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CLUSTER-BASED INNOVATION POLICIES: A METHODOLOGICAL APPROACH APPLIED TO BIOTECHNOLOGY RESEARCH IN FLANDERS

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Abstract

In this paper, we apply a network methods approach to understand clustering in new technologies. Sociometric modelling techniques are used to map the technology relationships between academic as well as industry organisations in the field of transgene plants. We demonstrate how different clusters of innovative organisations can be detected and how these clusters can be related to the evolution of the new technology. Implications for technology policy are discussed.

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Introduction

Innovation policies can take on different forms and formats. Different economic schools of thought advocate different approaches to stimulate innovation in industry. Classical economic principles consider technology to be an exogenous factor to the economic system. New growth theorists, on the contrary, consider technological innovation as an engine of progress which is an integral part of our economic system. Evolutionary economists consider technological innovation to be shaped by the interactions of a myriad of actors in our economic system.

These different approaches have serious consequences as to the role governments can and should play within the economic system when it comes to stimulate innovation. A central tendency, though, is the general acceptance that knowledge has become an important production factor, and hence, that governments might look to stimulate knowledge transfers between (different types of) organizations. These knowledge transfers often cannot be embedded into a simple market-like transaction. The presence of quite some "tacitness" in these transfers, often results in cooperative modes of knowledge transfer, often visualized in the so-called networks of innovation. It is against this context that we can situate the development of cluster-based innovation policies. In this paper, we want to shed a look on the relevance and the bottlenecks associated with cluster-based innovation policies, as well as to provide a first insight at methodological approaches to underpin cluster-based innovation policies.

Origins of cluster-based innovation policies

In order to understand the current interest in cluster-based innovation policies, one has to turn to Michael Porter's work, *The Competitive Advantage of Nations* (1990). Jacobs and De Man (1995) define clusters as *"An interwoven set of companies and supporting institutions within an industrial sector as well as within an integrated, overarching set of industrial sectors, in which companies compete and cooperate with each other."* It is obvious that this definition offers quite some degrees of freedom as to the content and the level of analysis addressed by the cluster concept. This then may be a first

bottleneck with respect to cluster-based innovation policies: the very definition and operationalisation of the cluster concept may need a deeper understanding and a better articulation of its modi operandi.

At present, the operationalisation of a particular cluster cannot be seen in isolation from the policy context against which it is deployed. This is most obvious in the various clusters that are defined and operationalised in the Flemish Region at present. Certain of these clusters explicitly aim at stimulating cross-sectoral technology diffusion and application; while others aim at supporting supplier-producer networks or (at the opposite end of this production spectrum) to create networks of excellence in newly emerging technologies; and, still others just provide a 'quality label' that should set and raise the standards for export-intensive (but mature) sectors and hence, positively influence their competitive position in export markets.

In his seminal work, Porter distinguishes between 16 possible clusters: 4 upstream clusters (materials/metals, oil/chemical, agriculture/forestry, computers/ semiconductors), 6 supportive clusters (transport, office, energy, telecommunication, defence, others), and 6 downstream clusters (food/beverages, housing/household, leisure, health, textile/ clothing, personal affairs). From this overview, it becomes obvious that the cluster-concept attempts to go beyond the traditional industrial sector approaches and classifications in our economic system. Cluster approaches hence stress the complementarities between sectors rather than the polarisations. The real challenge is to find out where cross-sectoral specialisations occur within the economic system.

Extensive research in the Netherlands (Jacobs and De Man, 1995) has shown that clusters occur under various forms and that clusters do not necessarily consist of thight network-like structures and arrangements. For instance, in their research, Jacobs and De Man reach the conclusion that the plastics sector does not maintain any close or intense linkages with the chemical industry (anymore). Three other Dutch colleagues, Kusters and Minne (1992) and Nooteboom (1993), explicitly try to understand clusters in the Dutch economy using a network perspective. They look at linkages between actors and they also take into account the role and the presence of knowledge institutes such as TNO and the universities. This is an important methodological step since it clearly demonstrates that the cluster-concept should not only be operationalised at the level of products and product groups, though that we should consider knowledge creation and diffusion within the cluster as well.

Jacobs and De Man (1995) conclude their interesting research agenda with an overview of seven dimensions (geographic, horizontal, vertical, lateral, technological, knowledge linkage, and quality) that can be applied to define a cluster. Starting from these dimensions, they arrive at a typology with six different cluster-definitions: (1) regionally concentrated activities, (2) supplier/outsourcing networks surrounding a focal company, (3) macro-level (industrial) sectors, (4) horizontally defined sectors in the economy, including customer-supplier relationships, (5) meta-level sectors, and (6) cross-sections of sectors leading to new activities, including service development.

Despite this interesting work, many question marks remain as to the role clusters can or might play in stimulating (regional and national) innovation systems. In addition, it raises questions about the role public policy should or should not play in cluster-based innovation schemes. Hence, the need to devote more attention to understand the dynamics of network versus cluster formation and the role public policy can play in this area.

Clusters: some methodological questions

The literature and insights on clusters did not develop in a vacuum. In his interesting book, *The Economics of Localised Technological Change and Industrial Dynamics*, Antonelli (1995) develops a typology of (meta-) networks that develop in an economic system. A network is defined as an organised set of partially separable productive units, characterised by high levels of diversity, complementarity and interrelatedness both with respect to existing technologies and eventual ones. This leads to the following typology:

Pluralistic networks are based upon reciprocal agreements, as in industrial distrcits in Italy. Within Marshallian districts, the necessary complementarity and cooperation among firms is achieved ex-ante on the market place by means of a variety of contractual agreements among firms that enforce the arms-length mode of interaction. Proximity in the regional space, moreover, makes easier the necessary coordination among the complementary activities of different firms. Hence, agglomeration economies arise and small specialised firms located into Marshallian districts enjoy - with respect to 'lonely' often larger competitors - the competitive advantages of aggregate downward sloped supply curves and of significant demand externalities for bundles of products that have high levels of complementarity in usage and in production.

Federative networks are based upon regulating boards as the financial federations built around banks and financial companies in France and Germany.

Centralised networks develop around a large company specialising in research and development, procurement, core manufacturing, linked by means of long-term contracts and on-line communication, to a variety of smaller companies specialising in components manufacturing and retailing, as in the Italian experience and in the Japanese Keiretsu system.

Technological networks or clubs exist when the complementarity between firms is especially strong in generating and implementing new technologies based upon alliances and cross-patenting as it is more and more the case in many high-tech industries.

