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Technological Progress and the Duration of Contribution Spans

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ABSTRACT

This study uses the scientific and patent literature as a source of data to analyze the relationship between author/inventor contribution spans and the rate of technological progress in two chemical fields. Using survival analysis statistics, the authors examine the probability that an individual will contribute to the field for a specified length of time and the probability that an individual, having contributed to the field for a specified period of time, will cease to contribute in the future. The authors also test the significance of several covariates in predicting the length of contribution spans.

Introduction

Predicting the rate of technological progress within a given field is an enduring problem for those individuals who are responsible for the allocation of scarce resources. Ideally, if managers and government policy makers had at their disposal an array of indicators to enable them to predict the rate of technological progress in a field, optimal resource allocation would be assured. Indeed, the ability of managers and policy makers to comprehend the pace and the direction of technological advancement will largely determine their firm's or nation's competitive performance in world markets into the next century. This is no small task. Historical accounts of industrial evolution, such as with the development of semiconductors, videocassette recorders, and personal computers, show the immense difficulties some firms encounter when confronted by new technologies [1–3].

Undoubtedly, there is an obvious need to enhance our understanding of the way in which new technologies emerge. To this end, different methodologies, ranging from qualitative case studies to sophisticated quantitative forecasting models, have been developed [4–7]. These developments have established technological forecasting as an academic discipline in its own right. However, the many pitfalls characteristic of technological forecasts and the often limited usefulness of their outcomes have been noted with striking regularity [8–10]. As a consequence, technological forecasters face a dilemma. On the one hand, indicators of technological progress have often been illusive. On the other hand, intense global competition in industry and constrained government

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budgets for science and technology have made the search for such indicators all the more urgent.

One approach to understanding the rate of technological progress within a given field is to focus on the actions of those individuals who are responsible for creating progress, namely, the scientists and engineers who solve the problems that enable the technology to move forward. The basic rationale for this perspective follows that in the process of solving problems at the technological frontier, researchers continually formulate their own opinions regarding the rate of progress and the probability of success within a particular field. Based upon their assessment and reassessment of a particular field, researchers will decide (or influence the decision) where to best apply their energies.[1] Simply stated, if progress is rapid, researchers will be more likely to stick with their research agenda long enough to reap the rewards of their work. Conversely, if progress is slow, researchers will be more likely to seek out more promising research areas where they can apply their energies. As a result, it may be possible to ascertain the relative rate of progress in a field by examining the duration of the contributions made by those individuals who are actively involved in shaping its technological progress.

The following study focuses on how long researchers persist in a field in order to assess the relative rate of technological progress. Scientific and patent literature are used as a source of data to measure the length of time that individual authors and inventors contribute to the field and to determine statistically the survival and hazard rates as well as some of the factors associated with longevity.[2] In particular, the duration of the participation of individuals is examined through an analysis of their "contribution spans" in a field, that is, the time span between their first and last paper or patent contribution. From an analysis of the contribution spans, estimates are made of (a) the probability that an author/inventor's contribution span will extend a given number of years and (b) the probability that, having contributed a given number of years, an author/inventor will cease to contribute in the future. Furthermore, the relevance of a number of covariates in predicting the duration of author/inventors' contribution spans is examined.[3]

Catalysts for two stereoregular polymers—EPDM and polypropylene—were selected as the technical fields for comparative analysis in this study.[4] The choice of EPDM (a synthetic rubber) and polypropylene (a plastic) as comparative test cases was based solely on the independent evaluation of individuals in the chemical industry that these fields experienced markedly different rates of technical progress over the past several decades. Indeed, the historical record reveals that since the discovery of the Ziegler-Natta catalyst process in the 1950s, from which both processes are based, the rate of catalyst development in each field diverges significantly. In the case of polypropylene, four major breakthroughs have led to the development of three well-defined generations of catalysts. In contrast, EPDM catalysts have evolved less rapidly. No major breakthroughs have occurred, and in the past 15 years no radically new processes have been developed. The catalysts used in EPDM are generally considered to be first-generation technology.[5]

[1]This basic rationale has been a recurring theme among many sociologists of the sciences, who have come to view scientists as "investors of credibility." That is, scientists are likely to invest their credibility in those specialties where they hypothesize the probability of reaping rewards to be the highest [11].

[2]The methodology is discussed in Rappa and Garud [12].

[3]For lack of a better term, we will refer to these individuals as author/inventors in order to encompass individuals whose contributions may include scientific publications or patents.

