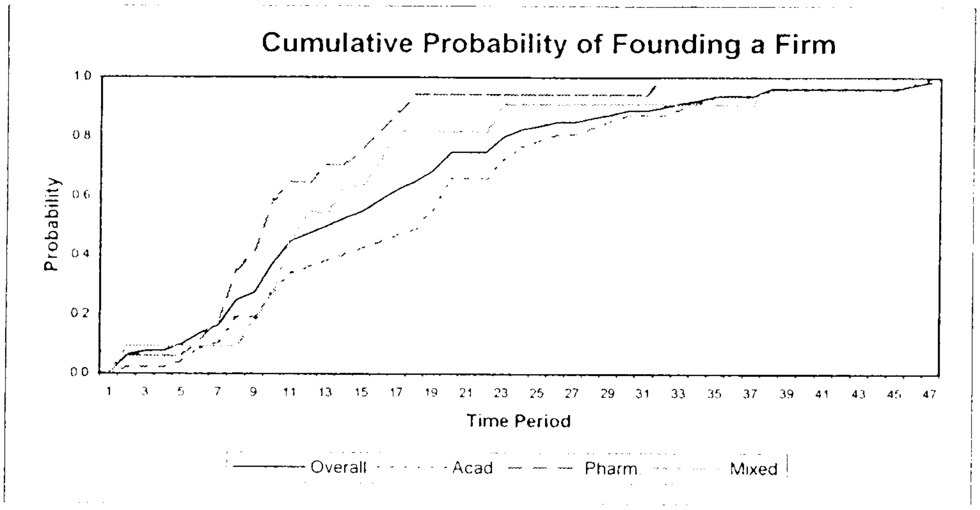

Cumulative Probability of Founding a Firm
Probability
1.0
0.8
0.6
0.4
0.2
0.0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Time Period
Overall
Acad
Pharm
Mixed

Figure 2

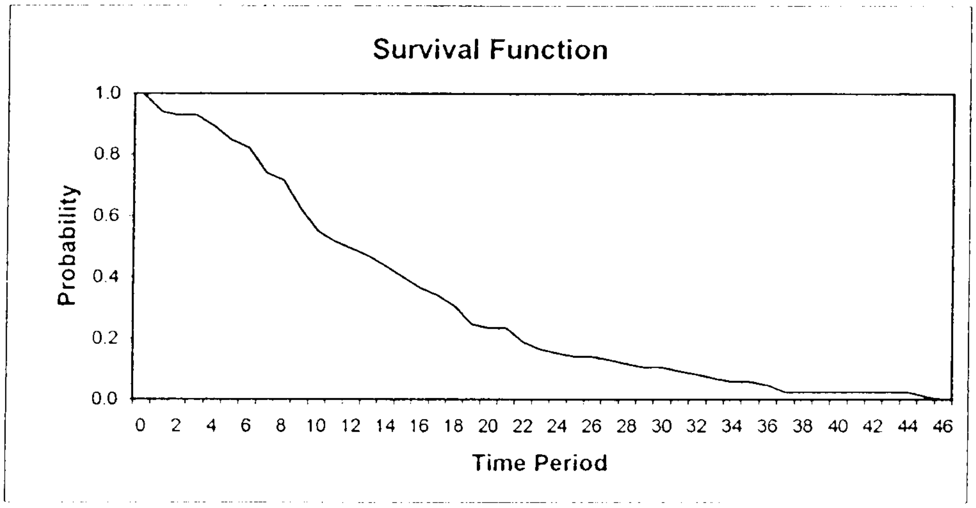
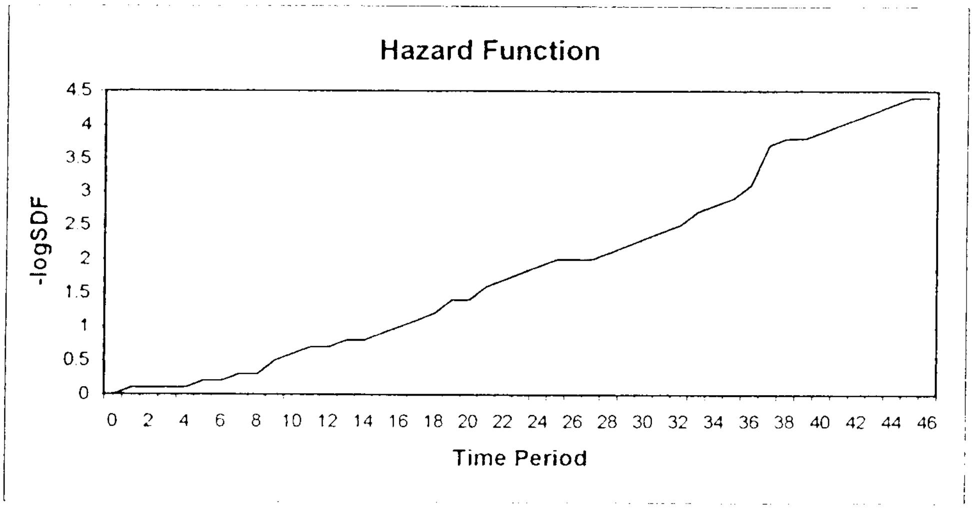

