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SURVIVAL IN THE NETWORK: ON THE PERSISTENCE OF RESEARCH ORGANIZATIONS IN AN EMERGING FIELD

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This paper examines the persistence of research organizations in their efforts to participate in the development of an emerging technology. Several hypotheses relating the position of a research organization in a network of R&D collaborations to its persistence are formulated and tested using data on 367 research organizations in the field of transgene plants over thirteen-years. Evidence of the hazard rate and the significance of various sociometric time-varying covariates is provided. The analytical results support the hypothesis that network embeddedness is a significant determinant of organizational survival in an emerging field of technological activity.

INTRODUCTION

Widely accepted models of the growth of technical knowledge view this process as a cumulative progression of ideas and techniques embedded in "traditions of practice" (Constant, 1980), "rules of thumb" (Sahal, 1981) or "search heuristics" (Nelson and Winter, 1982). New ideas and techniques are generated through individual and organizational investments in problem-solving activities (Allen, 1966; Laudan, 1984; Layton, 1974 and 1977; Mowery and Rosenberg, 1989; Nelson and Winter, 1982; Sahal, 1981). As only infrequent major disruptions or discontinuities disturb the problem-solving process (Dosi, 1982; Tushman and Anderson, 1986), the cumulative character of the growth of scientific and technological knowledge is important to understand the persistence of research organizations participating in the knowledge race. More specifically, organizations have to persist in their efforts to develop a new technology in order to contribute to its development.

However, as technological progress often depends on the synthesis of different competencies, collaboration between researchers and research organizations becomes imperative to solve the complex, indivisible problems that are difficult to address in isolation (Metcalfe and Soete, 1983). The creation of knowledge by researchers engaged in collaborative relationships with peers results in a steady accumulation of knowledge that other researchers can build upon. Thus, the development of a new technology is not only a cumulative problem-solving process, but also a collective endeavor. This collective dimension of knowledge creation most obviously appears in the acceptance of practices and procedures (e.g. the 'search heuristics' described by Nelson and Winter, 1982) that become institutionalized within a technological community. The outcome of this process of institutionalization is an increase in legitimacy of the technology being developed. This creates a technological momentum by attracting new researchers and organizations to the

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field, which in turn augments the rapidity with which new technological knowledge is created (Rappa and Debackere, 1992). As more and more organizations participate in the knowledge race, an obvious question becomes what determines the survival of research organizations within a specific technological community.

TECHNOLOGICAL COMMUNITIES AS A LOCUS OF COLLECTIVE ACTION

As technological knowledge creation is both a cumulative and a collective process, an appropriate level of analysis has to be chosen to study technological development. Constant (1980) and Thomson (1989) both suggest that technological development takes place within a community of practitioners where traditions of practice develop. Gray (1985: 912) advocates a domain level of analysis to study collective problem-solving processes. The domain consists of "*the set of actors (individuals, groups, or organizations) that become joined by a common issue or problem.*" Obviously, this domain-level can be applied to technological development. The domain then becomes the group of individuals and organizations committed to solve a set of interrelated scientific and technological problems. We have defined this group of individuals and organizations as the technological community (Rappa and Debackere, 1992; Garud and Rappa, 1992). In a sense, just as the firm is a means of collective action in instances in which the individual fails (Arrow, 1974), the technological community defines the arena for collective action in instances in which the organization fails.

PERSISTENCE IN TECHNOLOGICAL COMMUNITIES: A SOCIAL NETWORK PERSPECTIVE

In this paper, we define organizational survival, or for that reason, persistence, as the contribution-span of a research organization. The contribution-span is defined as the time-period during which the organization contributes actively and visibly to the knowledge creation processes in the technological community. Thus, we operationalize 'survival' as the ongoing contribution of a distinct research organization (regardless whether it is an academic or an industrial research organization) to the problem-solving process in a specific community. Defining persistence or survival in this way implies that research organizations leaving the domain do not necessarily disappear as a legal entity. Only, they have stopped their active contribution to knowledge creation and diffusion in the emerging field.