[4]The historical development of EPDM and polypropylene is described elsewhere [13–15].

[5]It must be noted that although the fields realized different rates of technical progress in catalyst development, this does not imply that one field is necessarily unsuccessful in a commercial sense. Both fields are considered commercial successes, although polypropylene has become much more widely used.

By comparing the contribution spans of EPDM researchers and polypropylene researchers, some insight may be gained into the question of whether or not the duration of their participation in the field can serve as an accurate indicator of the rate of technological progress. It is expected that EPDM researchers would be more likely to leave their field sooner than their counterparts in polypropylene.

Data Collection and Methods

Commercial electronic data bases were used to identify patents and publications related to the fields of EPDM and polypropylene catalyst development. The data bases were searched on-line using a set of key terms that are known to be commonly used in the lexicon of author/inventors and might be in either the title, abstract, or classification terms of a document. The searches resulted in the retrieval of 1383 polypropylene- and 613 EPDM-related patents and publications between 1955 and 1989. In each case, the majority of documents retrieved were patents (60% of the polypropylene documents and 78% of the EPDM documents).

The documents were retrieved electronically and were temporarily placed in a bibliographic relational data base operating on a personal computer. This allowed for a careful inspection of each document in order to ensure the accuracy and integrity of the search procedure. Since multiple-source data bases were used, it was necessary to remove duplicate documents. In addition, while inspecting the data base, an effort was made to remove misclassified documents that did not pertain to EPDM or polypropylene catalyst development. In the process of inspecting the documents, any that seemed inappropriate were flagged, so that an individual active in these areas could make the final judgment as to its relevance. Furthermore, to avoid problems of incompleteness in the later years due to patent lags, as well as in the earlier years, the data bases were constrained to the period from 1960 to 1986.

The data collection procedure described above ultimately resulted in the identification of 613 EPDM and 1314 polypropylene patent applications and publications from 1960 to 1986. The contribution span data subsequently used in this study were derived from these documents. However, before the documents could be used as a source of data, they required extensive editing in order to create consistency among author/inventor names and their affiliation names. It is frequently the case with commercial data bases that the name of an author or an affiliation is not standardized across documents. Sometimes the inconsistencies arise because of misspellings, but mostly they are the result of variations in the use of abbreviations, middle initials, capitalizations, and hyphenations. Although such a lack of standardization might not be a problem for the typical user of an electronic literature data base, it would be a major source of error in determining the duration of author/inventor contribution spans. Therefore, it was essential to meticulously inspect the name of each author and affiliation in the relational data base so that all inconsistencies could be eliminated. A particularly unfortunate complication specific to the patent literature data bases is the frequent absence of inventor names from corporate patents. This required the use of multiple data bases and the cross-checking of patent numbers in order to obtain the missing data.

Upon completing the editing of the documents, the data base was used to identify each author/inventor who contributed to the field over the 27 year period. This procedure yielded a total of 3280 individuals. At this stage, a statistical data base was created containing several covariates for each author/inventor that were derived from information obtained from the published documents as well as other sources. Table 1 provides a list of the variables and their definitions.

The dependent variable for the analysis, the contribution span, is calculated as the

TABLE 1
Variables Used in the Analysis and Their Definitions

Category and variable	Description
Dependent variable	
Contribution span	Span of years since researcher's first and last patent application or publication in the field
Covariates	
Technical field	EPDM = 0; polypropylene = 1
Author/inventor productivity	Cumulative number of patent applications or publications in the field by the author
Organization productivity	Cumulative number of patent applications and publications in the field by the author/inventor's organization
Industrial	Author/inventors employed in industrial firms = 1; otherwise = 0
Eastbloc	Author/inventors from Eastern bloc countries = 1; otherwise = 0
Market size	Annual industrial production of EPDM and polypropylene in kilotons
Patents	Cumulative number of patents granted in the field
Population	Total number of author/inventors in the field
$\text{Population}^2/1000$	Second-order term of population size
Dispersion	Index of organizational dispersion of author/inventors in the field (Hirfindahl index)

number of years that have elapsed from the first to the last known patent or publication for each author.[6] Although calculating the contribution span is relatively straightforward, there are some methodological issues that arise that require further explanation. The primary issue of concern is that for those author/inventors who are active in the fields of EPDM and polypropylene during the last year of the data base, the ultimate length of their contribution span is indeterminate. In other words, since these individuals have not yet left the field, it is only known that the length of their contribution span is some minimum value (that is, the entry year to the present year). To account for this, survival analysis statistics were implemented in analyzing the data [16–19]. Such techniques take into consideration precisely this kind of problem in the calculations with a procedure that adjusts for the biases that right-censored data create.

