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Modeling the persistence of organizations in an emerging field: the case of hepatitis C

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Abstract

This paper explores the persistence of research organizations in their efforts to participate in the development of an emerging field of science and technology. Persistence is operationalized as the ongoing contribution of a research organization to knowledge creation and diffusion. In particular, we relate the position of a research organization in a network of R & D collaborations to its ongoing contribution to knowledge development, using data on 991 research organizations in the field of hepatitis C over the period 1979–1992/3. Event-history modeling is used to explore the influence of sociometric time-varying covariates on organizational contribution-spans. The analytical results support the hypothesis that network embeddedness is a significant determinant of organizational persistence in an emerging field. More specifically, the position of a research organization in a network of collaborative R & D activities (rather than the number of network partners or collaborative relationships) has a significant and positive influence on its ongoing contribution to the field.

1. Introduction

How do new fields of science and technology emerge? What explains the persistence of research organizations in an emerging field? Or, furthermore, what factors explain the variation in contribution-spans among research organizations in emerging fields of science and technology? Obviously, these questions are important to students of the generative processes through which novel forms of technology emerge. They are at the heart of the empirical examination reported in this paper.

Typically, new scientific and technological knowledge is generated through the problem-solving activities of scientists and engineers who, in the process, generate new ideas and techniques (Allen, 1966; Layton, 1974, 1977, Sahal, 1981; Nelson and Winter, 1982; Laudan, 1984; Mowery and Rosenberg, 1989). As only infrequent major disruptions or discontinuities disturb the problem-solving process (Dosi, 1982; Rosenberg, 1982; Tushman and Anderson, 1986), widely accepted models of the growth of scientific and technical knowledge view this process as a cumulative progression of knowledge embodied in new ideas and techniques. This cumulative character of the growth of scientific and technological knowledge is important for understanding the persistence of research organizations participating in the knowledge race. More specifically, organizations

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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 in order 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 (Constant, 1980; Rappa and Debackere, 1992b; Debackere and Rappa, 1994; Debackere et al., 1994). The outcome of this process of institutionalization is an increase in legitimacy of the technology being developed. Using Thomas Hughes' metaphor (1987), this legitimacy creates a momentum by attracting new researchers and organizations to the field (Hannan and Carroll, 1992), which in turn augments the rapidity with which new technological knowledge is generated (Rappa and Debackere, 1992b). As more and more organizations participate in the knowledge race, an obvious question becomes what determines the persistence of research organizations within a specific technological community.

2. 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) 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" (p. 912). Obviously, this domain-level approach can be applied to technological development. Paraphrasing Gray (1985), the domain then becomes the group of individuals and organizations committed to solving a set of interrelated scientific and technological problems.

We have defined this group of individuals and organizations as the technological community (Rappa and Debackere, 1992b; Debackere and Rappa, 1994; Debackere et al., 1994). This community consists of those organizations that are committed to solving a set of interrelated scientific and technological problems, regardless of whether they belong to the private or public sector; they may be geographically dispersed, though they are involved in an information-exchange process. 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.

Within a particular technological community, collaborative research has become imperative due to the increasing cost and complexity of R & D (Katz and Shapiro, 1985; Katz, 1986; Pisano et al., 1988; Sapienza, 1989; Arora and Gambardella, 1990; Freeman, 1991). No single organization possesses the financial and scientific capabilities necessary to control the problem-solving process. Therefore, research organizations face a growing need to participate in networks of technology development. As William Parfet, President of Upjohn, stated:

> the only way (pharmaceutical) firms can afford the increased R & D costs is to form strategic alliances with academia, technology start-up firms and even with competitors with complementary R & D strengths and strategies (IMS Market Letter, 1992).

During research collaborations, partners benefit from mutual learning and knowledge exchange, which enable them to overcome the complex, often indivisible technical problems they face. Because this knowledge-based division of labor cannot be mediated through arms-length market transactions, research collaborations typically take the form of more long-term relationships such as research joint ventures and strategic alliances. Mutual trust is considered a key success factor in this process (Cohen and Levinthal, 1989).

3. Persistence in technological communities: a social network perspective

In this paper, we define organizational 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 'persistence' as the ongoing contribution of a distinct research organization (regardless of whether it is an academic or an industrial research organization) to the problem-solving process in a specific community. Defining persistence in this way implies that research organizations leaving the domain do not necessarily disappear as a legal entity, only that they have stopped their active contribution to knowledge creation and diffusion in the emerging field.

Industrial economists, on the one hand, have traditionally explained organizational survival through the mechanisms of efficient price and quantity competition (Katz and Shapiro, 1985; Williamson, 1985; Katz, 1986; Grossman and Shapiro, 1987; Pisano et al., 1988; Arora and Gambardella 1990). 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 (Granovetter, 1985; Coleman, 1988; Barnett, 1990; Hannan and Carroll, 1992).