Institutional economists, on the one hand, have traditionally explained organizational survival through the mechanisms of efficient price and quantity competition (Arora and Gambardella, 1990; Grossman and Shapiro, 1987; Katz, 1986; Pisano, Shan and Teece, 1990; Tirole, 1988; Williamson, 1985). Social theory, on the other hand, has looked at organizational survival from a different perspective. Mainly through the analysis of interactions among organizations, social theorists have contributed to our understanding of organizational mortality rates (Barnett, 1990; Coleman, 1988; Granovetter, 1985; Hannan and Carroll, 1992).

Thus, whereas institutional economics has adopted a utilitarian point of view to explain incentives for competition and subsequent survival, social theory has built on the social embeddedness of organizations to analyze organizational mortality rates. As a consequence, institutional economists have analyzed the stimulation of patent protection and R&D subsidies as an incentive to invest in technological development. Social theorists, on the other hand, point to resource scarcity and power interdependence among organizations which necessitates collaboration in order to survive (Burt, 1992; Cook, 1977; Pfeffer and Salancik, 1978).

To this end, the notion of social capital of the organization has been introduced, besides the well-entrenched concepts of physical and human capital (Granovetter, 1985; Katz and Shapiro, 1985). Coleman (1988: 96) defines social capital as *"the variety of different entities which reflect the structure of relations between actors and among actors."* Thus, social capital reflects the relations among and between actors in a broader community. These relations can be studied from different perspectives. For instance, they may reflect friendship, family, financial or information exchanges.

Within a technological community, the network of interest has to capture those relations that embody the potential for knowledge exchange. Through publication and patent activities, research organizations posit their knowledge in a certified way and make it accessible to other actors in the technological community (Jagtenberg, 1983; Shenhav, Lunde and Goldberg, 1989). Resource dependency theorists further hypothesize that access of organizations to multiple external sources of power is positively correlated with their chances to survive (Aldrich, 1979; Cook, 1977; Pfeffer and Salancik, 1978). As far as technological development is concerned, technical knowledge has been recognized as one of the most important sources of power (Cohen and Levinthal, 1990; Nonaka, 1991; Tushman and Anderson, 1986).

Especially, access to 'tacit' knowledge (Collins, 1974; Polanyi, 1958) is considered to offer a competitive advantage to actors in the technological community, which essentially is a market for ideas. Tacit knowledge is embodied in the absorptive capacity each distinctive organization in the community possesses. As a consequence, collaborations between a focal research organization and other organizations in the community, will increase its access to external sources of 'tacit' knowledge, and hence, the likelihood the organization will persist in its efforts to continue working on a particular research agenda.

H1: The likelihood of persistence in the development of a technology increases when the focal organization belongs to an interconnected clique of collaborating organizations in the community.

It is obvious, though, that the position of a research organization in a collaborative R&D network is a multidimensional concept. Based on sociometric theory (e.g. Burt, 1992; Freeman, 1977 and 1979; Knoke and Kuklinski, 1983) several indicators of the position of an organization in its collaborative network can be operationalized. The first indicator is the size of the network to which an individual organization belongs. As the number of organizations collaborating with a focal organization increases, its exposure to diverse sources of 'tacit' knowledge increases (Cohen and Levinthal, 1990). Access to multiple knowledge sources may in turn have a positive effect on the persistence of the organization to continue its efforts in the field.

H2: The number of organizations with which a focal organization directly interacts will have a positive effect on its contribution-span.