Having determined the distribution of contribution spans, it is interesting to examine what factors might affect how long an author/inventor contributes to the field. Using the literature, a number of covariates were constructed. Although they could be treated as time-varying covariates (that is, as having values that vary yearly in the course of an author's contribution span), the present analysis does not implement such an approach to formulating the data set. Therefore, the value for each covariate is taken according to the last year of the author's contribution span. In this manner, several covariates were created, including two dummy variables to control for factors that might account for heterogeneity within the population examined. First, the kind of organization in which each author is employed was coded according to whether they are employed in an industrial or nonindustrial (that is, academic or government) research laboratory. Second, the country in which the author is located was coded, and a covariate was created to signify whether the individual's affiliation is located in a Western industrial country or in an Eastern bloc country.

Additional covariates were created which reflect individual, organization, or pop-

[6]For example, if a researcher first published in 1975 and last published in 1980, the researcher's contribution span would be calculated as six years. Furthermore, it is assumed that a researcher who publishes in only one year has a span of one year. Note that the contribution span is unaffected by the frequency of publication within a given year.

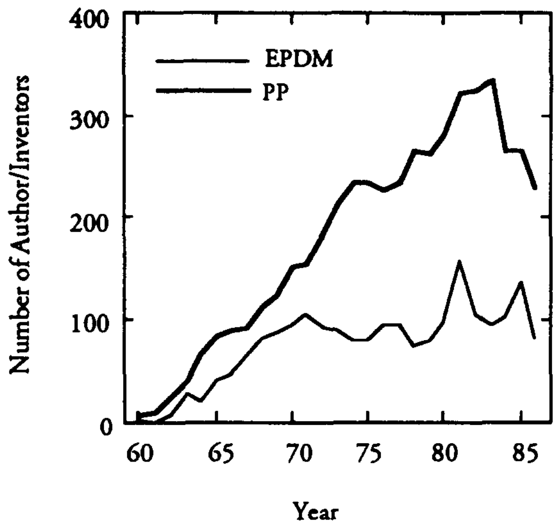

Fig. 1. Growth in the EPDM and polypropylene author/inventor populations, 1960–86.

ulation attributes. At the individual level, a covariate was constructed to reflect an author's productivity in the field as measured by the cumulative number of publications and patents credited to the author. An organizational-level covariate was created to reflect the productivity—or what might be considered as an organization's cumulative investment in the field—in terms of the cumulative number of patents and publications assigned to the author/inventor's affiliation.

Three population-level covariates were created to reflect the size and dispersion of each field in each year. Population size is measured in terms of the number of individuals who publish or patent in the field in a given year, as described below and illustrated in Figure 1. A second-order covariate, the square of population size, was created in order to capture any quadratic association between population size and contribution spans. The third covariate is a measure of dispersion of author/inventors among different organizations, that is, the extent to which the population is concentrated in a few organizations or spread across many. For this purpose, a Hirfindahl concentration statistic, which is determined by calculating the sum of the squared share of author/inventors affiliated with each organization annually, is used.

Lastly, two covariates were included to reflect the maturity of the field. The first is market size (in terms of kilotons of EPDM and polypropylene produced annually). Because statistics for total world production are not available over the entire 27 years, the aggregate production of Western Europe, Japan, and the United States is used instead.[7] The second maturity covariate is the cumulative number of patents granted in each field.

Results

Using data from the scientific and patent literature on EPDM and polypropylene published between 1960 and 1986, the contribution spans for 3280 author/inventors and

[7]The market data were provided by the marketing research department of a major chemical firm. The data were checked for accuracy with data from Kline & Co., an organization that publishes statistics on the chemical industry.