It is obvious that this typology comes close to the cluster concept discussed in the previous paragraph. Antonelli also brings to mind two important dimensions of 'networks.' First of all, networks imply linkages. However, these linkages can be varied in their strength as well as in their content. Second, not all 'transfers' imply the existence of a formal linkage. The notion of spillovers is implicitly present in the Antonelli typology. This is in line with the observations of Porter as well as those of Jacobs and De Man that clusters do not need to be characterised by extensive formal linkages between the various actors identified in the cluster. Agglomeration effects (and the spillovers that occur within those agglomerations, e.g. via the labour market) should be explicitly taken into account when identifying and operationalising the cluster concept.

In the next sections of this paper, we want to apply some of these network concepts to study clustering patterns in a knowledge-intensive technological field (transgenic plants) which is (deemed) of significant importance to the competitive position of Flanders as a region in the next decade. We acknowledge that by studying a high-technology cluster, we limit the scope of the present study and hence, provide an extremely focused input to the current debate on cluster-based policies. However, this paper should be a first step toward a more refined taxonomy and methodology in the area of cluster-based approaches to innovation. These approaches should not only model clustering in a regional context, though they should allow to model the embeddedness of regional clusters in international networks as well.

Identifying technology clubs using network methods

We first describe a method to classify organisations based on the similarity of their patterns of network relationships. This method results in clusters of organisations with a similar network strategy (Burt (1992)). Indeed, social network theory offers the techniques to cluster organisations with similar collaboration patterns into structural equivalent classes (for a review, see Burt (1980)). In the present example, the published (international) literature on plant biotechnology is used as a source of data. Based on these data, we trace the evolution of structurally equivalent clusters and their respective 'structural' characteristics. We also provide a critical discussion on the usefulness of bibliometric data to study entry, exit and mobility in a technological club or network.

Detecting network clusters: inspiration from the strategic group literature

Ever since Hunt (1972) introduced the notion of 'strategic groups,' the concept has offered an attractive perspective to study industrial organisation (e.g. McGee & Thomas (1986), Reger & Huff (1993)). Although no real consensus exists on the criteria for clustering organisations into strategic groups, two major categories are distinguished, i.e. input and output criteria. The input criteria refer to differences in resource availability (e.g. organisational boundary issues), while the output criteria emphasise differences in product-related issues (e.g. differences in marketing or manufacturing capabilities). Both criteria make divergent assumptions about the grouping object, i.c. competition. For instance, groupings based on output criteria view competition as 'result-driven' (see Burt (1992)). Two organisations are grouped together when they serve the same market segments, attain an equivalent amount of sales or are similar as to their marketing efforts.

Most initial studies have formed strategic groups based on output-related criteria in order to explain differences in profit rates among these groups (Oster (1982), Porter (1980)). However, recent research has questioned the value of the strategic group concept to explain the (market) structure-conduct-performance relationship (Barney & Hoskisson (1990), Hatten & Hatten (1987), McGee & Thomas (1986)). Competition is no longer defined as a configuration of results. But, it is a process which results itself from the division of resources. However, competition itself is too stringent a criterion on which to group organisations. Indeed, cooperation may be a viable alternative to the competitive war. Hence, organisations should not solely be grouped on the basis of the results of competition but also on its antecedents. Strategic groups are then commonly defined as *'a grouping of organisations which pursue similar strategies with similar resources' (Hatten & Hatten (1987)).*

From a knowledge creation perspective, this means that research organisations which have access to the same kind of knowledge resources belong to a similar 'strategic research group.' In other words, the pattern of relations an organisation is involved in determines the strategic group it belongs to (Debackere et al. (1994)). Strategic groups then contain organisations with similar network positions. This definition of strategic groups is obviously much less stringent than Porter's output driven approach (1979). Porter defines strategic groups as collections of firms in direct competition with each other. However, following Schendel and Patton (1978), we emphasise that organisations with similar network roles (i.e. having access to the same resources) are not necessarily competing *with* each other, they just compete *like* each other. Hence, we hypothesise that in some strategic groups competition among members will be important, while in others it will be of less importance.

Following this reasoning, strategic groups are computed as structurally equivalent sets of organisations derived by blocking the patterns of their relationships within the technological community. Freeman and Barley (1990) and, more recently Burt (1992), have emphasised the value of social network techniques to identify niches of similar organisations. More specifically, the concepts of blockmodels or structural equivalence maps can be used to identify sets of actors possessing similar patterns of relationships (Burt (1980), White, Boorman & Breiger (1976)). In social network models, '*two actors are considered as structurally equivalent to the extent that they have identical relations with every actor in every network within a social structure.*' This means that two research organisations are considered to be structurally equivalent actors in a network if they jointly occupy a similar position in that network. Furthermore, two actors can only occupy the same network position if they have identical patterns of relationships. For example, a research organisation which has co-authored a publication with two other research organisations which in turn have co-authored a paper with two other research organisations, which in turn have only these research organisations as network contacts is considered structurally equivalent with another research organisation which has exactly the same structure of network contacts. In Figure 1, we provide an example of a more complex set of structurally equivalent organisations.

— INSERT FIGURE 1 ABOUT HERE —

Structural equivalence, in the sense of having completely identical patterns of relationships (as it is shown in Figure 1), is in reality too stringent a criterion to identify strategic groups (Knoke & Kuklinski (1983)). Therefore, we use the Euclidean distance between relation patterns to measure ***the extent to*** which two actors are involved in identical network relations. The Euclidean distance is zero for organisations which have completely equivalent patterns of relations (see Figure 1). It is increasing for organisations showing decreasingly equivalent patterns. For example, producers are competitors in the same market to the extent that they use the same resources, in other words, to the extent that they have identical patterns of relations to each potential source of resources. Such actors are structurally equivalent. The degree of their equivalence is measured by the Euclidean distance between their relation patterns, such as:

$$d_{ij} = [\Sigma_q (u_{iq}-u_{jq})^2]^{1/2} \qquad \textit{with } q \neq i,j$$

where zero distance between *i* and *j* indicates that they have identical relations with each resource segment *q*. In our research, the usage of relations, u_{iq}, is based on the research organisation's sociometric ties (measured via co-authorships, see below) to other organisations in the community.

Following previous research, we make use of cluster analysis to identify subsets of structurally equivalent organisations (Harrigan (1985), Miles, Snow & Sharfman (1993)). After calculating the Euclidean distances for each research organisation, we use Ward's error sum of squares method to identify different clusters. The landscape and tree diagrams generated by the sociometric program STRUCTURE (Burt (1991)) are then used to make a first classification of organisations into strategic groups. Research organisations 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 strategic group, a co-variance matrix of the distances among the 'structurally equivalent' organisations is computed. For completely structurally equivalent organisations, this matrix should have a rank of one. We then make the final group classification after having determined that the co-variance 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.