Thus, whereas industrial economics has adopted a utilitarian point of view to explain incentives for competition and subsequent survival, social network theory has built on the social embeddedness of organizations to analyze organizational mortality rates. As a consequence, industrial 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 (Cook, 1977; Pfeffer and Salancik, 1978; Burt, 1992).

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; Burt, 1992). Coleman (1988) defines social capital as "the variety of different entities which reflect the structure of relations between actors and among actors" (p. 96). Thus, social capital reflects the relations among and between actors in a broader community. Burt (1992) defines *social* capital as being different from *human* or *physical* capital since (1) it is a thing owned jointly by the parties in a relationship (i.e. no one player has exclusive ownership rights to social capital), and (2) the relations it embodies create opportunities to transform physical and human capital into profit. 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 et al., 1989). Resource dependency theorists further hypothesize that access of organizations to multiple external sources of power is positively correlated with their chances of surviving or persisting (Aldrich, 1974; 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 (Tushman and Anderson, 1986; Cohen and Levinthal, 1990; Nonaka, 1991).

Especially, access to 'tacit' knowledge (Polanyi, 1958; Collins, 1974; Faulkner and Senker, 1994) 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. From a sociometric perspective this means that whenever a particular research organization is a member of an interconnected clique of collaborating organizations, a critical mass is created which positively influences organizational persistence.

It is obvious, though, that the relations and the position of a research organization in a collaborative R & D network is a multidimensional concept. Based on social network theory (e.g. Freeman, 1977, 1979; Knoke and Kuklinski, 1983; Burt, 1992), several indicators of the relations and the position of an organization in its collaborative network can be defined and operationalized. First of all, there is the size of the network to which each 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; Nonaka, 1991).

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. Indeed, it seems logical to assume that the rate of progress in scientific and technological development is a function of how quickly problems are solved, which, in turn, depends on the amount of information produced, the number of solutions attempted, and the extent to which information and knowledge circulate among researchers. The more information available to researchers the more likely they are to arrive at a useful solution. Moreover, the more diversity in the types of solutions attempted, the more likely that critical solutions will be found. Lastly, communication between research organizations enhances the probability of finding useful solutions. Hence, one may hypothesize that the number of contacts a focal organization has with other organizations positively influences its exposure to diverse knowledge sources, and hence, positively contributes to its persistence.

Network size alone, though, 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 one, the more unified (or homogeneous) 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 the previous hypothesis, the influence of network homogeneity on organizational contribution-spans warrants further exploratory attention.

Two prominent characteristics of an organization's network position are power and prestige. Power is based on the definition of Mizruchi et al. (1986). It indicates the extent to which a focal organization is able to dominate its primary network of collaborations. Prestige (Burt, 1991: p. 192) is an indicator of the extent to which an organization's time and energy are solicited by other (powerful) organizations.

Obviously, these are multidimensional constructs with the relative importance of their components differing according to the market, industry or population of organizations studied. For instance, both size and profitability have been used as proxies for organizational prestige (DiMaggio and Powell, 1983; Haveman, 1993). Size stands for visibility and 'visible' organizations receive a great deal of prestige (Scott, 1992). Profitability is a reflection of success, which in turn is one of the building blocks of prestige (Burns and Wholey, 1993). However, in emerging technological communities (as well as industries) neither size nor profitability of the incumbents are stable or transparant. Therefore, they may not be suitable indicators of constructs like 'power' and 'prestige'. In biotechnology, for instance, prestige is related to technical expertise and experience.

Social network research has shown that prestigious organizations occupy central positions in their respective industry or community networks (Bonacich, 1987; Davis, 1991). Central network positions provide access to vital information that flows through the network (Useem, 1984). As a consequence, Davis

(1991: p. 592) concludes: "By maintaining ties to a large number of organizations, more central firms are able to notice and respond to environmental changes more rapidly ... in addition, centrality indicates a firm's status and the degree to which it is integrated into the corporate elite." Thus, given our focus on the influence of the structure of R & D networks on organizational persistence, sociometric indicators are

Table 1
Variables in the parametric models of organizational contribution-spans for the hepatitis C community

Category	Variable	Explanation
Dependent variable	Contribution-span	Number of years between an organization's first and last publication in the field.
Control variables	Density^2/1000	Number of organizations^2/1000 for each of the structural equivalence classes detected in the dataset. This refers to Hannan and Carrol's (1992) contemporaneous density measure.
	Relative entropy	Entropy is based on the publication output within each of the structural equivalence classes detected in the dataset (entropy = $\Sigma p \ln(p)$, 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. Relative entropy is a normalized version of the entropy measure. It varies from 0 to 1, with 0 reflecting a monopoly situation and 1 perfect competition.
Network embeddedness	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 organizations 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 = $(\Sigma_j \Sigma_q \delta_{jq})/N(N-1)$ with $j \neq q$; where ∂_{jq} equals 1 if the number of co-authorships/co-inventorships between organizations j and q is non-zero, 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 the definition of power of Mizruchi et al. (1986).
	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 productivity	Cumulative publications	Cumulative number of publications/patents of the organization over its contribution-span.

a valid way of operationalizing the power and prestige constructs. Hence the use of power and prestige definitions based on social network theory.