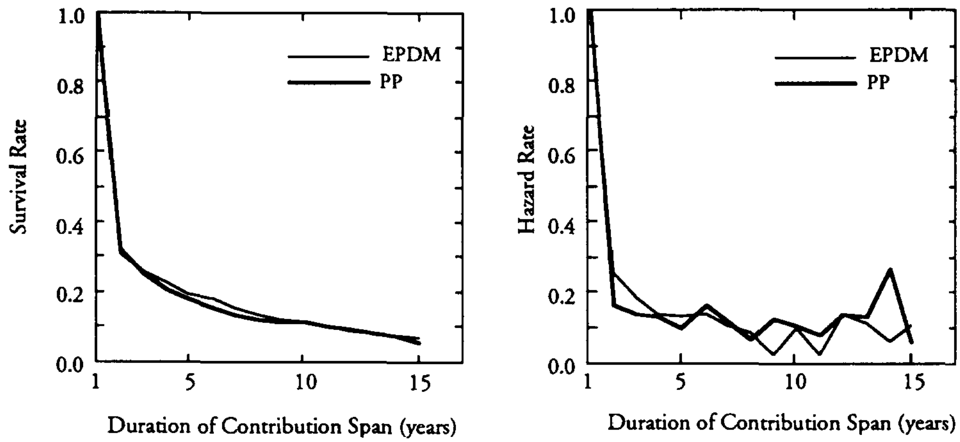

Fig. 2. Nonparametric estimates of survival and hazard functions for author/inventor contribution spans in EPDM and polypropylene.

several explanatory variables associated with each were compiled into a statistical data base: 2267 (69%) individuals in polypropylene and 1013 (31%) in EPDM. Of the 3280 cases, 739 (22.5%) were active the last three years of the data base and were therefore classified as censored. Sixty percent of the total population are employed in industrial firms and nearly 25% are located in Eastern bloc countries.

The historical growth in participation in each field can be seen clearly in terms of the number of author/inventors contributing to the literature (see Figure 1). The number of researchers in each field in a given year is calculated to be the cumulative number of individuals entering the field (as evidenced by an initial publication or patent application) subtracted by the cumulative number of individuals who have left the field (as evidenced by their failure to continue to publish or patent in a future year).

The data were analyzed using the LIFETEST and LIFEREG procedures of SAS (v5.18). Using the LIFETEST, the first step in the analysis was to make nonparametric estimates of the survival and hazard functions for the data. The life-table approach was chosen. The results of this procedure are illustrated in Figure 2. The survival function for each field is a monotone decreasing function and they are nearly identical. Tests of homogeneity of the survival curves stratified by field cannot reject the null hypothesis that the strata have identical survival distributions. The probability of a author/inventor's contribution spans lasting two years or longer is about 0.3. After two years, the survival rate continues to diminish, eventually leveling off at about 0.07 for contribution spans of 15 years or more.

The hazard functions are nonmonotonic and initially very different for each field. In both cases the hazard rate decreases markedly for author/inventors who have contribution spans of at least two years. In the case of EPDM, however, the probability of a author/inventor ceasing to contribute after having contributed for two years is 0.25. In comparison, for polypropylene, the probability of a author/inventor ceasing to contribute after having contributed for two years is 0.16. Thus, the hazard rate in the second year is 1.56 times higher in EPDM than in polypropylene, and this difference is found to be statistically significant (95% confidence interval). Beyond the second year, there is no statistically significant difference between the functions. For both fields the hazard rate varies between about 0.05 and 0.15 between the second and tenth years. The basic

TABLE 2
Maximum Likelihood Estimation of Contribution Spans Using Different Distributions

	Exponential	Weibull	Gamma	Log-logistic
Intercept	−0.228*	−0.458***	−0.101	−0.261***
	(0.133)	(0.068)	(0.061)	(0.042)
Technical field	0.090	0.052	0.022	0.007
	(0.089)	(0.044)	(0.042)	(0.028)
Author/inventor productivity	0.487***	0.671***	0.349***	0.419***
	(0.022)	(0.016)	(0.007)	(0.009)
Organization productivity	0.002*	0.002***	0.002***	0.002***
	(0.001)	(0.001)	(0.001)	(0.000)
Industrial	−0.033	−0.050	−0.083***	−0.047**
	(0.070)	(0.034)	(0.031)	(0.021)
Eastbloc	−0.011	−0.080	−0.043	−0.015
	(0.085)	(0.042)	(0.038)	(0.026)
Market size	0.0004***	0.0001***	0.0002***	−0.0002***
	(0.000)	(0.000)	(0.000)	(0.000)
Patents	0.005***	0.003***	0.002***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Population	−0.005***	−0.003***	−0.003***	−0.002***
	(0.001)	(0.001)	(0.001)	(0.000)
Population^2/1000	−0.024***	−0.012***	−0.011***	−0.010***
	(0.003)	(0.001)	(0.001)	(0.000)
Dispersion	−0.001*	−0.001***	−0.001**	−0.000*
	(0.001)	(0.000)	(0.000)	(0.000)
Scale parameter		0.493	0.465	0.197
		(0.007)	(0.000)	(0.004)
Shape parameter			0.074	
			(0.000)	
Log-likelihood	−2880	−2047	−1761	−1287