Data sources used in the present example

For this example, we have chosen the field of plant biotechnology (transgene plants) as a research site. Plant biotechnology is a subdomain of biotechnology, applying the technique of genetic engineering to plant varieties. The genetic engineering of transgene plants has resulted in three major application areas: (1) plant crop protection, (2) plant quality improvement, and (3) plant hybrids (for a review, we refer to Grierson (1991)). Interest in plant quality improvement was first aroused in the 1950s as a result of the research into tissue cultures and the restrictions of tissue cultures. 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 three major foci of interest. Plant crop protection aims at developing virus-free plants with increased stress, herbicide or disease resistance. Plant crop quality improvement aims at the engineering of proteins with increased nutritional value, control of ripening, prolongation of shelf life and, control of flower colouring. On the one hand, the production of hybrid seeds implies the conversion of open pollinated varieties to hybrids in order to provide farmers with superior quality seeds. On the other hand, it allows seed companies to protect the value they create through research and breeding. The first commercial products in all areas have appeared in the period 1993-1996. Thus, between the early 1980s and 1993, transgene plants have moved from being a scientific curiosity to a promising commercial activity (for a current state-of-the-art, we refer to Kareiva (1993)).

Journal articles, research notes, conference papers and patents provide an appealing source of information to identify networking in emerging technological fields. Given the widespread availability of electronic bibliometric and patent databases, these sources of bibliographic information can now be accessed at reasonable cost. They do offer a wealth of data that can readily be used for research purposes. For instance, using bibliometric data, R&D collaborations are identified through the occurrence of a joint publication between two or more organisations.

Given publication conventions, this also means that the collaboration's outcome, before its publication, has been subject to a quality and authenticity control by the peer review system. Besides the quality issue, this method of data collection has several methodological advantages. For instance, the data collection process can easily be replicated with other research areas. Thus, findings in one area can be tested for reliability and external validity. Also, numerous studies have proven the usefulness of bibliographic data for the development of R&D indicators and the measurement of R&D performance (e.g. Levin & Stephan (1991), Moed, Burger et al. (1985), Weingart, Sehringer & Winterhager (1992)).

We have used the databases of the Institute for Scientific Information (Philadelphia, U.S.) to identify publications related to the field of transgene plants. For the period before 1982, we have accessed the ON-LINE version; from 1982 onwards, the quarterly updated CD-ROM versions were available. Both databases were searched using a search strategy which contained a set of 18 key terms, commonly used by transgene plant researchers. The search strategy was validated indepth by three independent experts. A comparison with a sample of 100 hardcover articles which had been selected by one of the plant genetic experts showed that over 80% of the publications in the sample were covered by the electronic search strategy.

The data collection procedure resulted in the identification of 1,425 unique source documents published between 1974 and 1992. The database was then used to identify each organisation which has performed plant-biotechnology research during this nineteen-year period. For the identification procedure, we used a common sectoral categorisation scheme to classify different types of organisations based on their distinctive competencies (see Daly (1985) or Pisano, Shan & Teece (1988)). This resulted in four categories of organisations: (1) universities; (2) non-profit government-sponsored laboratories; (3) new biotechnology firms (NBFs); and (4) established firms. No distinction is made between the different research groups working within the same organisation. Also, different subsidiaries of the same organisation were treated as one organisation. This procedure yielded a total of 367 research organisations that have been active in the field during the period of observation: 203 universities; 102 non-profit government-sponsored laboratories; 29 established firms; and 33 new biotechnology firms. During the last year of observation (i.e. 1992), 246 research organisations were still active in the field.

— INSERT FIGURE 2 ABOUT HERE —

It should be noted here that the exponential growth of the field, observed from 1990 onwards, may be partly due to our computational approach since a censoring effect occurs (see Figure 2). We treated research organisations as having left the field if they did not publish during the two year-period following their last publication. Hence, the observation during the third year after the last publication is used to confirm the organisation's exit status. Since only seven organisations (0.20%) have a gap between their publications of longer than three years, this exit-criterion seemed realistic. As we do not have publication data for the period 1993-1995, this approach implies that during the last three years of observation (1990-1992) no organisations could be classified as having left the field, i.e. their exit status is censored. Therefore, the increase in research organisations during this period probably is an overestimation of reality. Based on an extrapolation of the exit rates for the period 1988-1989, we could assume that growth actually slows down during the period 1990-1992. This is shown by the dashed extrapolation curve in Figure 2.

Identifying clusters

For the period 1974-1979, it is impossible to identify collaboration-based clusters. Only a small number of research organisations was working on the genetic engineering of plants and there was no consensus on the techniques to be used. Although each research organisation in the field knew exactly what the others were doing, there was no interest in cooperation. This is illustrated by a straightforward example. In 1976, a Belgian lab (the Study Center for Nuclear Energy (SCK) in Mol, Belgium) announced that it had succeeded in the genetic manipulation of a plant species. Each organisation in the field was surprised by these findings. From the very beginning, much confusion and discussion existed as to the robustness of the results. However, it was not until several years later that the findings were proven false. Why then did it take so long before the leading organisations did react? How is it possible that so much confusion existed among the major players in the field? An analysis of the field indicates that the research groups worked in a relatively isolated way, competing with each other for the first plant to be genetically engineered. There was no structure in the research activities nor in the relations among the major research organisations that allowed for a careful scrutiny of the results.

Consequently, we argue that those research organisations correspond to the '*pioneers*' or the '*innovators*' as defined by Rogers (1962,1983) in his seminal work on the diffusion of innovations. Twelve 'pioneers' could be identified during this period. Only two of them have been involved in a joint research project during this embryonic stage of the technology's development. Seven of them will leave the research domain before 1983. Today, five pioneers are still active in the problem-solving process. The empirical findings support the hypothesis that *'pioneers'* or *'innovators'* are often a less integrated part of a 'local' social system. (e.g. Granovetter (1974), Kerckhoff, Back & Miller (1965), Rogers (1962)). This finding further emphasises the relevance of studying network formation in R&D from a community-level perspective rather than from a (limited) organisation level of analysis. Moreover, the empirical findings support the hypothesis that many pioneers may not contribute longer than average to knowledge creation in the research domain. Hence, pioneering behaviour is not necessarily related to persistence in an emerging field.

— INSERT FIGURE 3 ABOUT HERE —

In the early 1980s, clusters of structurally equivalent organisations emerge. The structural equivalence maps in Figure 3 were computed with STRUCTURE (Burt (1991)). During the period 1980-1984, clusters of organisations with similar collaboration patterns become apparent. It is not astonishing that, from 1980 onwards, the first collaborations emerge. After having elaborated several (potentially successful) techniques for the genetic manipulation of plants, the major research groups gradually focused on the use of bacterium-related plasmids for genetic manipulation. Especially the Ti-plasmid associated with the plant pathogen *agrobacterium tumefaciens* caught their attention. It was this convergence in research ideas which forced the researchers at four major pioneering groups (Monsanto Company, Washington University, Max Planck Institute in Cologne and University of Gent in Belgium) into the race for the first transgene plant. Eventually, it were the two collaborating research groups (Max Planck Institute in Cologne and University of Gent) that won the race in 1983 (Gasser & Fraley (1992)). It is remarkable that besides these four pioneers, only one other pioneer (Leiden University in the Netherlands) survived (as an active player in the field) during the subsequent years.