Survival Function
Probability
1.0
0.8
0.6
0.4
0.2
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46
Time Period

Figure 3


Hazard Function
-logSDF
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46
Time Period

5. Dummy variable indicating that the scientist was on the *pharmaceutical trajectory* (employed by a pharmaceutical company)

6. Dummy variable indicating that the scientist was on the *mixed trajectory* (employed in both the pharmaceutical industry and academic sector)

The semiparametric hazard duration model, or the Cox-Regression technique, was estimated to test the hypotheses that the career trajectory shapes the time in his career when he decides to commercialize his knowledge in the form of a new-firm startup in biotechnology. The results are shown in Table 2 for three different specifications of the error structure. As the positive and statistically significant coefficients suggest, the career trajectory of a scientist influences when a scientist starts a new biotechnology company. The career trajectory of those scientists who have been in university and non-profit research institutes leads them to start new biotechnology companies somewhat later than their counterparts in the pharmaceutical industry. The mixed career trajectory is somewhere in between the academic and pharmaceutical scientists. Thus, the evidence suggests the life-cycle theory that the career trajectory of a scientist shapes the decision to start a new biotechnology.

6. Conclusions

This paper has attempted to penetrate the black box of the knowledge production function. In addressing the questions how and why knowledge spills over, an assumption implicit to the model of the knowledge production function is challenged – that firms exist *exogenously* and then *endogenously* seek out and apply knowledge inputs to generate innovative output. Although this may be valid some, if not most of the time, the evidence from biotechnology suggests that, at least in some cases, it is the knowledge in the possession of economic agents that is *exogenous*. In an effort to appropriate the returns from that knowledge, the scientist then *endogenously* creates a new firm. Thus, the spillover of knowledge from the source creating it, such as a university, research institute, or industrial corporation, to a new-firm startup facilitates the appropriation of knowledge for the individual scientist(s) but not necessarily for the organization creating that new knowledge in the first place.

This paper also sheds light on the questions which have plagued economists for decades, Where do new industries come from? The answer, at least in the case of biotechnology, appears to have something to do with new knowledge created with perhaps one purpose in mind, but is, in fact, valuable in a very different context. We observe that the participants in the biotechnology industry come from a broad range of diverse backgrounds. Because no biotechnology industry has traditionally existed, no set career paths have been established. Rather, the participants in an emerging industry choose to leave what otherwise would be established career trajectories in more traditional industries. Through the flow of scientists into this new industry, knowledge which was generated with a more traditional context in mind spills over by becoming applied in the process of creating a new industry.

References

Acs, Zoltan J. and David B. Audretsch, 1990, *Innovation and Small Firms*, Cambridge: MIT Press.

Acs, Zoltan J. and David B. Audretsch, 1988, "Innovation in Large and Small Firms," *American Economic Review*, 78(4), 678-690.

Acs, Zoltan J., Maryann P. Feldman and David B. Audretsch, 1994, "R&D Spillovers and Recipient Firm Size," *Review of Economics and Statistics*, 100(2), 336-340.

