The Institutional Embeddedness of High-Tech Regions: Relational Foundations of the Boston Biotechnology Community

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Introduction

The biotechnology industry exemplifies many of the key features of science-based clusters. Biotechnology firms in both the U.S. and Europe are located in a small number of geographic regions. Within these clusters, there are extensive relations between firms and public research organizations, including universities, government laboratories, and research hospitals. In the United States, the strength and robustness of the three leading biotechnology clusters - - the San Francisco Bay Area, the Boston Metropolitan area, and San Diego County - - stem from the joint contributions of both public and private organizations to scientific and technical advance (Owen-Smith et al, 2002). The combination of dense social networks and geographic co-location has been critical to the genesis of these high-tech regions (Bunker Whittington et al, 2004).

Research in both economics and sociology has made notable strides in accounting for the factors that generate regional advantage. A rich literature has chronicled the tendency for the research and development efforts of organizations to leak out and aid the innovation efforts of other organizations (Jaffe, 1986, 1989). Such spillover effects occur broadly across industries (Jaffe et al, 2000), but are accelerated within regions (Jaffe et al 1993). These effects are further amplified when key participants in a region are public research organizations, committed to norms of open science and information disclosure (Dasgupta and David, 1994; Owen-Smith and Powell, 2004). Studies of regional advantage have also emphasized the myriad dense connections that knit together high-tech clusters (Saxenian, 1994; Kenney, 2000). The effects of propinquity are further increased when strategic alliances connect local participants (Almeida and Kogut, 1999).

Consequently, both Kogut (2000) and Brown and Duguid (2000) argue that in a technology cluster, the network of relationships among participants is the primary source of knowledge.

Thus, we know that the joint and contingent effects of geography and network connections are crucial to the innovative capacity of high-tech clusters. But what types of network relations are most critical? Do informal personal ties and occupational relations provide more open pathways to enhance the flow of ideas than more formal, contractual affiliations? Does the institutional form of the dominant organizations shape the organizational practices of the members of a regional community, determining the nature of spillovers? How does the overlap of multiple types of networks across a diverse array of organizations create an ecosystem, with a distinctive character and accompanying norms that define membership in this community? To address these questions, we combine four unique data sets that account, in various ways, for the organization of the life sciences community in the greater Boston, Massachusetts metropolitan area.

Boston is home to one of the largest concentrations of dedicated biotechnology firms in the world.[1] In addition, Boston has a rich array of public research organizations, including research universities (Harvard, MIT, Tufts, etc.), research hospitals (Brigham and Women's, Massachusetts General) and medical research institutes (Dana Farber

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[1] The other significant large biotech cluster is the San Francisco Bay Area. This region has more firms in number, and some of the oldest and most established companies, such as Genentech and Chiron. The Bay Area is also more geographically dispersed, with several smaller, local clusters in Palo Alto, South San Francisco, and Emeryville in the East Bay. While larger in scale, the Bay Area is not as tightly agglomerated as Boston. Some analyses even treat the Bay Area as three separate regions, according to the major metropolitan areas of Oakland, San Francisco, and San Jose (DeVol et al, 2004), although we think this division is misleading. The most distinctive difference between Boston and the Bay Area is the notable presence of medical research institutes in Boston, and the major concentration of venture capital in the Bay Area (Owen-Smith and Powell, 2005).

Cancer Center). During the 1990s, the Boston area also developed a very active venture capital sector that funded biotech start-up firms (Powell et al, 2002). By the beginning of the 21st century, the Kendall Square neighborhood in Cambridge, Massachusetts was home to the world's largest single, geographically concentrated cluster of biotech firms. Kendall Square is also home to MIT and the Whitehead Institute for Biomedical Research, an international leader in the Human Genome Project. More recently, multinational pharmaceutical firms such as Pfizer and Novartis have moved R&D facilities to Kendall Square, as has the Los Angeles-based company Amgen, the largest biotech firm in terms of annual sales. In sum, by one accounting (Owen-Smith and Powell, 2004), the Boston region had a total of 57 independent, dedicated biotech firms, 19 public research organizations, including universities and hospitals, and 37 venture capital firms between 1988 and 1999. This diverse set of organizations was linked by a wide array of formal and informal relationships.