On the structural equivalence maps shown in Figure 3, we distinguish four clusters. In the lower-right corner of the first structural equivalence map, we find the *'social isolates'* in the research domain. Social isolates are organisations that do not collaborate at all. This group is further divided into two subsets. In the first subset, we find the other pioneers. They remain social isolates till they exit the domain. The second subset consists of new entrants that have no connection (yet) with one of the leading organisations (the five pioneers). The upper-left group contains three of the five successful pioneering organisations, while the two other pioneers are situated at the lower-left corner of the structural equivalence map. Finally, the group which is at the lower-middle of the map consists of new entrants who are in some way connected to one or two of the successful pioneers.

At this point, the distinction between pioneers and early adopters should be made. Among the 16 organisations active in 1980, eight are new entrants, five are successful pioneers, while the remaining pioneers will exit before 1983. Although there exists no unambiguous criterion for delineating the transition from the pioneering period to the early adoption period, we argue that from 1980 onwards early adoption, as defined by Granovetter (1974), sets in. Unlike the pioneers, early adopters are a *more integrated part of the local social system than the innovators (Rogers (1962: 183)).* Also, the majority of them persist in the field (as opposed to 7 out of 12 *'pioneers'* who leave the community before 1984). Most early adopters that survive eventually become 'successful' in the sense that they are leaders when it comes to cumulative number of publications in the field and that, by 1992, they occupy a quite central place in the research network.

Although we can detect strategic groups of structurally equivalent research organisations from 1980 onwards, they are not stable in size, shape nor structure. It takes till 1984 before four distinct strategic groups can be identified that remain stable during the subsequent years of observation (here we refer to the second map on Figure 3). Again, the underlying technological developments are indicative of this evolution. During the period 1980-1984, two major breakthroughs in the field of transgene plants occurred: (1) Max Planck Institute and University of Gent successfully manipulated the first transgene plant, while (2) Max Planck Institute [in a collaboration with Monsanto] succeeded in the construction of an engineered gene, which made plant cells resistant to the antibiotic kanamycin. From then on, it was demonstrated that alien genes and proteins could be successfully expressed in plants. As a consequence, from 1984 onwards, more research organisations entered the domain (see Figure 2); i.e. a bandwagon phenomenon is observed. Especially, a gradual entry of new biotechnology firms takes place.

A closer examination of the structural equivalence maps in Figure 3 reveals several interesting patterns. First of all, the most successful pioneers (i.e. Max Planck Institute in Cologne, University of Gent in Belgium, Washington University and Monsanto Company) are coalescing in the (upper) left corner of structural equivalence map. Second, the early adopters (e.g. INRA in France, University of California, etc...) cluster in the middle or even at the top of the maps, whereas most new entrants during this period still remain social isolates (lower-right corner of the maps). From 1984 onwards the groups described in this paragraph further evolve as four distinct strategic groups of structurally equivalent organisations.

This evolution eventually results in the structural equivalence map of 1992, where the four strategic groups which first emerged in 1984 are clearly recognisable. The first group is still situated in the upper-left corner of the map. This group contains the same four pioneering organisations as in 1984. However, one new biotechnology based firm (Plant Genetic Systems Inc., Belgium) is joining them. The second group contains several of the major early adopters, but also some of the new biotechnology based firms (e.g. Calgene Inc.). This group is slowly moving towards the four pioneers. The third group is composed of two distinct classes of research organisations.

First of all, we can identify a subset of research organisations that are receding. This tendency really is observable from 1988 onwards. It is not surprising to detect this movement since from then on the importance of making progress in product development increases; while being on the hardcover of SCIENCE gradually becomes of less value to most research organisations. The second class of actors in the third strategic group are research organisations which cooperate with the members of group 2 without having direct contacts with the four organisations in group 1.

Finally, the group of social isolates is still located at the lower-right corner of the map. The majority of the social isolates are 'new entrants' that remain in group 4 for a one-to-two year period (calculated as the median of the contribution-spans in this group) and subsequently, either exit the domain or move on to group 3. The contribution-span serves as an indicator of the research organisations' persistence in the field (Rappa, Debackere & Garud (1992), Rappa & Garud (1992)). It is defined as the time-period between an organisation's first and last publication in the field as measured from the bibliometric databases used in our analyses. By way of comparison, the median of the contribution-spans (under the assumption of normality, i.e. not taking into account the censor effect) in group 3 is between 3 and 4 years; in group 2 it is between 6 and 7 years; and, finally in group 1, it is between 11 and 12 years.

Thus, the major network dynamics as they are revealed by the spatial mapping of structurally equivalent organisations can be summarized as follows. First of all, collaboration-based strategic groups emerge after a period of building and gaining legitimation for the new research agenda. In the case of transgene plants, this is the period 1974-1979. During this period, organisations that can be qualified as pioneers are active in the field. Second, distinct clusters emerge contemporaneously with the major breakthroughs in the technology (in plant biotechnology this is from 1980 onwards). During this period, research groups were successful with the genetic manipulation of plants. Ultimately, four distinct strategic groups are identified after the major breakthroughs have set the main research options and directions in the field (from 1984 on). In the case of transgene plants, once the first plant was genetically transformed, three distinct application avenues emerged: (1) plant crop improvement; (2) plant resistance; and, (3) hybrids. Finally, in the early 1990s, groups seem to move towards each other as the field evolves from 'fundamental' research to product development and subsequent commercialisation. Especially from 1990 onwards, an increasing number of field trials (e.g. in 1992: 161) has been permitted by the U.S. Department of Agriculture, thus indicating that the time of commercialisation is approaching (Kareiva (1993)). The first commercialisation (Calgene's transgene tomato) was planned for the beginning of 1994.

This section has offered empirical support for the hypothesis that underlying technological developments may account for the emergence and formation of collaboration-based strategic groups in plant-biotechnology (Miles, Snow & Sharfman (1993), Pisano, Shan & Teece (1990)).

A structural analysis of structural equivalent groups

In Table 1, we highlight some of the salient characteristics of the four collaboration-based strategic groups detected in the previous section. The data are based on an analysis of group membership as it had evolved in 1992. Each group consists of research organisations belonging to the four sectors defined earlier in the paper. In each group, the majority of actors are academic laboratories, followed by government-sponsored laboratories like the Max Planck Institute in Cologne. Industry-based research groups are a minority, although their presence steadily increases with time; i.e. as the knowledge base evolves towards commercialisation.