Acs, Zoltan J., Maryann P. Feldman and David B. Audretsch, 1992, "Real Effects of Academic Research," *American Economic Review*, 82(1), 363-367.

Arrow, Kenneth J., 1962, "Economic Welfare and the Allocation of Resources for Invention," in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity*, Princeton: Princeton University Press, pp. 609-626.

Audretsch, David B., 1995, *Innovation and Industry Evolution*, Cambridge: MIT Press.

Audretsch, David B. and Paula E. Stephan, 1996, "Company-Scientist Locational Links: The Case of Biotechnology," *American Economic Review*, 86(3), 641-652.

Audretsch, David B. and Maryann P. Feldman, 1996, "R&D Spillovers and the Geography of Innovation and Production," *American Economic Review*, 86(3), 630-640.

Cox, David R., 1975, "Partial Likelihood," *Biometrics*, 62(3), 269-275.

Cox, David R., 1972, "Regression Models and Life Tables," *Journal of the Royal Statistical Society*, 34, May/August, 187-220.

Cohen, Wesley M. and Steven Klepper, 1992, "The Anatomy of Industry R&D Intensity Distributions," *American Economic Review*, 82(4), 773-799.

Dasgupta, Partha and Paul A. David, 1994, "Toward a New Economics of Science," *Research Policy*, 23(5), 487-521.

Griliches, Zvi, 1992, "The Search for R&D Spillovers," *Scandanavian Journal of Economics*, 94(S), 29-47.

Griliches, Zvi, 1979, "Issues in Assessing the Contribution of R&D to Productivity Growth," *Bell Journal of Economics*, 10(1), 92-116.

Griliches, Zvi (ed.), 1984, *R&D, Patents, and Productivity*, Chicago: University of Chicago Press.

Grossman, Gene and Elhanan Helpman, 1991, *Innovation and Growth in the Global Economy*, Cambridge: MIT Press.

Hirschman, Albert O., 1989, *Exit, Voice, and Loyalty*, Cambridge: Harvard University Press.

Jaffe, Adam B., 1989, "Real Effects of Academic Research," *American Economic Review*, 79(5), 957-970.

Jaffe, Adam B., Manuel Trajtenberg and Rebecca Henderson, 1993, "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," *Quarterly Journal of Economics*, 63(3), 577-598.

Kiefer, Nicholas M., 1988, "Economic Duration Data and Hazard Functions," *Journal of Economic Literature*, 26(2), 646-679.

Krugman, Paul A., 1991a, *Geography and Trade*, Cambridge: MIT Press.

Krugman, Paul A., 1991b, "Increasing Returns and Economic Geography," *Journal of Political Economy*, 99(3), June, 483-499.

Levin, Sharon G. and Paula E. Stephan, 1991, "Research Productivity over the Life Cycle: Evidence for Academic Scientists," *American Economic Review*, 81(4), 114-132.

Prevezer, Martha, 1997, "The Dynamics of Industrial Clustering in Biotechnology," *Small Business Economics*, 9(3), June, 255-271.

Romer, Paul, 1994, "The Origins of Endogenous Growth," *Journal of Economic Perspectives*," 8(1), Winter, 3-22.

Romer, Paul, 1990, "Endogenous Technological Change," *Journal of Political Economy*, 94(1), 71-102.

Paul Romer, 1986, "Increasing Returns and Long-Run Economic Growth," *Journal of Political Economy*, 94(5), November, 1002-1037.

Scherer, F.M., 1991, "Changing Perspectives on the Firm Size Problem," in Z.J. and D.B. Audretsch (eds.), *Innovation and Technological Change: An International Comparison*, Ann Arbor: University of Michigan Press, pp. 24-38.

Stephan, Paula E., 1996, "The Economics of Science," *Journal of Economic Literature*, 34(3), 1199-1262.

Stephan, Paula E. and David B. Audretsch (eds.), 1999, *The Economics of Science and Technological Change*, Vols. 1 and 2, London: Edward Elgar Publishing.

Stephan, Paula E. and Sharon G. Levin, 1992, *Striking the Mother Lode in Science*, New York: Oxford University Press.