The Origins of Biotech in Boston. The initial burst of organizational foundings in Boston occurred in the late 1970s and early 1980s. The year 1980 is often cited as a watershed year, as a trio of events generated widespread legitimacy for biotechnology. Savvy analysts, however, argue that the acceptance that occurred in 1980 was icing on the cake because considerable university and company activity was already underway (Mowery et al, 2004). In 1980, the Supreme Court approved the patenting of genetically engineered biological material in the Diamond v. Chakrabaty case, while the U.S. Congress passed the Bayh-Dole Act, allowing U.S. universities to retain intellectual property rights to the commercial applications based on basic research funded by federal grants. In the fall of

1980, the Bay Area company Genentech had a hugely successful initial public offering. These events are regarded as a catalyst to the legitimation of biotechnology (Teitelman, 1989; Robbins-Roth, 2000).

The emergence of biotechnology in the Boston area was not a smooth process, however. Unlike in California, where biotechnology was regarded as the new alchemy, in Boston there was much more contention (Watson, 2003: Ch. 4). In the summer of 1976, the city of Cambridge, MA passed a ban on research involving DNA, based on fears that researchers would contaminate the local water supply. In early 1977, the city council overturned this ban. In the interim, however, Harvard researcher, entrepreneur, and Nobel laureate Walter Gilbert moved his work to the United Kingdom. One of Boston's most notable firms, Biogen, co-founded by Gilbert, established its legal charter in Switzerland to avoid local restrictions and controversies.

The relative absence of a venture capital community and the strong presence of public research organizations also stamped Boston in other ways. Three of the major early firms - - Biogen, Genzyme, and Genetics Institute - - had unusual developmental trajectories. Biogen soon settled in Cambridge, MA after its European legal origins. The company chose a strategy of licensing its lead development projects to large pharmaceutical companies rather than pursuing the more independent and innovative path chosen by firms founded in California. Genzyme was very much influenced by "refugees" from the health care corporation, Baxter, most notably Henri Termeer, from Baxter's blood plasma division (Robbins-Roth, 2000; Higgins, 2004). Genetics Institute (GI) followed the more upstart approach of California biotechs, attempting to develop a genetically engineered medicine that was a biotech alternative to an existing pharmaceutical product for heart attacks. GI lost out in this race to the Bay Area firm Genentech, and was subsequently acquired by the large corporation, American Home Products (Powell and Brantley, 1996). Many GI scientists, however, refused to accept their loss of autonomy, and continued to both publish and patent under the GI name. Eventually, American Home Products and Wyeth merged, and GI re-emerged as the biotech branch of Wyeth. We have documented that Boston-based biotech companies have focused more on orphan drugs and medicines for well-defined patient groups than have Bay Area biotechs, which have aimed their R&D efforts at larger markets with first-to-the-world medicines (Owen-Smith and Powell, 2005). We contend this distinction between delivering therapeutic treatments for known populations and "swinging for the fences" reflects the strong public research organization imprint in Boston and the significant venture capital influence in the Bay Area.

Tracing Technology Networks

Relations between U.S. universities and industry have a deep and long-standing history (Rosenberg and Nelson, 1994; Geiger, 1988). This "knowledge plus" orientation of American research universities has contributed to the rapid development of a number of key science and technology based industries, particularly in information and communications technologies and in the bio-medical field. University-industry interfaces may well be more extensive in the field of biotechnology than any other science or technology sector. Unlike in other technology fields, universities have continued to play a fundamental, driving role in biotech, long after initial discoveries emerged from university laboratories and were commercialized by science-based companies (Powell, 1996; Mowery et al, 2004). The array of university-industry linkages in the life sciences spans both formal connections and informal flows. A partial list includes:

- the movement of university graduates into commercial firms;
- consulting relations between faculty and companies;
- licensing of university technologies;
- industry gifts supporting university research and student training;
- faculty entrepreneurship leading to the founding of new companies;
- faculty involvement on scientific advisory boards;
- co-patenting between university and industry scientists;
- formal contractual partnerships to pursue joint R&D, product or prototype development, and clinical trials.