Network size alone does not yet capture the intensity of collaboration among directly interconnected organizations. If ego's network consists of N organizations, then the maximum number of possible linkages among the N actors is $N(N-1)/2$, if the network is symmetrical. Burt's proportional density indicator (1991) reflects the number of contact pairs the focal organization is involved in divided by the maximum number of contact dyads the organization could be involved in, given the size of its network. Proportional density can now be linked to knowledge diversity. The more the proportional density in ego's network approaches its maximum value of 1, the more homogenous we assume the knowledge sources represented by the various actors in the network to be. Homogeneity has the advantage of introducing focus in the research agendas by the members of the network, but it has the potential disadvantage of reducing the variety of problem-solving approaches pursued by the network actors. Therefore, as a corollary to hypothesis 2, the influence of network homogeneity on organizational contribution-spans warrants further exploratory attention.

Two prominent relational characteristics of organizational network position are power and prestige. Power is based on Mizruchi et al.'s definition (1986). It indicates the extent to which a focal organization is able to dominate its primary network of collaborations. Prestige (Burt, 1991: 192) is an indicator of the extent to which an organization's time and energy are solicited by other organizations. Both variables are thus indicators of the embeddedness or position of an individual organization within its contact network. Whereas network size and homogeneity provide an insight into the network to which a focal organization belongs, power and prestige define its relative position in the contact network. Both are hypothesized to exert powerful exit-barriers, and thus, to positively influence the organization's persistence in the development of a technology. Power and prestige indicate the degree to which an organization is able to impose its research agenda onto the other members of its network. Since technological competencies build up in a path dependent manner (Arthur, 1988; Cohen and Levinthal, 1990; David, 1985), earlier technological choices direct future options and solutions. As organizations develop a more prestigious and powerful position in the network, they may be able to impose their trajectory and paradigm upon other organizations, thus exerting a dominant influence on future options and solutions.

H3: The likelihood of persistence in the development of a technology increases with the ability of the organization to dominate its collaborative network.

H4: Organizational persistence is likely to increase with the organization's prestige position in a collaborative network.

Finally, as technological competencies become specialized, it becomes increasingly difficult to re-deploy them to pursue other trajectories or other technological paradigms. Organizational investments along a dedicated technological trajectory therefore are like a sunk cost. Hence, longevity of the organization's association with the technology will further influence its persistence.

H5: The likelihood of persistence in the development of a technology increases with the duration of an organization's association with the technology.

RESEARCH SITE

We chose the field of transgene plants as an illustrative case for the present analysis. Transgene plants are a sub-domain of the new biotechnology. Interest in plant quality improvement was first aroused in the 1950s as a result of the research into tissue cultures and their restrictions. The emergence of genetic engineering in the 1970s, combined with the specification of the Tumor Inducing Plasmid (Ti-Plasmid) in 1974, caused a renewed interest in the field. More specific, the identification of the Ti-Plasmid laid the foundations of the field that would become known as *plant genetic engineering* in the 1980s.

The first plants to be genetically engineered appeared in 1983. Ever since, transgene plant research has shown two major foci of interest. Plant crop protection aims at developing virus-free plants or crops with increased stress, herbicide or disease resistance. Plant quality improvement aims at the production of hybrids and at protein improvement. Both areas of interest are believed to develop into attractive, lucrative market opportunities in the coming years. In the early 1990s, the first 'prototype' products have appeared. Thus, between the early 1980s and 1993, transgene plants have evolved from a scientific curiosity to a promising commercial activity.

DATA COLLECTION AND METHODS

Journal articles, conference papers and patents in a given field represent a detailed, self-reported archival record of the efforts generated by research organizations to solve the scientific and technological problems confronting them. Furthermore, the published literature is an appealing source of data in several respects: the publication conventions ensure a level of quality and authenticity; the data can be collected unobtrusively; the findings can be replicated and tested for reliability; and the data are publicly available and not very expensive to collect. When taken together, the literature can be viewed as a unique chronology of the efforts to establish a new field, and can provide information about the research organizations involved, whether they are academic or industrial, who they collaborated with, what problems they pursued, and when they were active in the field. Clearly, it would be difficult to match the comprehensive scope and longitudinal nature of the literature using other data collection techniques.