— INSERT TABLE 1 ABOUT HERE —

As far as inter-organisational collaborations are concerned, the group of pioneers obviously is the most prolific one with an average of 18 collaborations per organisation. Research organisations in group 2, the majority of whom are early adopters, have on average 5.3 inter-organisational collaborations. In group 3 we find the less connected research organisations, the majority of whom jumped on the bandwagon in the late 1980s, with an average of 1.9 inter-organisational collaborations. As group 4 consists of the social isolates, no collaborations can of course be recorded for this group. For each group, the majority of inter-organisational collaborations is *between* the four sectors of employment. In group 1 (i.e. successful pioneers) university-industry collaborations account for nearly half of the total number of collaborations. In group 2, the majority of collaborations occurs between academic and government-based research groups. In group 3, about one-third of all collaborations occur between the government and the academic sector, while about 40.0% of the collaborations are between research organisations belonging to the same sector of employment.

In Table 1, the patterns of intergroup collaborations are also highlighted. For group 1, 50.0% of all collaborations occur between actors belonging to that group. For group 2, more than 70% of the collaborations connect the research organisations belonging to that group to actors either in group 1 or 3; while the majority of organisations in group 3 are only loosely connected to organisations belonging to the other strategic groups.

Finally, Table 1 provides some additional descriptive statistics for the four groups. Using the electronic databases from the European and U.S. Patent Offices we identified the patent applications for each research organisation. Once again, group 1 is the most prolific one, with an average of 6 patent applications for each organisation. Groups 2 and 3 are similar with an average of about 3 patent applications per organisation involved in patenting. Of course, a majority of organisations in groups 2 and 3 never applied for a patent. In group 2, only 10 organisations applied for a patent; in group 3 this figure amounts to 25 organisations. Group 4 (the social isolates in the field) clearly lags behind: only 5 out of 62 organisations applied for a patent, with an average of 1.2 patents per applicant. In Table 1, we further provide statistical evidence on the average cumulative number of researchers and publications for the research organisations belonging to each group. The differences detected sofar between the four groups persist: organisations in group 1 are the most prolific, while the social isolates (group 4) obviously lag behind.

We further computed a sociometric prestige index for each organisation in the domain. Prestige is based on Burt's algorithm (1991):

$$\text{prestige of } i = p_i = \Sigma_j[z_{ji}/\Sigma_k(z_{jk})]p_j \quad \textit{with } j \neq i,k$$

where z_{ji} equals the number of collaborative co-authorships between organisation j and i, and p_j represents an element in the left-hand eigenvector in the row-stochastic matrix.

Based on Burt's definition, the prestige of an organisation *i* increases with the demand for *i's* network time and energy. In other words, the prestige index combines two essential sociometric features. First, it indicates the extent to which each organisation *i* is able to dominate, through its pattern of collaborations, other research organisations in the domain (i.e. it takes into account the power position of the organisation). Second, it takes into account whether the organisations dominated by *i* are themselves 'powerful' organisations in the field or not. In other words, prestige reflects the degree to which an organisation is a central actor in the domain or not. The prestige indices reported in Table 1 were scaled by dividing each organisation's prestige position p_i by the prestige position of the most prestigious organisation in the field. The result is a value varying from 0 (no prestige at all in the field) to 1 (for the most prestigious institution in the field).

As can be seen from Table 1, the organisations belonging to the first group have an average prestige index of 0.751; which once again demonstrates their domineering role in the field's collaboration structure. Average prestige for the organisations belonging to group 2 is 0.242. Organisations in group 3 attain the lowest average prestige level.

— INSERT FIGURE 4 ABOUT HERE —

We also summarised the major organisational entry, exit and inter-group mobility patterns in the transgene plant community over the time-period 1980-1992 (see Figure 4). In addition, the evolution of the number of organisations in each group over the time-period is shown in Figure 5.

During the observation period, about 200 organisations have entered the group of social isolates (group 4). Of these, 62 are still in the group in 1992. Due to the way exits are computed (here we refer to our previous discussion on the presence of a censoring effect), the number of 59 exits is an underestimation since from 1990 onwards no exits can be detected. When extrapolating the number of exits based on the exit data for the period 1984-1990 (because from 1984 onwards the strategic groups are relative stable), the cumulative number of exits might end up in the neighbourhood of one-hundred. Based on this extrapolation, group membership in the social isolate cluster would thus be sharply declining.

This estimation is confirmed by the pattern in Figure 5. There we see that the number of organisations in group 4 increases till 1987 and then continuously decreases till 1990. From 1990 onwards, the censoring effect causes an overestimation of the number of organisations in this group. An extrapolation of the trend for the period 1987-1990 suggests a further decline in research organisations belonging to this group. This inverted U-shaped curve of organisational density can be explained by the formation and subsequent consolidation of an untenable 'research' niche. The major breakthroughs in the early 1980s entailed a period of over-optimism in the field. As a consequence, government and industry multiplied their investments in the field during the mid-80s. These financial interventions created room for new organisations (i.e. universities as well as goverment-sponsored laboratories, established firms or new biotechnology based firms) to enter the field. Most of these organisations stayed for one-to-two years in the group of social isolates before exiting the field or moving to group 3 (as mentioned previously, the median contribution-span in group 4 is one-to-two years).

— INSERT FIGURE 5 ABOUT HERE —

As the research outcomes did not live up to the high expectations, the initial growth slowed down in the late 1980s. In addition, the incumbents experienced increasing pressures to develop commercial products based on the results of their previous research before pursuing new research avenues. To paraphrase a well-reputed scientist in the field: "*For us it has become more important to succeed in developing a successful transgene plant than being on the hardcover of NATURE.*" We therefore hypothesise that group 4 provides a typical example of an untenable research niche. The organisations populating this group can be compared to comedones living on the excess capacity of resources during a period of high growth. During the mid-80s, each research organisation was able to apply for funding and thus to enter the domain, whatever the quality of its research experience and expertise. In the late 1980s, though, most organisations entering the domain had to collaborate with incumbents. Hence, they enter in group 3 instead of in group 4. These findings further indicate that when a research domain matures, entry barriers for new organisations without contacts with the established players in the field rise. In other words, as the field matures, the imperative of being embedded in the community's R&D network may deter potential new entrants.