In detailed work on the specific area of tissue engineering, Murray (2002, 2004) has chronicled a wide range of relationships that promote knowledge transfers between university labs and biotech firms. Joint authorship, the sharing of research tools and equipment, mentoring relations, and personnel movement all contribute to the creation and maintenance of a closely-linked technological community.

Most current research on science networks focuses on just one type of relationship - - contractual ties, patent or publication citation networks, or academic entrepreneurs (Powell et al, 1996; Fleming et al, 2004; Shane, 2004). Thus, we do not know how networks are overlaid on one another, and which types of linkages are generative and which ones provide the relational glue that sustains relationships over time. In previous work, we have argued that formal contractual relationships are but “the tip of an iceberg,” and are built on prior informal relations that may stem from common graduate school training, post-doctoral experience, or professional careers (Powell et al, 1996). Murray (2004) suggests that, in addition to intellectual capital, academics who start biotech firms bring social capital through their local laboratory networks and their wider, cosmopolitan affiliations with co-authors and colleagues. In his research on the high-tech sector in Boston in the early 1990s, Gulati (1995) also found that business relations commonly grew from prior friendship ties. There are, however, other forms of affiliation than friendship or business; moreover, relations that begin as formal partnerships can become cemented through friendship, just as friends may become business partners. A full understanding of the development of a regional economy or an industrial district requires insight into how multiple networks stitch together a community, generating multiple independent pathways through which ideas, people, and resources can travel. In short, we argue that the intersection of multiple networks - - precisely what Granovetter (1985) termed embeddedness - - is the wellspring of successful technology clusters.

Collecting data on multiple networks, however, is a daunting task. And discerning the extent to which one type of association is either related to, or amplifies, another type of affiliation is even more challenging. We attempt this task here in order to explore the relational foundations of the Boston biotechnology cluster. We begin with formal linkages as a starting point, using a data set on contractual ties as a basis on which to identify organizational founders, members of scientific advisory boards, and inventor networks. Our goal is to discern how the overlap of these four different networks - - alliances, founding teams, science boards, and inventors - - constitutes the nexus of a community of practice in the Boston region.

Alliances. We begin with a database that covers the formal contractual ties involving 482 dedicated biotechnology firms (DBFs) over the period 1988-1999 (Powell et al, 1996; Powell et al, 2005).[2] The data on biotech firms, their partners, and the associated inter-organizational relations among them were drawn from *Bioscan*, an industry source published six times a year. The organizational data include firm age, size, public status, and (when applicable) reasons for exit. Tie data allow us to calculate measures of network experience, diversity, and centrality, as well as to classify individual linkages by the type of business activity they entail. These linkages represent annual snapshots of the formal network that constitutes the 'locus of innovation' in biotechnology. We extract from this global network the 114 organizations located in Boston, and the alliances among them (Owen-Smith and Powell, 2004).

Founding teams. This group of 114 Boston-based organizations, along with their collaborators, serves as the foundation for three complementary, more relational data sets that capture different kinds of collaborations. The first is a detailed database on organizational foundings. We were able to obtain complete information on the founders for 52 of the 57 dedicated human biotech firms established in the Boston area. Founders were identified on a company's web site, designated as such in press releases, or reported in a firm's filing with the Securities and Exchange Commission (SEC). There are 131 individuals involved in creating biotech companies over the period 1980 to 1997. Fifty

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[2] We define a dedicated biotech firm as an independently held, profit-seeking entity involved in human therapeutic or diagnostic applications of biotechnology.