Data collection. Four electronic databases (including the databases of the Institute for Scientific Information, Philadelphia) were used to identify publications and patents related to the field of transgene plants. The databases were searched using a set of key terms that are known to be commonly used in the lexicon of transgene plant research. These key terms might be either in the title, abstract or classification terms of a document. Both the search strategy and the search results were further validated through a detailed scrutiny by three experts in the field.

The data collection procedure resulted in the identification of 1,425 unique literature documents and 97 patents related to transgene plants published between 1980 and 1992. The database revealed the existence of 2,926 researchers employed at 367 research organizations who contributed to the field over the thirteen-year period. As the focus of the analyses presented in this paper is on organizational persistence, a statistical database was created containing time-varying covariates for each research organization in the dataset. A detailed description of the variables included in the present analyses is provided in the Appendix.

Dependent variable. The number of years spanning a research organization's first and last known publications or patents in the field—that is the 'contribution span'—serves as a unique and useful measure of its persistence in a field.

Whenever contribution-span data are computed at the level of individual researchers, a problem of continuity arises. The reason for this is that researchers may not publish or patent every year. Therefore, a researcher's contribution-span in the field can be characterized by gaps of several years in duration in which there are no publications or patents to his or her credit. The question then arises: How long after someone ceases to publish is it reasonable to assume that they are no longer in the field?

This is an important issue when analyzing contribution-span data at the individual level (Rappa and Garud, 1992). At the organizational level, though, the problem is less critical. The transgene plant data show that only 7 organizations (0.2%) have a gap between their publications or patents of longer than three years. These sparse contribution-spans may be indicative of organizations who do not contribute continuously to the field. We treated them as having left the field if they had contributed during a two-year period, and as having begun a new cycle when they again started contributing.

Explanatory variables. Two variables were computed that account for the degree of competition among organizations in the emerging field. These provide measures of contemporaneous density (Hannan and Carroll, 1992) and entropy (Tirole, 1988). They were derived from both population ecology and industrial economic theory. It is important to note that those variables where not computed at the level of the technological community studied. Instead, we followed Burt's theory (1992) on the social structure of competition stating that: (1) competition is a matter of relations, not player attributes; (2) competition is a relation emergent, not observed; (3) competition is a process, not just a result; and (4) imperfect competition is a matter of freedom, not just power.

For these reasons, Burt argues that competition is best studied at the level of groups of structurally equivalent actors. Two actors are structurally equivalent to the extent that they have identical relations with every person in every network within a social structure. The extent to which two organizations i and j are involved in identical relations so as to be structurally equivalent can be expressed as the Euclidean distance between their relation patterns. Hierarchical cluster analyses enable the identification of subsets of equivalent actors within a system. Using the algorithms described by Burt (1991: 124-147), we were able to identify four structurally equivalent groups in the transgene plant dataset. Tests, based on the density table results provided by STRUCTURE, were conducted to further assess the adequacy of the equivalence hypothesis.

For each structurally equivalent group in the community, we then computed two indicators of competition. The first indicator is based on Hannan and Carroll's definition (1992) of contemporaneous density. It is described in Table 1 as the variable 'density^2/1000.' The second indicator is the entropy index of the relative number of publications for the organizations belonging to a structurally equivalent group. The entropy index is computed as $\Sigma p.\ln(p)$, with p the relative number of publications for each organization in the structurally equivalent group.

The value of this variable is negative, with a maximum of 0 attained in the case where one organization completely dominates the publication market.

The sociometric variables used to test hypotheses H1-to-H4 are described in detail in Table 1. The various network variables were operationalized through the data on inter-organizational co-authorships/co-inventorships in the bibliometric databases retrieved. The computational algorithms adopted were derived from social network theory (Burt, 1991 and 1992; Knoke and Kuklinski, 1983) and are outlined in Table 1. The first variable is a dummy variable indicating whether the organization belongs to an interconnected clique of organizations within the community. The second variable measures the size of the network of the organization. The third variable is the proportional density measure which we defined as a homogeneity indicator. The fourth and fifth sociometric indicators capture the network position of the organization in terms of power and prestige.