About 280 organisations enter group 3 and about 130 leave the group; 56 of which exit the research domain (not taking into account the censoring effect). The historical evolution of this group as well as the type of organisations populating it, differ a lot from group 4. Whereas the group remains relative small till the mid-80s, it grows exponentially in the late 1980s (see Figure 5). There are two major explanations for this growth. First, after the period of over-optimism characterising the mid-80s, it becomes more difficult to enter the domain without any contacts (i.e. the situation in group 4). Hence, more organisations look for an incumbent to cooperate with and almost by definition, they enter the domain in group 3. Second, the number of exits out of the group increases sharply in the late-1980s. Based on an extrapolation similar to the one used previously, we might predict that the cumulative number of exits in 1992 might also approach one-hundred. As a consequence, the growth in this group resembles the growth of the research domain as a whole and slows down in the early-90s. We label the incumbents as 'regional or local research organisations.' Only a very small number of these organisations ever produce an article that reaches the front-page of NATURE. The very few (about 15) which have succeeded in producing such a publication, quickly moved from group 3 to group 2 or even to group 1.

Although group 3 might appear to be an untenable niche, prone to disappear during a period of consolidation, 'regional, government-sponsored' research programs on transgene plants may enable organisations in group 3 to survive. Such subsidies tend to create inefficient niches which nevertheless remain sustainable. Especially when the social, economical and related political interest grows, government research budgets increase and, as a consequence, more organisations are able to enter the domain. In plant-biotechnology research, the socio-economic importance of the domain increased exponentially during the period 1984-1990 (Hodgson (1990)). In the late 1980s and early 1990s, several conferences were organized to deal with the socio-economic context of the field (e.g. OTA (1991)). In several countries, government-sponsored research programs were created in order to allocate research subsidies among several international as well as local research organisations. In addition, these programs explicitly 'forced' research organisations into 'networking' as they made funding contingent upon having partners in the domain. Thus, it became increasingly difficult to remain a social isolate in the community.

However, as this allocation is not only based on economic factors (but also on political ones), it allows for the creation of an 'inefficient niche.' However, R&D subsidies are only one possible example of imperfect market conditions. Another example are unrealistic expectations based on imperfect information. In plant-biotechnology as well as in biotechnology in general, venture capitalists have invested heavily in many research projects, the results of which will never meet expectations (see for instance, Spalding (1992)). Hence, we assume that group membership may grow as long as those imperfections persist, i.e. as long as the perceived importance of the research domain grows. Especially during the period 1984-1990, the growth of the field may be indicative of a bandwagon-phenomenon based on those imperfections. However, one might also speculate that, as local government agencies raise their quality standards for

R&D subsidies, the niche represented by group 3 may become increasingly 'un'tenable in the near future. For instance, such a trend has recently been observed in Belgium, where subsidies for biotechnology research are subject to increasing quality standards and peer review scrutiny. The consequence has been a dramatic shake-out in the number of research organisations receiving significant government support for their biotechnology research.

Finally, as these research organisations do not have a high prestige in the community (see Table 1), this further supports our previous hypothesis that the majority of the research organisations in group 3 probably survive as a result of the inefficient resource allocation at both national and regional levels.

Finally, about 80 organisations have entered group 2 and about 50 have left the group. Seven out of those 50 have exited the research domain. Six organisations have entered group 1 and only one moved from group 1 to group 2 (in 1983). No organisation in group 1 has left the field. All the domain exits in groups 1 and 2 occurred before 1984, i.e. before the groups stabilised. The relatively high mobility between groups 2 and 3 can largely be attributed to a number of organisations (about fifteen) which have moved a couple of times between both groups before stabilising. This may be partly due to computational issues, i.e. the Euclidean distance criterion of 0.10 which we have adopted as a cut-off value for determining strategic group membership. It is remarkable that no organisation which belongs to one of both groups has exited the domain after 1984. Everything points to the hypothesis that network embeddedness (because these two groups contain those organisations which are most socially embedded in the research domain) raises exit barriers (besides the fact that it increases entry barriers for new entrants). Indeed, it seems reasonable to hypothesise that organisations with high prestige in the domain will face more difficulties to leave the domain than a relatively unknown one (see also Table 1).

Conclusions and policy implications

In this paper, we have used bibliographic data sources to examine clustering in what Antonelli (1995) would call technology networks or clubs. As has been shown, this type of data allows for a truly longitudinal study of the structural dynamics of technological communities. Still more interesting, certain bibliographic databases (most notably the ones developed by the Institute for Scientific Information in Philadelphia) allow for a detailed sociometric analysis of the evolving network structure in a technological community. This is because the databases include detailed and reliable information on the affiliations of the co-authors on a particular paper. Using these co-authorship data, it becomes possible to map the structure of the research network over time. This then is a major strength of this sort of data. As demonstrated, this approach further allows for a detailed examination of the structural development of the field as major technical breakthroughs occur. In this respect, we also want to point to the insights to be gained from applying social network theory to the analysis of emerging technological communities. Both its theoretical foundations and its mathematical rigor will undoubtedly help to further shape our understanding on the network processes that generate new technological knowledge and, ultimately, new technology-based products.

Of course, the present analysis is restricted to one specific "technology club." However, the methodology could be stretched to include other Antonelli cluster types as well. For instance, using survey data, one can start mapping networks in less technology intensive areas (Debackere, 1997; Debackere and Vermeulen, 1997). This effort has now been done for the New Materials Program in Flanders, for example (Lambrechts and Debackere, 1997).

To conclude, the present review suggests that: (1) there is a need to define and operationalize an appropriate cluster taxonomy; (2) cluster-based policies can benefit from network methods and their associated operationalization techniques; (3) those networks and clusters are a dynamic phenomenon, i.e. they are a matter of becoming rather than being, and (4) managing trust and expectations among network/cluster partners may be a crucial prerequisite to achieve more "stable" network forms and hence, clusters. These suggestions obviously have important implications for government cluster policies. Albeit because they highlight the evolutionary nature of cluster-formation.

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FIGURE 1: HYPOTHETICAL SETS OF STRUCTURAL EQUIVALENT POSITIONS

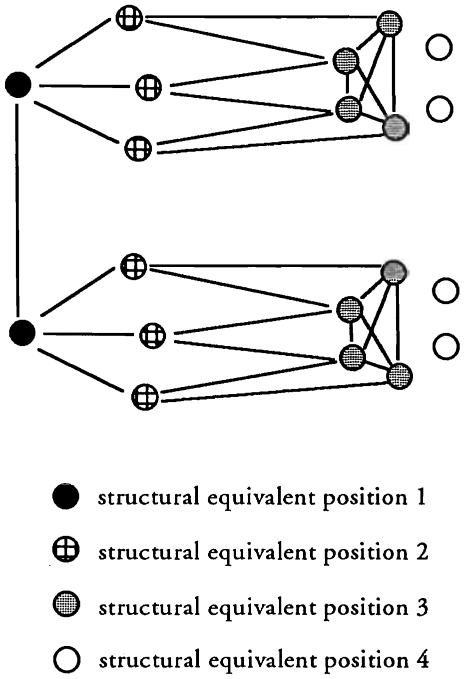


FIGURE 2: GROWTH OF THE TRANSGENE PLANT COMMUNITY, 1974-1992

[Dashed extrapolation is based on exits as they occurred in 1988-1989. It corrects for the censor effect]