four percent of the founders are from local Boston organizations.[3] The average number of founders per DBF is 2.5, although 13 companies have only one founder. More than half (52%) are faculty from universities, and the large majority (48 out of 67) are from Boston-area universities. Interestingly, nearly all university-based founders retain some form of affiliation with their universities. For example, none of the six scientists who came together to start Biogen left their primary jobs. Other founders come from a business background, typically as a pharmaceutical executive (15%) or a venture capitalist (12%). Another group comes from a scientific background, either as a post-doctoral fellow or a scientist at an established company (17%). A small number (4%) are serial entrepreneurs who have started more than one company, and have both prior science and business experience. Only 34% of the founders work full time for the biotech start-up, the others hold a part-time affiliation and retain their affiliation with their 'home' organization. Unlike the contractual linkages, which we restrict to Boston because of their large number, we include both founders and scientific advisory board members whose affiliations are from within as well as outside the Boston area.

Scientific Advisory Boards. We supplement the founders' database with information on the scientific advisory boards (SABs) established by these companies. Firms create science advisory boards in order to access cutting-edge research, evaluate the clinical development prospects for research that is underway, create linkages to practitioner and patient communities, as well as consolidate on-going relations with prestigious research scientists (Audretsh and Stephan, 1996). We have information on the advisory boards of

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[3] By contrast, the Bay Area is much more a magnet for outsiders to start companies, as well as open to less veteran entrepreneurs (Porter, 2004).

45 of the 57 Boston biotech firms.[4] The average size of a scientific advisory board is 8.8, with variation ranging from a low of two to a high of 26. In total, there are 366 scientists on the advisory boards, with approximately one-third from Boston-area institutions. Of the 366 individuals on SABs, 319 sit on only one Boston DBF, 37 on two boards, nine serve on three, and one scientist is a member of four Boston-based SABs. Among these board members, 47 are also founders of Boston-area DBFs.[5]

Inventor Networks. To capture less formal linkages, we turn to data on research collaborations. We collect data on co-assigned patents by inventors at both dedicated biotech firms and research universities in the greater Boston area.[6] Our focus is only on those patents that are assigned to more than one inventor. These represent, we think, interesting examples of scientific collaborations that allow us to understand the impact of research on the development of a biotech cluster. The co-inventor science network also highlights the critical role played by founders, scientific advisory board members, and scientists that move between universities and companies.

The patent data consist of inventor-level information from United States patents filed between 1976 and 1998 from universities and DBFs in the Boston region. The academic sample includes all “Research One” universities in the Boston region (Harvard, Tufts, Boston University, and MIT).[7] To gain information on the individuals involved with each patent, the patent numbers were obtained by matching Boston area DBF and

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[4] The remaining 12 firms either do not have SABs or information about them is unavailable. Murray (2004) reports that 83% of the firms in her sample of 12 biotech companies have scientific advisory boards.

[5] Note that we count only Boston SABs and Boston founders. Some of these individuals also serve on SABs of firms in other regions, and several have been founders of DBFs outside of Boston.

[6] At present, we lack the complete data to include patent activity by research hospitals.

[7] “Research one” is a designation of research intensity that was previously applied to U.S. universities by the Carnegie Foundation. In order to qualify as a research one institution, a campus had to receive at least $40 million per year in federal R&D funding, while granting at least 50 PhD degrees.

university names with patent assignees from the United States Patent and Trademark Office database. Patent numbers for these organizations were then matched with the NBER inventor data obtained from the United States Patent and Trademark Office (Hall, Jaffe, and Trajtenberg, 2001).[8]

Multiple inventions by the same person require the confirmation of similar names. Inventions are considered to be from the same person when two inventors match in first, middle, and last name (or part thereof, in the case of missing middle or first names). Importantly, however, two names are only considered a match if they have similar first, middle and last names and a similar city and state, assignee name, or the same primary and secondary technology class. We also locate Boston biotechnology founders and their scientific advisory board members in the inventor network. Of the 131 founders and the 366 scientific advisory board members, 67 (51%) and 67 (18%) have been granted patents that were assigned to Boston universities and DBFs.