Finally, we added four R&D input-output indicators for each organization in the dataset. They are: (1) the cumulative number of authors/inventors at the organization over its contribution-span; (2) the cumulative number of publications at the focal organization; (3) the research productivity of the organization; and (4) the number of patents accumulated by the organization over its contribution-span.

ANALYSIS AND RESULTS

Failure time modeling techniques were used to study the persistence of organizations in the transgene plant community (Kalbfleisch and Prentice, 1980). The data were first analyzed using the LIFETEST and LIFEREG procedures of SAS. Time-varying covariates were analyzed using LIMDEP (Greene, 1992). Of the 367 organizations, 249 (67.8%) were active within two years of the last year of the data and were therefore classified as censored. The basic model adopted for the analysis was:

$$Y = X\beta + \sigma\varepsilon$$

where Y is the log of the contribution-span (the failure time), X is the matrix of covariates, β 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 often referred to as an accelerated failure time model because the effect of the explanatory variables is to scale a baseline distribution of failure times. Four different types of distributions were evaluated: the exponential, Weibull, log-normal, and log-logistic distributions. Using the baseline model, the goodness of fit was evaluated in term of minimizing the absolute value of the log-likelihood score. As a result, the log-logistic distribution was chosen as the basis for estimating the regression coefficients of the explanatory variables in the model. The model was estimated in a sequence of steps by adding sets of explanatory variables into the equation (see Table 1).

TABLE I:

ML Estimation of Organizational Contribution-spans using a Multiple-Spell Approach

EXPLANATORY VARIABLES	MODEL 1	MODEL 2	MODEL 3
Degree of competition within structurally equivalent classes:			
density^2/1000 (=contemporaneous density)	-0.123[c]	-0.140[c]	-0.133[c]
	(0.016)	(0.014)	(0.015)
entropy	-0.638[c]	-0.390[c]	-0.322[b]
	(0.032)	(0.090)	(0.101)
Degree of network embeddedness at organizational level:			
clique membership		1.319[c]	1.273[c]
		(0.214)	(0.213)
contacts		-0.292[b]	-0.313[c]
		(0.092)	(0.093)
homogeneity		0.010	0.031
		(0.306)	(0.306)
power		0.050[c]	0.050[c]
		(0.009)	(0.009)
prestige		1.978[c]	1.753[c]
		(0.348)	(0.368)
R&D input and output indicators at organizational level:			
cumulative researchers			0.029
			(0.019)
cumulative publications			-0.043
			(0.037)
research productivity			0.401
			(0.233)
cumulative patents			0.053
			(0.062)
scale parameter	0.496[c]	0.417[c]	0.407[c]
	(0.030)	(0.031)	(0.032)
LOG-LIKELIHOOD	-617	-542	-539

Notes:

1. Significances: ^{a}= 0.05<p<0.01; ^{b}= 0.01<p<0.001; ^{c}= p<0.001
2. Total number of research organizations=367 (118 or 32.2% are non-censored)
3. Standard errors of estimates between parentheses
4. Best-fitting Log-linear survival regression model: Logistic distribution
5. Multiple-spell model with 1424 spells

The first model included the competitiveness indicators. The second model listed in Table 1 presents the final results from adding the sociometric covariates stepwise. Finally, the third column in Table 2 describes the complete explanatory model with all covariates included. The log-likelihood scores indicate that the fit of the models improved as covariates were included. The negative (and statistically significant) sign of the contemporaneous density variable implies an inverted U-shaped relationship between the density (or number of organizations) within a structurally equivalent group and organizational contribution-spans, thus pointing to an oligopolistic optimum. Given the definition of the entropy variable, its values are negative with a maximum of zero. Combined with the negative sign of its coefficient ($p<0.01$), the results indicate that a more fragmented publication market increases the likelihood of organizations persisting in the field.