Total number of cases = 3139; number of right-censored values = 739. The figures in parentheses are standard errors of estimates. Significance level: *<.1; **<.05; ***<.01.

implication of the hazard function is that the longer an author/inventor contributes to the field, the less likely he or she will be to leave it. The risk of leaving the field is highest within the first year.

The next step in the analysis was to determine the parametric model that best fits the distribution of contribution spans. Although nonparametric analysis permits certain assumptions that can be made about the shape of the survival distribution (for instance, that it is nonmonotonic), nonetheless we decided to examine statistically several different distributions for goodness of fit. The basic model adopted for the analysis is:

$$\mathbf{Y} = \mathbf{X}\beta + \sigma\varepsilon$$

where **Y** is the log of the contribution span, **X** is the matrix of covariates, β is a vector of unknown regression parameters, σ is a scale parameter, and ε is a vector of errors from an assumed distribution. This model is referred to as an accelerated failure time model because the effect of the explanatory variables is to scale a baseline distribution of failure times. In order to determine the underlying distribution that best fits the data, four different types of distributions were evaluated: the exponential, Weibull, gamma, and log-logistic distributions. Using LIFEREG, the results of this procedure for the entire sample are provided in Table 2. The parameters are estimated by maximum likelihood using a Newton-Raphson algorithm. The overall fit of each model is represented by the log-likelihood function. Minus two times the log-likelihood value has a chi-square distribution with appropriate degrees of freedom. Using the baseline model, the goodness of fit for each distribution is evaluated in term of minimizing the absolute value of the log-likeliness score. As a result, the log-logistic distribution (with a log-likelihood score of -1287) was chosen and became the basis for estimating the regression coefficients of the explanatory variables in the model. This result, which is consistent with the nonparametric findings, suggests a nonmonotonic hazard function.

Table 2 also shows the results of the inclusion of a dummy variable (technical field) to stratify on the two fields being investigated. The estimates for the log-logistic distribution indicate no field effect. There is no evidence to suggest that the distribution of contribution spans for the two fields are divergent, which confirms the findings from the nonparametric analysis. This result is consistent across all distributions.

In the next step, the model was estimated with LIFEREG in a sequence of steps by adding each covariate into the equation using the log-logistic distribution. Since it is desirable to investigate whether the significance of covariates differs among the two fields, the modeling results are presented separately (see Tables 3 and 4). In the case of each field, the addition of each covariate has the effect of generally improving the log-likelihood score. Model 9 was chosen as the baseline for the comparison to understand the effect of the covariates.

The estimation results of model 9 indicate a number of differences in terms of the significance of the covariates examined. First, several covariates that are significant in the case of polypropylene are not significant for EPDM; namely, organization productivity (+), industrial (−), patents (+), and market size (+) are all significant for polypropylene but not for EPDM. Second, although the population size variables are significant in both cases, the signs of the coefficients indicate a different relationship in each case. The only similarities between the two fields are the significance of author/inventor productivity (+) and the lack of significance for the Eastern bloc and concentration covariates.

In the case of the population variables, the first- and second-order population terms are significant right from their initial inclusion in both fields. However, in the case of EPDM, the negative coefficient for population size combined with the positive coefficient for the second-order term implies a U-shaped relationship between population size and author/inventor contribution spans (see Figure 3). The data indicate that when the population is small, its size is negatively related to the length of contribution spans, but after it reaches the size of about 150 individuals, the slope of the curve turns positive. This result suggests that there may be a point of critical mass for the EPDM author/inventor population, at which its size is sufficiently large to become significant in increasing contribution spans. It is interesting to note that the EPDM population never grew beyond this size (refer back to Figure 1). In contrast to the EPDM case, the relationship between population size and the length of contribution spans in the case of polypropylene is negatively sloped, and increasingly so, as the population grows larger.