The data for this analysis represent actor-by-actor networks, derived from two-mode affiliation data, where the inventors are the actors and each patent is the event. In this way, a connection between inventors is assumed on the basis of their collaborative research activity. Most patents represent a costly and time-consuming process of collaboration between two or more inventors. The lengthy two plus year timeline between a filed and issued patent, and the considerable cost in filing, render patents a less common form of dissemination, compared to publishing or conference presentations. As such, co-patenting represents a strong partnership linking scientific research with commercial application.

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[8] The NBER inventor data contains lists of inventors sorted by patent number, making it useful to quickly gather inventor names from patent numbers obtained elsewhere.

We focus our analysis of the patent collaboration network on the largest, weakly connected component in a network (White and Harary, 2001; Moody and White, 2003). This structure, the 'main component,' represents the greatest concentration of co-inventors, and the largest hub of patenting collaboration in the Boston region.[9] Of the 57 firms in our Boston sample, just 14 appear in the main component at least once between 1976 and 1998. Three universities - - Harvard, MIT and Boston University - - also appear in the main component. Between 1976 and 1998, there are 907 inventors who have been assigned 896 patents in the Boston main component: 67% (N = 610) of the inventors are assigned to patents from a university, and 29% (N=266) are from patents granted to biotechnology firms, and 4% are to scientists who patent with both firms and universities. Of the 67 founders and 67 advisors who have patents, 15 and 13, respectively, are located in the main component.

Visualizations of the Networks

We turn now to graphical representations of the four network databases we have assembled.[10] Our aim is to provide "maps," or visual images of the networks at key points in their emergence and evolution.[11] We draw inferences from the representations

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[9] To non-network analysis readers, consider that you are trying to connect a series of dots. The main component represents the dots that can be linked without ever lifting a pen.

[10] We use Pajek, a freeware program developed by Vladimir Batagelj and Andrej Mrvar, to develop meaningful and replicable visual representations of these two networks. Pajek implements two minimun-energy, or spring-embedded, network drawing algorithms based on graph theoretic conceptions of distance and the physical theory of random fields. We draw on one or both of these two algorithms (Kamada and Kawai (KK) 1989; Fruchterman and Reingold (FR) 1991) to create images that position nodes by appeal to the overall pattern of connections in the network. These images locate isolates on the periphery of the image while situating more connected nodes centrally. Figures 1-8 are optimized with FR alone, while the density of Figures 9 and 10 is aided by an optimization using FR followed by KK. For more information on the algorithms or their use for visualization, see Owen-Smith et. al. 2002; Powell, et al 2005, and http://vlado.fmf.uni-lj.si/pub/networks/pajek.

[11] To ease the viewing of our network graphics, we shorten or abbreviate names of key institutions whenever possible. The Appendix provides a code to convert abbreviations into full names.

of each data set, and then culminate by locating the firms and universities, company founders, and scientific advisory board members in the co-patent network. Recall that our goal is to understand how multiple networks overlap, as well as to explicate the intersection of university and commercial science. We believe this embeddedness is crucial to the development and growth of successful high-tech clusters. For readers who are unfamiliar with network visualizations, allow us to suggest how the pictures should be viewed. The software we employ, Pajek, utilizes algorithms that represent centrality in a network of affiliations. The nodes are the actors - - be they individuals or organizations - - and the lines are forms of affiliation - - contractual linkages, founding teams, advisory boards, and co-patenting. With this program, nodes repel one another and lines pull nodes together. Thus, our representations are stable configurations that reflect a local equilibrium - - the overall pattern and density of affiliations as the field is captured at rest. Hence, the visualizations are referred to as minimum-energy drawings. These representations create real clusters of tightly connected participants, which are central to the formation and durability of the overall network. As an illustration, Harvard scientists sit on numerous scientific advisory boards. Because of these connections, Harvard is centrally located in the advisory board network. A line, or edge, links the Harvard node with each of the DBF nodes. The more Harvard faculty that sit on the board of a particular DBF, the shorter the line connecting Harvard and that DBF. We use the visualizations to discern which individuals and organizations provide the foundation of the network, and which function as its backbone over time.