For a computational definition of both variables, we refer to Table 1. Both variables are indicators of the embeddedness or position of an individual organization within the contact network. Whereas network size and homogeneity provide an insight into the relational dimensions of the network to which a focal organization belongs, power and prestige define its relative position in the network. Both are hypothesized to exert powerful exit barriers. As a consequence, they positively influence the organization's persistence with the development of a technology.

Moreover, as alluded to, power and prestige may be indicative of the degree to which an organization is able to impose its research agenda on the other members of its network. Since technological competencies build up in a path-dependent manner (David, 1985; Arthur, 1988; Cohen and Levinthal, 1990), 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' agenda on other organizations, thus exerting a dominant influence on future options and solutions. Hence, the likelihood of persistence with the development of a technology increases with the ability of the organization to dominate the network.

Finally, as technological competencies become specialized, it becomes increasingly difficult to redeploy 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. Thus, the likelihood of persistence in the development of a technology increases with the duration of an organization's association with the technology.

4. Research site

The field of hepatitis C was chosen as an illustrative case for the present analysis. After sensitive assays for hepatitis A and hepatitis B were developed, the existence of hepatitis non-A, non-B (NANB) was recognized in the early 1970s. The causal agent of hepatitis NANB was subject to controversy for years. Extensive investigation took place to identify this agent. Eventually, the hepatitis C virus (HCV) was cloned as a result of the availability of essential reagents, the creativity of key scientists, and intensive cloning projects that evolved over many years (Gitnick, 1993). This virus was subsequently identified as the causal agent in 90% of the cases of hepatitis NANB. Before the HCV discovery, though, research had already revealed that the major NANB agent was 30 to 60 nm in diameter, lipid enveloped, blood borne, and capable of causing liver disease in humans and chimpanzees (Gitnick, 1993).

The HCV discovery was announced in 1989. Before HCV was cloned, epidemiologists tracked its related liver disease as hepatitis NANB. Today, it is understood that 90% of all NANB disease is HCV-related; however, when referring to studies conducted before 1989, the year in which the HCV discovery was announced, it is appropriate to use the term hepatitis NANB as it was used in the original studies (Maddrey, 1993).

So far HCV research has focused on the development of diagnostics to detect the disease, vaccines to prevent the disease and therapeutics to remedy the disease. Recently, these streams of research have become highly interlinked. Whereas HCV therapeutics are yet to be developed, HCV testing is now in its third generation. Till now, only diagnostic applications have been commercialized. The third-generation tests analyze for a substantially larger portion of the HCV genome and therefore give a broader detection range (Issues in Hepatitis Research, 1993).

However, HCV treatment with α-2b-interferon has proven to be successful in almost 30% of the disease cases treated (Maddrey, 1993). Especially in those cases where the viral agent is linked to a certain 'weak' genotype and where the proportion of the virus is rather low, the interferon treatment has been shown to be very effective. Therefore, future HCV diagnostics should be able to detect the genotype responsible for the viral infection and the proportion of the virus in order to improve therapeutic treatment. Although the current third-generation HCV diagnostics are already much more sensitive and precise than their first and second-generation predecessors, they are not yet capable of doing this. This is because they almost solely rely on the use of monoclonal antibodies. The fourth-generation diagnostic assays will also include genotype specifications. As a consequence, therapeutic and diagnostic research have become highly intertwined.