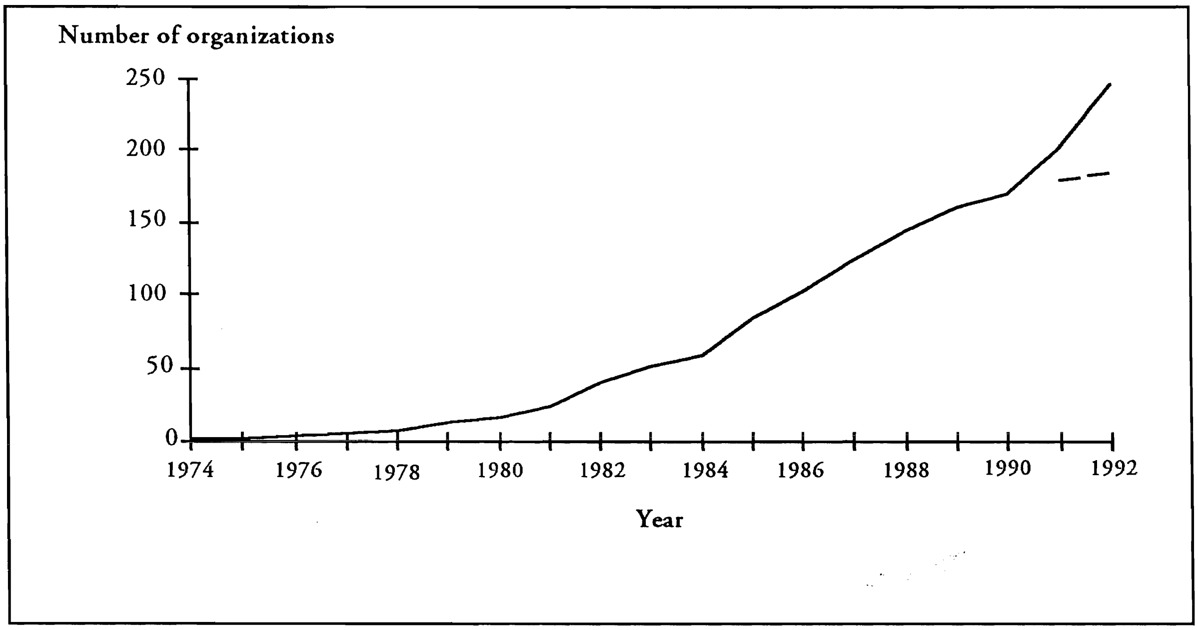
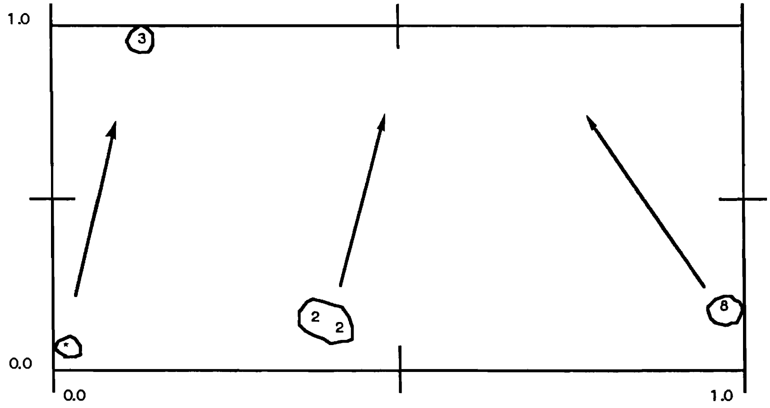
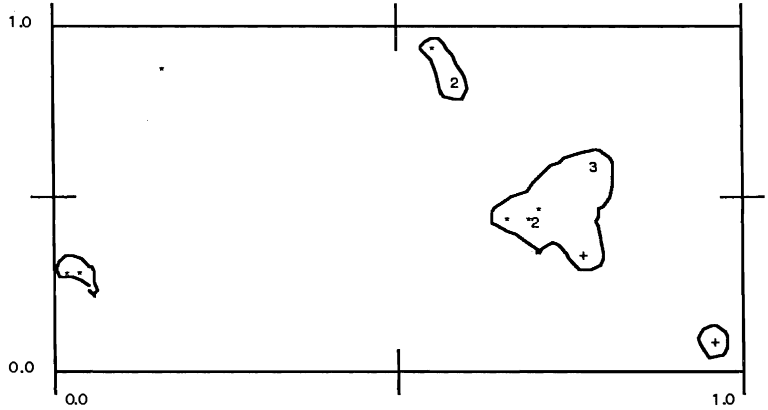


FIGURE 3: STRUCTURAL EQUIVALENCE MAPS (YEARS: 1980-1984-1992)

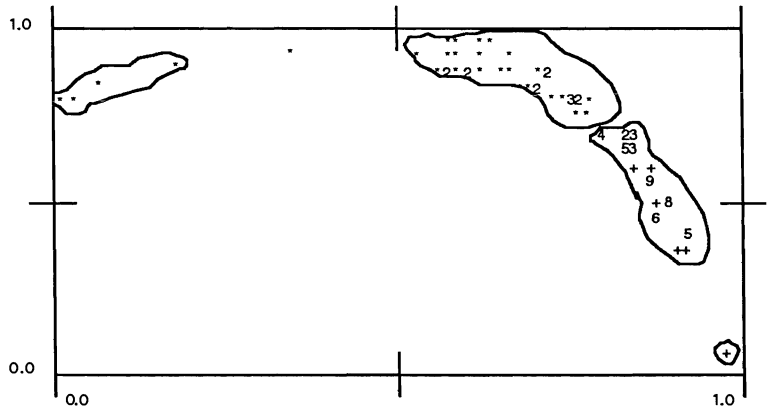
Year: 1980
Number of organizations: 16
Cumulative number of publications: 14
Number of cooperations: 4



Year: 1984
Number of organizations: 59
Cumulative number of publications: 68
Number of cooperations: 21



Year: 1992
Number of organizations: 247
Cumulative number of publications: 1181
Number of Cooperations: 265



Legend:

** one organization occupies this position*
2-9 the number of organizations registered on this position
+ more than 9 organizations jointly occupy this position