The results indicate that three out of the four hypotheses relating sociometric indicators to contribution-spans receive support. Belonging to an interconnected clique in the community increases the likelihood of survival. Also, both the organization's power and prestige position in the network positively influence its contribution-span. The only hypothesis that did not receive support concerns the size of the organization's primary contact network. Although, the coefficient is statistically significant, its sign indicates network size has a negative influence on contribution-span. This result may seem puzzling at first, though a closer inspection of the data may provide a logic explanation.

This explanation is derived from the finding that the number of organizations a focal organization is collaborating with does not necessarily reflect its position in terms of power and prestige. Indeed, we find that among the organizations leaving the field early, a majority shows 'one-shot' contacts with rather large numbers (3-to-6) of other organizations in the field. However, they remain at the periphery of the contact network, being unable to attain a position of power and prestige (which is captured by the other sociometric indicators). Thus, network size in and of itself is not sufficient to explain persistence. Rather, it is the organization's network position that matters.

As to the homogeneity question raised in the previous sections, the analyses do not even allow for speculation: the coefficient, although being positive, is not statistically significant. In addition, it is interesting to note that none of the input/output indicators attains statistical significance, as opposed to the sociometric indicators just discussed. Additional analyses reveal that the more powerful or prestiguous organizations in the field are not necessarily the most productive in terms of cumulative number of publications and patents, nor in terms of research productivity. Of course, a minimal productivity threshold is required to reach above-average power and prestige positions (with our data, this threshold appeared in the neighborhood of 15 publications over an organization's contribution-span). However, once this threshold is reached, the relation between network position and productivity weakens considerably.

Finally, to further explore determinants of organizational persistence over time (hypothesis five), we conducted a non-parametric analysis of the hazard function based on the duration of the organizations' association (see Figure 1).

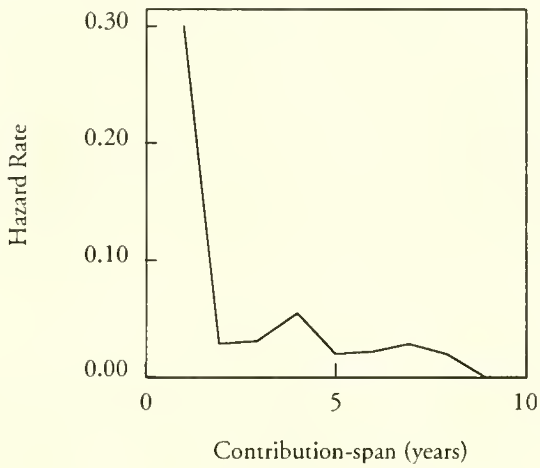

FIGURE 1: Non-parametric estimate of hazard funcrion for research organizations in the transgene plant community, 1980-1992

The hazard rate is a negatively-sloped function. It decreases very rapidly for organizations that have contribution-spans of at least two years: that is, the probability of an organization ceasing to contribute after having contributed for two years is only about 0.03, compared to 0.30 for an organization in the field only one year. The basic assumption of the hazard function is that the longer an organization contributes to the field, the less likely it is to exit the field; thus supporting hypothesis five. In addition, the hazard function for the transgene plant organizations suggests that the initial years of involvement are critical: organizations tend to become locked in rapidly.

CONCLUSION

Non-parametric estimates of the hazard rates in transgene plant research show that the risk of exiting the field is greatest in the initial year of the organization's contribution-span. Once an organization starts its investment in a particular technological trajectory, exit barriers build up rapidly. Parametric multiple-spell models of organizational contribution-spans provide insight into the determinants of persistence. The competitive situation within a structurally equivalent group (which is, after all, comparable to a strategic group in industrial economics) appears to have a strong, curvilinear influence on organizational contribution-spans. More interesting still, the embeddedness and position of an organization in a network of ongoing collaborations appeared to be a strong and positive determinant of its persistence. As indicated, network size alone is certainly not sufficient to explain persistence. Also, productivity indicators did not exert a statistically significant influence on organizational contribution-spans.