5. 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 technologi-

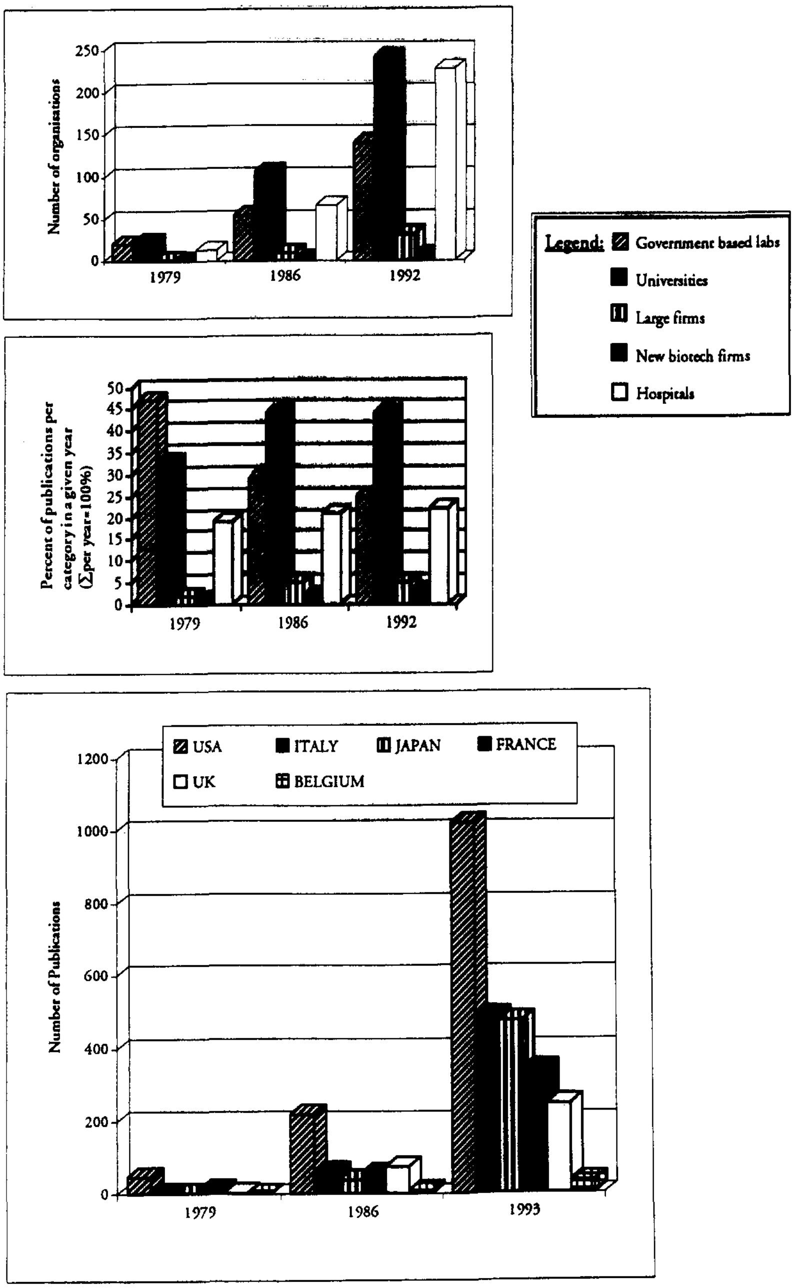

Fig. 1. Structural characteristics of the hepatitis C community at three time points.

cal 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, whom 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 (Rappa and Debackere, 1992a).

5.1. Data collection

The electronic databases of the Institute for Scientific Information (Philadelphia) were used to identify publications related to the field of hepatitis C. The databases were searched using a set of key terms that are known to be commonly used in the lexicon of hepatitis C 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 two experts in the field.

The data collection procedure for the analyses reported in this paper resulted in the identification of 3,060 unique literature documents related to hepatitis C published between 1974 and 1992. If we include the documents published in 1993, we arrive at a dataset of 3,850 unique documents. However, due to the time-lags involved in incorporating documents in electronic databases, we use 1992 as the last year in our analyses. The data available for 1993 are only used to examine in greater detail whether organizations have left the field or not in order to complete the censoring scheme in the event-history models developed in the next sections of this paper. In addition, given the sparsity of research organizations in the field between 1974 and 1978, we collapsed those five years and used the data on that period to compute the levels of the different variables for the first year of the analyses, i.e. 1979. Hence, the analyses reported in the next sections of the paper focus on the fourteen-year period between 1979 and 1992.

The database revealed the existence of 991 unique research organizations which contributed to the field. 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 Table 1. Sector-wise, the total set of 991 research organizations are distributed as follows: 321 (or 32%) are universities; 238 (or 24%) are non-profit government-sponsored laboratories; 43 (or 5%) are established firms (e.g. SmithKline); 9 (or 1%) are new biotechnology firms; and, finally, 380 (38%) are hospitals conducting clinical research. In Fig. 1, a structural classification of organizations in the study (at three discrete points in time) is provided both with respect to the numbers involved as well as with respect to their shares on the hepatitis C publication market. Finally, Fig. 1 also provides a summary view of the hepatitis C research effort in the six major countries present in our dataset.

As is obvious from the time points considered in Fig. 1, there has been a considerable growth in absolute numbers both in terms of organizations and publications. This growth occurred almost in a similar way for each organization category considered (except for government-based research laboratories and universities: between 1979 and 1986, they swapped their first and second position in terms of publication shares).

The strong publication position of government-based research laboratories in 1979 can be (partly) explained by the pioneering roles of the Center for Disease Control in Atlanta, the NIH (Bethesda) and the Lindsey Blood Bank in New York. These organizations have been the most significant and prolific pioneers in hepatitis C research. Their initial leading role can be explained by the fact that they were the ones that had direct access to and experience with the chimpanzee serum and the related experiments vital to hepatitis C research. As the field develops (along with the problem-solving progress and the related breakthroughs), new entrants rush in. This may be indicative of a bandwagon phenomenon (see also Fig. 2 below, which shows a critical inflection point by the end of the 1980s, almost simultaneous with the major breakthrough in the field). Although still a minority, industrial organizations are becoming active players in the field, pointing to a 'dynamic complementarity' between the ongoing and evolving research efforts.