The Boston Contractual Network. We begin with formal linkages among organizations in the Boston area, conceiving of these connections as one indicator of membership in a regional community. We have shown in previous work that both membership and position in the local network have a significant effect on the volume of patenting by biotech firms (Owen-Smith and Powell, 2004; Bunker Whittington et al, 2004). Figure 1 presents a series of images of the Boston network in 1988. The shape of nodes in the network represents organizational type -- triangles represent public research organizations (PROs), circles indicate DBFs, and squares reflect the position of venture capital (VC) firms. No pharmaceutical companies are headquartered in Boston during this time period.

[Figure 1 here]

Note several interesting features of Figure 1. First, consider the Boston network at the upper left. In 1988 this network is relatively sparse with the bulk of organizations isolated from the network of formal relationships. The ties that do exist, though, form a dominant main network component.[12] More interestingly, note the critical role that PROs (triangles) play in connecting the main component of the network and the relative absence of VC firms (there are few squares and only one is connected even peripherally to the main network corridor). Six public research organizations (MIT, Boston University, Tufts, Harvard, the Dana Farber Cancer Center, Massachusetts General Hospital, and the New England Medical Center) are centrally positioned; they are among the most connected organizations. Four circles, or biotech firms are also well connected.

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[12] In every year for which we have data, the Boston network is characterized by a main component, which should be regarded as the largest, coherent, minimally connected network structure. In graph theoretic terms, the main component is the largest group of organizations reachable through indirect paths of finite length. Thus, a tie to the main component represents the minimum level of connectivity necessary to enable an organization to access information through the largest portion of the network.

These are the companies Biogen, Genetics Institute, Genzyme and Seragen. But overall, in 1988, the Boston biotechnology community is rather sparsely connected internally by formal collaborations. While the network contains nearly 43% of active Boston-area DBFs, the main component is heavily dependent for its cohesiveness upon key public research organizations. Removing these organizations from the network results in the complete collapse of the main component. Put differently, the formal, contractual network dissembles without universities and research hospitals. Figure 1 suggests that, early in its development, the Boston biotechnology community was weakly linked with less than half of all local DBFs reachable through formal network channels. The early coherence of this regional network is dependent upon the very active engagement of local public research organizations.

As a point of comparison, Figure 2 reprises Figure 1 to present the Boston network in 1998. By then, more than 71% of Boston DBFs were connected to the main component. More importantly, the network itself has undergone a marked change as local biotech firms began working directly with one another, rather than forming indirect ‘chains’ through shared ties to PROs. Local VC firms are also much more engaged; their presence is apparent in the portion of the corridor to the right of MIT. PROs (particularly MIT, BU, Harvard, and Brigham and Women’s Hospital) still play an important role in 1998, but their dominance is declining, as evidenced by the image of the component with PROs removed.

[Figure 2 here]

Specifically, consider the final frame of Figure 2, which illustrates that nearly 36% of Boston DBFs remain connected in a component that does not rely on public organizations. Indeed, the growth of biotech-to-biotech ties and the increasing support of local VCs suggest that Boston has undergone a transition from its early dependence upon PROs to a more market-oriented regime where small science-based firms and venture capital play key connective roles.

In related work (Owen-Smith and Powell, 2004), we have shown that the Boston biotech community changed in another key respect as well. The network of contractual affiliations also spread out over the 1990s, with alliances to organizations outside Boston growing rapidly in number and density. This growing reach is accompanied by a similar shift from PRO dominance to commercial leadership. This expansion notwithstanding, the Boston biotech community was clearly anchored by universities and research institutes. These early institutional underpinnings came from organizations with a strong commitment to the norms of open science, where practices of publishing and wide dissemination of research results are paramount (Dasgupta and David, 1987, 1994; Powell, 1996). Interestingly, then, the rapid emergence of commercial biotechnology in Boston owes a considerable debt to public science. We turn now to three other sets of relations in order to more fully examine the Boston community.