To conclude, the empirical findings point to the necessity of a better understanding of the way in which network positions develop over time. The data analyzed in this paper provide a longitudinal insight into the network dynamics within a technological community. From this perspective, it certainly provides additional insights into the many writings on 'network organizations' that have appeared recently (e.g. Badaracco, 1991; Nohria and Eccles, 1993; Powell, 1990). What seems needed now are some detailed case-studies that trace the differential development of network positions among the organizations represented in the dataset.

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APPENDIX

Variables in the Parametric Models of Organizational Contribution-Spans

VARIABLE NAME	EXPLANATION
	DEPENDENT VARIABLE
Contribution-span	Number of years between an organization's first and last publication or patent in the field.
	CONTROL VARIABLES
$Density^2/1000$	Number of $organizations^2/1000$ for each of the four structural equivalence classes detected in the dataset. This is Hannan and Carroll's (1992) contemporaneous density measure.
Entropy	Entropy measure of publication output within each of the four structural equivalence classes detected in the dataset ($entropy=\sum p.\ln(p)$, with p the relative number of publications for each organization). This variable reflects the 'market shares' on the publication markets within each structural equivalence class.
	NETWORK EMBEDDEDNESS VARIABLES
Clique membership	Dummy 0-1 variable assuming a value of 1 when the focal organization is part of an interconnected clique of organizations.
Contacts	Number of other organizations in the community with which the organization has collaborated on the basis of co-authorships or co-inventorships. This variable provides an indication of the quantity of ego's direct network.
Homogeneity	This is Burt's (1991) proportional density measure. If ego's network size equals N (i.e. the number of organization's in ego's network), then the proportional density reflects the number of contact pairs the organization is involved in divided by the maximum number of contact dyads the organization could be involved in, given the size of its network. This variable is computed as follows: proportional $density=(\sum_j\sum_q\partial_{jq})/N(N-1)$ with $j\neq q$; where ∂_{jq} equals 1 if the number of co-authorships/co-inventorships between organizations j and q is nonzero, otherwise ∂_{jq} equals 0; and where N stands for the size of ego's network. The more the proportional density approaches its maximum value of 1, the more homogeneous we assume the different knowledge sources in ego's network to be.

Power	Number of linkages in ego's network in which ego is directly involved divided by the total number of linkages amongst the different players in ego's network. This total number of linkages thus consists of (1) all linkages involving ego with his direct alters, and (2) all linkages amongst ego's direct alters in which ego is not involved. This network variable thus indicates the degree to which ego is able to dominate his or her primary network. It is based on Mizruchi et al.'s (1986) definition of power.
Prestige	This variable is an indicator of the prestige position of each organization relative to the most prestiguous organization in the dataset. The absolute prestige position is computed according to Burt's (1991) definition: prestige of $i = p_i = \Sigma_j [z_{ji} / \Sigma_k (z_{jk})] p_j$ with $j \neq i,k$; where z_{ji} equals the number of co-authorships/co-inventorships between organization j and i; and p_j represents an element in the corresponding left-hand eigenvector in the row-stochastic matrix. The absolute prestige position for each organization is then divided by the prestige value of the most prestiguous organization. Based on this definition, the prestige of an organization i increases with the demand for i's network time and energy.
	R&D INPUT-OUTPUT VARIABLES
Cumulative researchers	Cumulative number of authors/inventors at the organization over its contribution span.
Cumulative publications	Cumulative number of publications/patents at the organization over its contribution span.
Research productivity	Cumulative number of publications divided by the cumulative number of researchers.
Cumulative patents	Cumulative number of patents generated by the organization over its contribution span.