The units of analysis in this study thus are the individual organizations in the dataset. This implies that whenever two research groups are affiliated with the same organization Y, they are treated as one unit of analysis, i.e. the hepatitis C research team at organization Y. This approach is believed to alleviate problems due to internal organizational restructuring which are difficult, if not impossible, to detect at the level of analysis at which our study is conducted.

5.2. The dependent variable

The number of years spanning a research organization's first and last-known publications in the field – that is the 'contribution span' – serves as a unique and useful measure of its persistence in a field (Garud and Rappa, 1992; Rappa et al., 1992).

Whenever contribution-span data are computed at the level of individual researchers, a problem of continuity arises (Rappa and Garud, 1992). The reason for this is that researchers may not publish 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 hepatitis C data show that less than 0.5% of the organizations have a gap between their publications of longer than three years. These sparse contribution-spans may be indicative of organizations that do not contribute continuously to the field. We treated them as having left the field if they had not contributed for more than three years, and as having begun a new cycle when they again started contributing. The choice of this cut-off point is further substantiated by the finding that the contribution-span distributions (including publication gaps) are similar across the organization types considered in the sample.

5.3. Explanatory variables – indicators of competition

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 relative entropy. They were derived from both population ecology and industrial economic theory. In computing those variables, we followed Burt's view (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. The Euclidean distance is zero for organizations which have exactly the same patterns of relations. So if the tie of interest is organizational co-authorship, all organizations which have co-authors in the same set of other organizations are structurally equivalent. Following previous research, we make use of the clustering approach and algorithms provided by STRUCTURE (Burt, 1991) to identify subsets of structurally equivalent actors (Harrigan, 1985; Miles et al., 1993).

Landscape and tree diagrams are generated by feeding the organizational co-authorship data into the sociometric program STRUCTURE (Burt, 1991). These are then used to make a first classification of organizations into structurally equivalent groups. Research organizations are clustered together if the Euclidean distance of their relation patterns is less than 0.10. This means that at least 90% of their collaboration patterns are similar. Finally, for each group, a covariance matrix of distances among the 'structurally equivalent' organizations is computed. For completely structurally equivalent organizations, this matrix should have a rank of one (Burt, 1991: p. 124–147). We then make the final group classification after having determined that the covariance matrix for each group has at least a rank of 0.90, which confirms the criterion that the Euclidean distance has to be less than 0.10. With this procedure, we were able to identify between four and five structurally equivalent groups in the hepatitis C dataset, depending on the time period considered.

For each structurally equivalent group in the community, we then compute two indicators of competitive dynamics. 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'. Contemporaneous density is hypothesized to enhance entry and survival rates at low levels within a community of organizations, but to decrease entry and survival rates at high levels, hence its sign is assumed to be negative (Hannan and Carroll, 1992).

The second indicator is based on 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 zero which is attained in the case where one organization completely dominates the publication market. Given our focus on technological communities, 'markets' are defined in terms of 'markets for ideas'. As ideas are embodied in publications, the total market is computed as the total number of publications in the field. Market shares are hence defined as the organizations' shares of the publication market.

The absolute value of the entropy index increases toward infinity when either the number of firms grows or the concentration of the market shares among these firms diminishes. Its minimum absolute value is zero when one organization occupies the entire market. Its maximum absolute value is infinite under the condition of perfect competition among symmetric firms with equal market shares. However, as this measure is sensitive to changes in the number of organizations, it does not allow easy comparison of market share concentrations between industries (read: technological communities) or groups in the industry (read: technological community) occupied by differing numbers of organizations. To allow for comparisons, we have normalized the index by making it relative to the ideal symmetric model given the (publication) market volume in each structurally equivalent group. Hence, the numerator contains the 'basic entropy index' for each structurally equivalent group and the denominator stands for the ideal symmetric situation where market shares (in our case: publications) are equally divided among the N organizations in the industry (in our case: the technological community). The result is an index ranging from zero to one, where zero stands for the monopolistic situation of complete concentration and one stands for the competitive situation with organizations holding equal market shares. We call this index the *relative entropy index*.

5.4. Explanatory variables – network indicators

The sociometric variables used to test the hypotheses and the propositions discussed in the previous section are described in detail in Table 1. The various network variables were operationalized through the data on inter-organizational co-authorships in the bibliometric databases retrieved. The computational algorithms adopted were derived from social network theory (Knoke and Kuklinski, 1983; Burt, 1991, 1992) 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 one R & D output indicator for each organization in the dataset, namely the cumulative number of publications of the focal organization over its contribution-span.

6. Analysis and results

Failure time modeling techniques were used to study the persistence of organizations in the hepatitis C community (Kalbfleisch and Prentice, 1980). The data were first analyzed using the LIFETEST and LIFEREG procedures of SAS. The influence of time-varying covariates on organizational contribution-spans were analyzed using LIMDEP (Greene, 1992). Of the 991 organizations, 643 (64.9%) were active within two years of the last year of the data and were therefore classified as censored. (Note: since we had data on 1993, we included 1993 as the 'last' year of the dataset to determine whether organizations had left the field or not.) The growth in number of research organizations over the fourteen-year period spanned by our analyses is shown in Fig. 2.