The Structure of Founding Teams. We have collected data on the founders of biotechnology firms in Boston, tracing their biographies back to their undergraduate training (Porter, 2004). These career history data allow us to construct a founder affiliation network[13], in which we link the newly founded firm with the organization that

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[13] In using the terminology "affiliation network", we do not refer to the traditional network methodology term, which implies a two-mode actor-by-affiliation network. Rather, we refer literally to linkages that exist between organizations based on their founders' prior and current affiliations. For example, a link exists between Biogen and Harvard because of founder Walter Gilbert's involvement with both

a founder belongs to either concurrently with or immediately prior to the creation of the biotech company. [14] A new biotech company typically requires some combination of scientific competence in the life sciences, some business experience in either the pharmaceutical industry or high-tech fields, and venture capital involvement (Porter, 2004).

Figure 3 presents an early picture of the founder affiliation network in 1983. Circles represent DBFs, triangles are PROs, and squares are venture capital, pharmaceutical, or biomedical companies. This visualization shows six hubs, representing the founding teams of Biogen, Advanced Magnetics, Integrated Genetics, Creative Biomolecules, Genzyme, and T Cell Science. These groups would be unconnected were it not for MIT which connects to Integrated Genetics, Genzyme, and Biogen, where Nobel Laureate and MIT faculty member Phillip Sharp was a co-founder. These three firms, along with Repligen and Applied Biotechnology, have one or more MIT faculty members on their founding team.

[Figure 3 here]

Figure 4 portrays the Boston sector a decade and a half later, in 1997. We see Millennium, the genomics company, Cubist, Argule, Mitotix, and CpG ImmunoPharma as key new entrants to the network. Again, MIT is an important bridge, linking Cubist, Millennium, and Genetix. Harvard appears as another major bridge, also connecting Millennium, Genetix, BLSI, and Leukosite.

[Figure 4 here]

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organizations. Thus, the founder networks (and those of the scientific advisory board, presented next) can be conceptualized as affiliation-by-affiliation networks.

[14] The network includes the formal affiliations of founders to other organizations in the five-year period leading up to and including the founding year. These affiliations remain in the dataset for a period of five years from the firm's date of founding.

Figure 5 depicts the founder network for all years - - 1976 to 2003. Because this visualization is incredibly dense and crowded when we include all relationships, we display the network with only those organizations that have two or more founder linkages. In this summary figure, the centrality of both MIT and Harvard is readily apparent, as these are the two most extensively linked organizations. Slightly more than one-quarter (26%) of biotech firms in Boston were founded exclusively by faculty from Harvard or MIT.

[Figure 5 here]

These figures highlight how the backgrounds of founders of Boston companies have shifted over time. This transition is reflected in the changes in both the shape and position of the nodes in Figures 3 and 4. Note in Figure 3 the important role played by VCs in establishing firms. In the early 1980s, about 30% of the startups had a venture capitalist on the founding team. By 1997, the role of VCs decreased and the importance of founders with prior experience in biotechnology rose. Thus, VCs returned to the more standard job of investor and biotech veterans provided the business expertise. Thus, throughout the 1980s and 1990s, Harvard and MIT remained the key source of scientific ideas, while those providing business acumen shifted from venture capital to biotech executives.

The Scope of Scientific Advisory Boards. We have collected data on the scientific advisory boards for as many Boston-area firms as are available through public sources. Membership on these boards changes over time, as the composition shifts to reflect new areas of research by a growing firm, as well as the movement of research into clinical development and eventual product launch. In contrast to the group of founders, there is a much more pronounced presence of physicians on SABs.[15] Given turnover on SABs, and variation in the pace of foundings of new companies across time, we had to make choices about how to represent the network linkages that are created through scientific board membership. Obviously, different representations are possible. We selected three 'snapshots' for this set of affiliations. We chose 1984 to represent an early period in the development of Boston biotech, 1997 as a portrait of a more developed stage, and a representation across all years (1978-2003) that includes only those organizations with three or more advisory board member connections.[16] These graphics serve as compliments to the pictures of the founding team networks.