FIGURE 4: ENTRY, EXIT AND MOBILITY IN THE TRANSGENE PLANT COMMUNITY

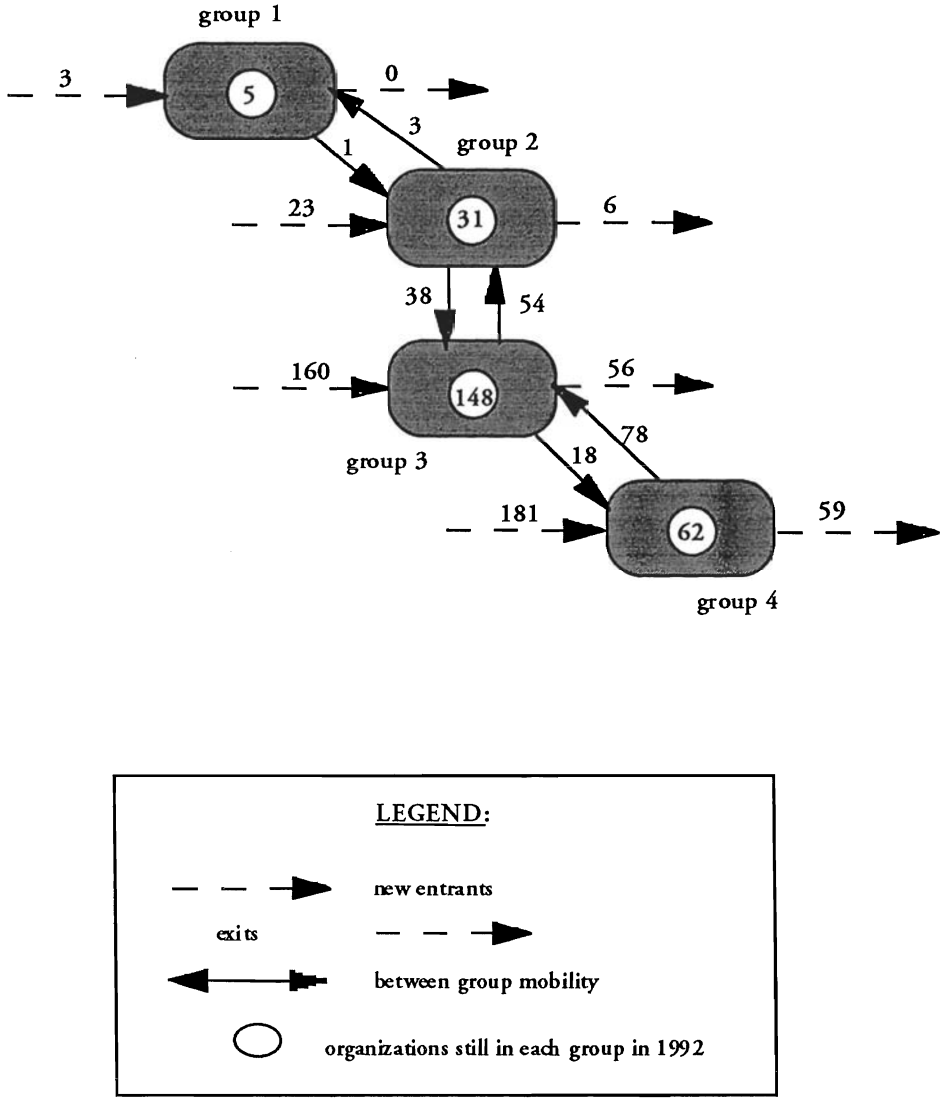


FIGURE 5: NUMBER OF ORGANISATIONS IN EACH STRATEGIC GROUP

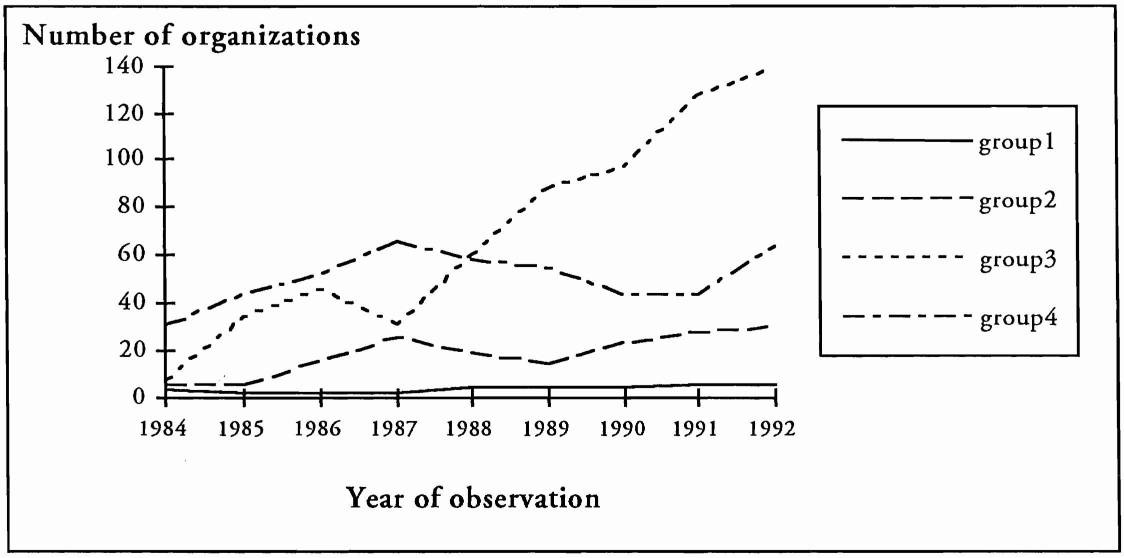


TABLE 1: DESCRIPTIVE STATISTICS FOR DIFFERENT STRUCTURAL EQUIVALENCE GROUPS (AS OF 1992)

	GROUP 1	GROUP 2	GROUP 3	GROUP 4
Number of organisations:	**5**	**31**	**148**	**62**
-universities	2	16	90	42
-government-sponsored	1	10	36	14
-large established firms	1	2	12	2
-new biotechnology firms	1	3	10	4
Number of collaborations:	**90**	**165**	**283**	**0**
-% government-industry	2.6%	9.6%	7.4%	—
-% university-government	30.8%	*40.1%*	34.4%	—
-% university-industry	*48.7%*	19.8%	16.9%	—
-%new biotech firm-large firm	2.6%	1.2%	1.4%	—
-% within same sector	15.4%	29.3%	*39.9%*	—
-% group1-2	27.8%	15.5%	0%	—
-% group1-3	22.2%	0%	7.1%	—
-% group2-3	0%	*56.0%*	31.4%	—
-% within group	*50.0%*	28.5%	*61.5%*	—
Number of patent applications	**30**	**32**	**68**	**6**
-average per applicant	6	3.2	2.7	1.2
Average cumulative number of researchers	**69**	**22**	**11**	**5**
Average cumulative number of publications	**47**	**12**	**5**	**2**
Average prestige position	**0.751**	**0.242**	**0.140**	—