As a first step in the analyses, non-parametric estimates of the survival and hazard functions were computed using the LIFETEST procedure of SAS. The LIFETABLE approach was chosen. The results of this procedure are shown in Figs. 3 and 4. The survival function, which is negatively sloped, illustrates that about half of the sample of organizations leaves the field over the fourteen-year period considered. The hazard function (see Fig. 4) is also negatively sloped. The hazard rate decreases very rapidly for research 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 becomes asymptotically low. The basic implication of the hazard function is that the longer an organization contributes to the field, the less likely it is to disappear from the field. As is obvious from Fig. 4, the risk of leaving the field is highest within the first year (0.40).

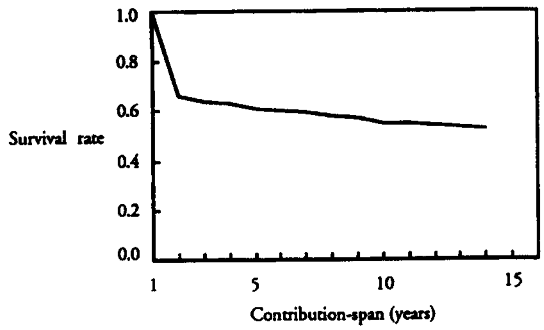

Fig. 3. Non-parametric estimate of the organizational survival function for the hepatitis C community, period 1979–1992.

The next step in the analysis is to determine the parametric model that best fits the distribution of contribution-spans. The basic model adopted for these analyses is:

$$Y = X\boldsymbol{\beta} + \sigma\boldsymbol{\epsilon}$$

where Y is the log of the contribution-span (the failure time), X contains the covariates, $\boldsymbol{\beta}$ is a vector of unknown regression parameters, σ is a scale parameter and $\boldsymbol{\epsilon}$ is a vector of errors from an assumed distribution. This model is often referred to as a 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-

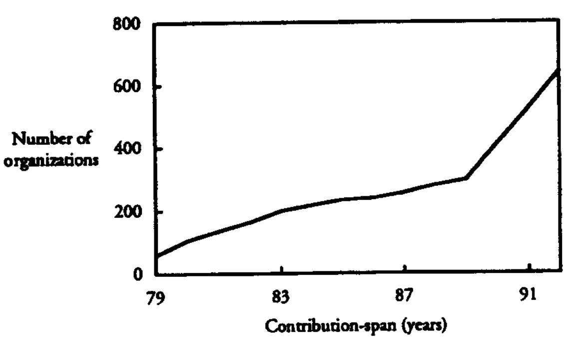

Fig. 2. Organizational growth in the hepatitis C community, period 1979–1992.

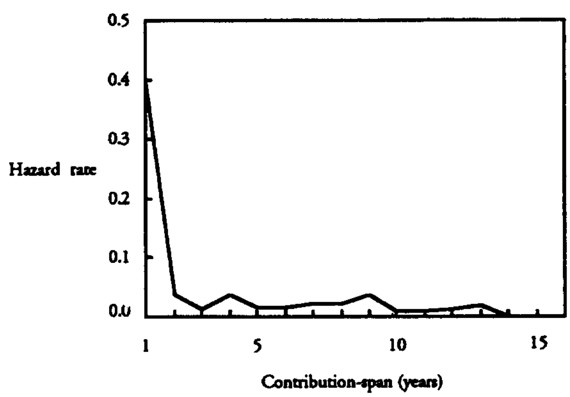

Fig. 4. Non-parametric estimate of the organizational hazard function for the hepatitis C community, period 1979–1992.

normal, and log-logistic distributions. Using the baseline model, the goodness of fit was evaluated in terms 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 to the equation (see Table 2).

The first model included the competitiveness indicators. The second model listed in Table 2 presents the final results from adding the sociometric covariates step-wise. 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, $p < 0.001$) sign of the contemporaneous density variable supports Hannan and Carroll's (1992) hypothesis. Given the definition of the relative entropy variable, its values range from zero (monopoly) to one (perfect competition). Combined with the positive sign of its coefficient ($p < 0.001$), the results indicate that a more fragmented publication market increases the likelihood of organizations persisting in the field.