Discussion

Using the scientific and patent literature as a source of data, this paper provides an analysis of the contribution spans of author/inventors in the field of EPDM and polypropylene catalyst development. Nonparametric estimates of the survival rate and hazard rate are made, and it is found that the distribution of contribution spans follows most closely a log-logistic function. In addition, a statistical model of the relationship between the contribution spans and a set of covariates is examined.

TABLE 3
Maximum Likelihood Estimations of Contribution Spans for EPDM: Log-Logistic Distribution

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Intercept	0.285***	−0.465***	−0.452***	−0.460***	−0.360***	−0.541***	−0.577***	−0.332***	−0.166
	(0.021)	(0.024)	(0.026)	(0.026)	(0.057)	(0.061)	(0.064)	(0.096)	(0.140)
Author/inventor productivity		0.538***	0.500***	0.497***	0.495***	0.485***	0.487***	0.486***	0.486***
		(0.018)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
Organization productivity			0.007***	0.007***	0.008***	0.002	0.003	0.003	0.003
			(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Eastbloc				0.047	−0.051	−0.033	−0.005	−0.008	−0.006
				(0.034)	(0.060)	(0.062)	(0.063)	(0.063)	(0.063)
Industrial					−0.107***	−0.064	−0.041	−0.044	−0.042
					(0.055)	(0.056)	(0.057)	(0.057)	(0.057)
Patents						0.001***	−0.000	0.000	0.000
						(0.000)	(0.001)	(0.001)	(0.001)
Market size							−0.001**	−0.001*	0.001
							(0.001)	(0.001)	(0.001)
Population								−0.005***	−0.007***
								(0.002)	(0.002)
Population^2/1000								0.016**	0.026***
								(0.008)	(0.010)
Dispersion									−0.001
									(0.000)
Scale parameter	0.371	0.204	0.213	0.212	0.212	0.211	0.211	0.210	0.210
	(0.012)	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)
Log-likelihood	−995	−556	−510	−509	−507	−460	−458	−450	−449
Number of cases	1013	1013	900	900	900	900	900	900	900
Cases censored	247	247	236	236	236	236	236	236	236

Figures in parentheses are standard errors of estimates. Significance level: *<.1; **<.05; ***<.01.

TABLE 4
Maximum Likelihood Estimation of Contribution Spans for Polypropylene: Log-Logistic Distribution

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Intercept	0.300***	−0.406***	−0.436***	−0.429***	−0.313***	−0.507***	−0.625***	−0.191***	−0.180***
	(0.015)	(0.014)	(0.015)	(0.015)	(0.025)	(0.029)	(0.031)	(0.045)	(0.149)
Author/inventor productivity		0.479***	0.463***	0.461***	0.459***	0.447***	0.438***	0.394***	0.394***
		(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Organization productivity			0.002***	0.003***	0.003***	0.001***	0.002***	0.001***	0.001***
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Eastbloc				−0.043**	−0.166***	−0.077**	−0.078**	−0.001	−0.001
				(0.021)	(0.030)	(0.030)	(0.031)	(0.029)	(0.029)
Industrial					−0.143***	−0.076***	−0.062**	−0.039*	−0.039*
					(0.024)	(0.024)	(0.025)	(0.023)	(0.023)
Patents						0.000***	−0.003***	0.002***	0.002***
						(0.000)	(0.000)	(0.000)	(0.000)
Market size							−0.000***	−0.000***	0.000***
							(0.000)	(0.000)	(0.000)
Population								−0.003***	−0.003***
								(0.000)	(0.000)
Population^2/1000								−0.010***	−0.010***
								(0.001)	(0.001)
Dispersion									−0.000
									(0.000)
Scale parameter	0.408	0.217	0.217	0.217	0.216	0.215	0.212	0.188	0.188
	(0.009)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)
Log-likelihood	−2425	−1375	−1324	−1322	−1303	−1217	−1128	−801	−801
Number of cases	2267	2267	2239	2239	2239	2239	2239	2239	2239
Cases censored	505	505	503	503	503	503	503	503	503

Figures in parentheses are standard errors of estimates. Significance level: *<.1; **<.05; ***<.01.