The results further indicate that the major hypotheses relating sociometric indicators to contribution-spans receive support. Belonging to an interconnected clique in the community increases the likelihood of being persistent ($p < 0.001$, positive sign of the coefficient). Also, both the organization's power and prestige position in the network positively influence its contribution-span ($p < 0.001$, both coefficients are positive). The only hypothesis that did not receive support concerns the size of the organization's

Table 2
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			
Contemporaneous density (= density^2/1000)	-0.016^{c}	-0.023^{c}	-0.025^{c}
	(0.002)	(0.001)	(0.001)
Relative entropy index	4.740^{c}	3.581^{c}	4.147^{c}
	(0.283)	(0.229)	(0.299)
Degree of network embeddedness at organizational level			
Clique membership		2.274^{c}	2.529^{c}
		(0.126)	(0.158)
Number of contacts		-0.276^{c}	-0.265^{c}
		(0.030)	(0.034)
Homogeneity		−0.147	−0.209
		(0.139)	(0.146)
Power		0.089^{c}	0.098^{c}
		(0.005)	(0.006)
Prestige		6.689^{c}	7.365^{c}
		(0.951)	(1.136)
R & D productivity at organizational level			
Cumulative number of publications			-0.086^{c}
			(0.018)
Scale parameter	0.519^{c}	0.353^{c}	0.361^{c}
	(0.021)	(0.016)	(0.017)
Log-likelihood	−1487	−1126	−1118

1. Significances: ^{a} $0.05 < p < 0.01$; ^{b} $0.01 < p < 0.001$; ^{c} $p < 0.001$.
2. Total number of research organizations = 991 (348 or 35.1% 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 3795 spells.

primary contact network. Although the coefficient is statistically significant ($p < 0.001$), its sign indicates that network size has a negative influence on contribution-spans. This result may seem puzzling at first, though a closer inspection of the data may provide a logical explanation.

This explanation is derived from the finding that the number of organizations with which a focal organization is collaborating 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 (three or more) 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 allow for speculation: the coefficient is not statistically significant. In addition, it is interesting to note that the output indicator is statistically significant ($p < 0.001$), though it has a negative sign. Additional analyses reveal that the more powerful or prestigious organizations in the field are not necessarily the most productive in terms of cumulative number of publications. Of course, a minimal productivity threshold is required to attain above-average power and prestige positions. 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, we refer to the non-parametric analysis of the hazard function based on the duration of the organizations' association with hepatitis C research (see Fig. 4).

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 0.04, compared to 0.40 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 the previous hypothesis. In addition, the hazard function for the hepatitis C organizations suggests that the initial years of involvement are critical: organizations tend to become locked in rapidly. Exit barriers thus tend to build up rapidly.

7. Discussion

Non-parametric estimates of the hazard rates in hepatitis C 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 research agenda, exit barriers build up rapidly. Parametric multiple-spell models of organizational contribution-spans provide insight into the determinants of persistence. In particular, the embeddedness and position of an organization in a network of ongoing collaborations appear to be a strong and positive determinant of its persistence. As indicated, though, network size alone is certainly not sufficient to explain persistence. Rather, it is the power and prestige position of the organization in the community R & D network that matters. In addition, the most productive organizations are not necessarily the most powerful nor the most prestigeful.

It is obvious that 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. Jarillo, 1988; Powell, 1990; Badaracco, 1991; Nohria and Eccles, 1993). More specifically, the approach developed in this paper is believed to contribute to this already extensive body of knowledge. It indeed builds on the argument that studies on inter-organizational relations have traditionally focused on individual firms and their immediate partners in exchange; while little attention has been paid to the influence of the relations among the partners or of the partners' relations with other organizations not tied to the focal firm.

This approach has therefore promulgated, however unwittingly, a fragmented view of the system of inter-organizational exchange:

> "In reality, the extent to which organizations are constrained by exchange relations is likely to be far greater than even resource-dependence theory implies. Not only are organizations suspended in multiple, complex, and overlapping webs of relations, but the webs are likely to exhibit structural patterns that are invisible from the perspective of a single organization caught in the tangle. To detect overarching structures, one has to rise above the individual firm and analyze the system as a whole" (Barley et al., 1992: p. 312).

This remark is at the very heart of the 'community' level of analysis advocated in this paper.

Of course, the research reported in this paper is also limited in the sense that it focuses solely on one specific type of network embeddedness, namely the organization's position in the R & D network relevant to a particular technological community. Following Freeman and Barley's research (1990) on inter-organizational relations in biotechnology, it is obvious that the network in which an organization is embedded transcends this R & D component. For instance, in their analysis of Genentech's and Centocor's 'networks,' Barley and Freeman distinguish among the firms' marketing network, their manufacturing network, their equity investment network, their cooperative research network, their joint-venture network, etc. It is obvious that a holistic analysis of the 'network organization' might ideally include all those different network types and components. However, at the same time, this diversity of network relations makes it all the more difficult to relate 'network position' to 'organizational performance' indicators.

Finally, in Fig. 5, we highlight a central part of the hepatitis C inter-company network as it was 'gearing up' toward commercialization by the end of 1993. This network is based on extensive case study

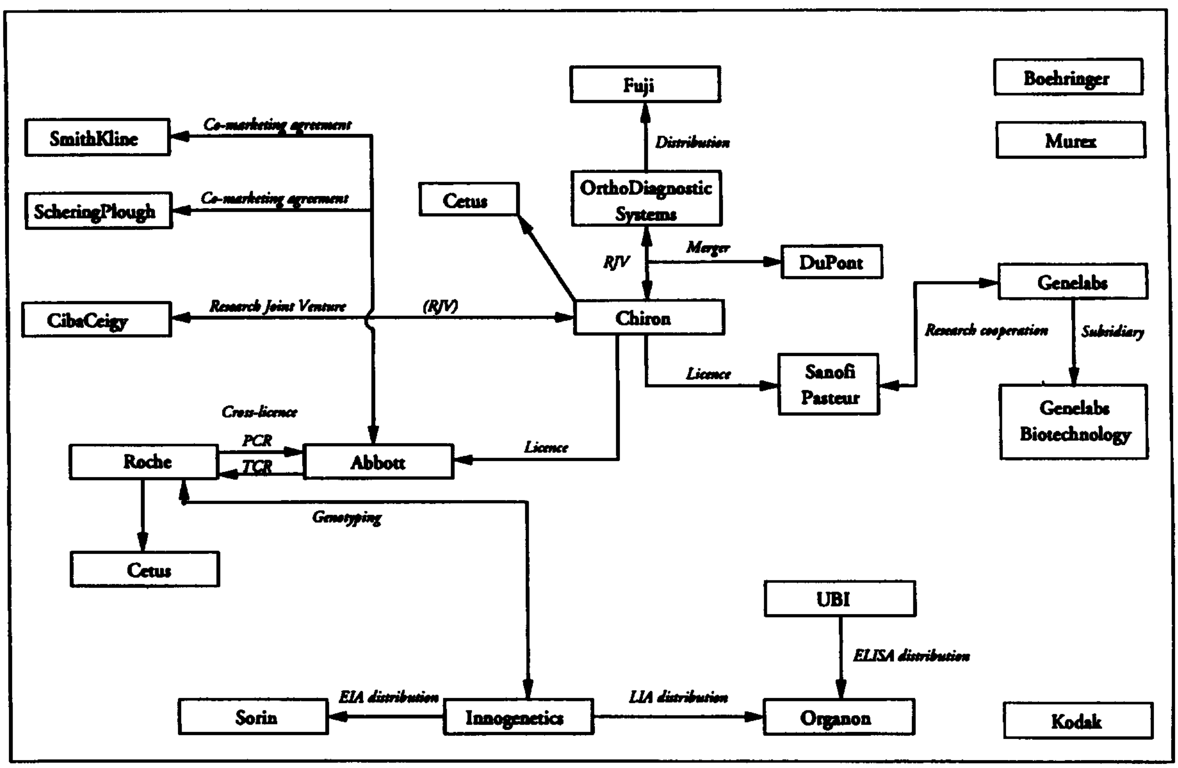

Fig. 5. The inter-company hepatitis C network gearing towards commercialization (1993).

research, interviews with (major) players in the field and archival information obtained through the BIODOC Information Services of the E.C. in Brussels. Also, the companies listed in this network happen to be major players in the R & D collaboration database used in the analyses in the previous sections.

The core corporate network listed in Fig. 5 consists of new biotechnology firms (e.g. Chiron, Innogenetics) as well as large, established pharmaceutical companies (e.g. Roche, SmithKline). The network relations are multi-faceted and include (1) research joint ventures, (2) technology 'swaps' (e.g. the cross-license between Abbott and Roche on polymerase chain reaction technology), (3) distribution agreements on diagnostics (EIA, LIA, ELISA), (4) research on genotyping, etc.

The central player in this network obviously is Chiron Inc. It is interesting to note that this new biotechnology company also figures among the most powerful and prestigious organizations in the sociometric analysis of the community network as described previously. Finally, from a legal point of view, Chiron also happens to hold the strongest patent position in the whole community.

8. Conclusion

The research reported in this paper has related network approaches to organizational survival (albeit in the context of technological development). However, understanding persistence in technological development may become an important issue in explaining why and how organizations participate in the many technology races going on today (Nelson and Winter, 1982; Dasgupta and David, 1987; Dasgupta, 1988; Dosi, 1988). The results presented in the previous sections suggest that, at least, network position and embeddedness may have significant effects on organizational contributions during the emergence of novel technologies.

Of course, the research raises additional questions that cannot be answered solely by the bibliometric approach adopted in this paper. Indeed, having detected the relevance of R & D networking to an organization's technical contribution and visibility, one is left with the question of how network positions develop and consolidate over time. In other words, what can organizations do in order to achieve positions of prestige and power in the R & D networks that are relevant to their technological activities. Or, furthermore do those R & D networks grow organically over time, with little or no possibility for an organization to influence its ultimate position in the network? To obtain some first insights into this important question, we are now conducting case studies that attempt to trace the differential development of network positions among a few organizations represented in the hepatitis C dataset.

It is obvious that technological breakthroughs may enable research organizations to achieve positions of power and prestige. However, technical prowess in and of itself may not be sufficient. Therefore, during the case study research, we want to focus on the extent to which a well-articulated R & D strategy and R & D management practices geared towards network creation and consolidation help achieve positions of power and prestige. In addition, for reasons of external validity, we advocate the replication of the current methodological approach in other technological communities as well.

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