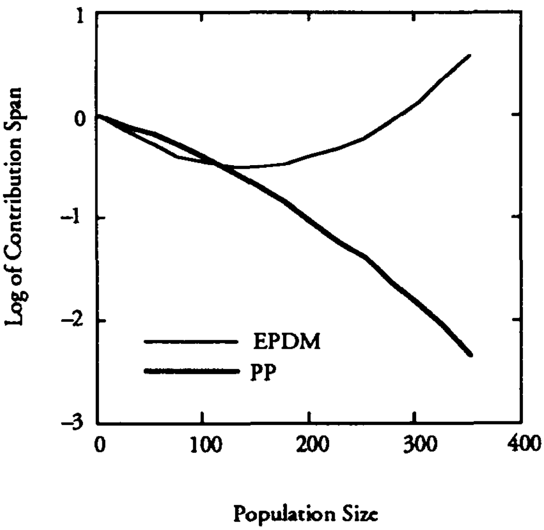

Fig. 3. Relationship between population size and contribution span for EPDM and polypropylene.

The findings of this analysis indicate that the sample survival and hazard functions for 3280 author/inventors in EPDM and polypropylene are generally similar. About 30% of the author/inventors have a contribution span of more than two years. The risk of author/inventors ceasing to contribute to the field is greatest in the first year of their contribution span. The hazard rate declines sharply after the first year and subsequently remains fairly constant. The critical difference between the two fields comes in the second year, when the hazard for EPDM researchers is more than 1.5 times higher than for polypropylene researchers. This result is suggestive of the basic hypothesis that individuals confronted with slow progress in a field will be more likely to seek an alternative area of research. The fact that it is the early years that are most critical is understandable, since at that point not much of a researcher's career has been invested in the field. Needless to say, the longer one stays in the field, the less likely one is to leave it, regardless of the rate of progress.

An examination of the relationship between several covariates and the length of contribution spans indicates that the EPDM and polypropylene fields are quite different. Most noteworthy is the difference in the relationship between population size and contribution spans. It appears that in the rapidly progressing field of polypropylene catalysts, the larger the field became, the shorter and shorter the duration of contribution spans became. This is perhaps the result of the competitive pressures that arise as more people work in a field. In contrast, EPDM shows a much different relationship, suggesting that a lack of individuals in the field had a detrimental effect on the length of contribution spans.

Another important difference lies in the effect of market size. In the case of EPDM, market size is not significant in influencing contribution spans. However, in the case of polypropylene, market size is significant and has a positive effect on the length of author/inventor contribution spans. This is suggestive of the notion that rapidly progressing fields of technology may have an important "market pull" component.

The present analysis has certain limitations, some of which are peculiar to literature-based studies and some of which are more generic in nature. Given that the primary interest in this research is to understand progress in a field, it will be necessary to construct a data set that implements a time-varying covariate data structure. Such an approach will permit a more careful scrutiny of the dynamic phenomena that affect an author/inventor's contribution span. Furthermore, this approach will allow for the examination of whether or not changes in the hazard rate of a community can serve as an indicator of future momentum of the field. It is also necessary to determine the extent to which the present and future findings from the EPDM and polypropylene fields can be generalized to other fields of science and technology and to examine the importance of other explanatory variables in understanding contribution spans.

Work is currently under way to address these issues. First, a preliminary investigation suggests that data from the literature are structured in such a manner that time-varying covariates should be feasible to create. Second, data sets for ten additional fields are currently being constructed, with fields varying in terms of their size and disciplinary composition, the national and sectoral distribution of their author/inventors, their commercial impact, and the degree to which they have succeeded in becoming well-established, institutionalized research communities. Third, further studies will be supplemented with other data, derived both from the literature and other sources.

We believe the approach toward the scientific and technological literature outlined in this paper offers new perspectives to the application of bibliometric methods to technological forecasting. Instead of predicting the growth and the decline of particular fields by looking at publication or patent volumes, our research points to the usefulness of publication and patent information in determining the contribution spans of researchers.

Analyzing contribution spans may eventually serve as a useful tool for managers and government policy makers who are responsible for monitoring the progress of emerging technologies globally. In essence, we are proposing a technique that allows one to gauge the worldwide pulse of technological progress by measuring the rate of change in researchers' commitment to a field. By focusing on the determinants of researcher contribution spans, our aim is to shift attention away from predicting the technological future and toward understanding the underlying fundamentals of research behavior. Improvements in our understanding of survival and hazard rates for researchers in a field may ultimately lead to the identification of critical factors and events that can inform our policy decisions regarding emerging technologies. In this manner, we suggest that measurements of researchers' persistence using contribution spans may serve as an indicator of change in the rate of technological progress in a particular field. Perhaps we can most clearly envision our technological future by understanding in a comprehensive and systematic manner the sustained commitment of researchers to the ideas they are pursuing today.

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