We conceptualize the SAB affiliation network as an organization to organization tie; thus, a professor at Harvard who sits on the board of Millennium creates a Harvard-Millennium affiliation. On average, a DBF's scientific advisory board reaches 11 different organizations. Because the focus is on a company's board, the representations will have some of the appearance of a hub and spoke figure, with DBFs at the center. In the early years of biotech in Boston, Figure 6 portrays several pioneering firms - - Biogen, Creative Biomolecules, Sepracor, and Endogen, as well-connected hubs. Note, however, that the most centrally linked organizations in 1984 are Harvard, Tufts, and MIT. Again, we see the central, generative role of public research organizations.

[Figure 6 here]

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[15] Some founders and advisory board members have multiple degrees and have founded or served with more than one company. Hence, counting degrees is somewhat tricky. Nevertheless, among the founders there are 82 PhDs and 31 MDs, while advisors have been awarded 245 PhDs and 174 MDs.

[16] Because the scientific advisory board affiliation network is considerably denser than the founder affiliation network (due to the large number of board members), we display the SAB all-years graph with *three* or more linkages as compared with the all-years founder network that draws from *two* or more.

Biogen reached out widely for its scientific advisors, drawing on scientists from Scotland, Belgium, Sweden, Germany, and Switzerland, as well as Wisconsin and MIT. Endogen has advisors from Harvard, Tufts, and several Boston hospitals and institutes, as well as Stanford. In contrast, Creative Biomolecules drew from throughout the United States, including Tulane, Miami, Connecticut, but added advisors from Tufts and Harvard. Sepracor, Integrated Genetics, and Advanced Magnetics all have advisors from both Harvard and MIT. Only one firm, Cambridge Medical, is isolated from the main component; it draws its advisors from a set of organizations markedly different than other Boston DBFs.

Fast forward to 1997, depicted in Figure 7. This dense network displays a new generation of Boston companies, including Millennium, with a quite large board, Ariad, Interneuron, and Hybridon. Note the number of triangles (PROs) at the center of the network; these firms provide the most scientists and physicians to serve on SABs. Once again, Harvard and MIT are at the very middle, joined by Massachusetts General Hospital (MGH), and the Dana Farber Cancer Center nearby. A handful of other public research organizations from Boston, including Tufts University, the Whitehead Institute, and Boston's Children's Hospital, and New York City, specifically Memorial Sloan Kettering hospital (MSK), Mt. Sinai Hospital (MSH), and Rockefeller University, are also densely connected. Thus, while Boston PROs remain central, by 1997 an elite group of New York City PROs are contributing advisory board members to Boston DBFs.

[Figure 7 here]

Figure 8 is the summary representation of advisory boards from 1976-2003, for organizations with three or more linkages. There is a notable absence of any square-shaped nodes in the figure, which points to the lack of involvement of scientists or executives from pharmaceutical companies on DBF boards. Repeated contacts on scientific advisory boards occur only between PROs and DBFs. Not surprisingly, Harvard is the most central organization in this network, providing the most SAB members. MIT, Massachusetts General Hospital (MGH), and Dana Farber are also very active. Boston DBFs avail themselves of the deep knowledge in local PROs, and venture outside the region rather infrequently.

[Figure 8 here]

The Inventor Network. The founders of biotech firms, the scientific advisory board members of these companies, and research scientists in Boston area universities and firms are all actively engaged in a variety of on-going collaborations and forms of interaction.[17] To drill deeper into the underlying scientific structure of the Boston region, we examine the patent co-inventor network, to discern linkages among Boston scientists in both universities and firms.

Once again, we focus our analysis of this collaborative network on the main component, where patenting collaboration is most concentrated. Figure 9 is a visualization of the co-patenting network, with 907 inventors. A white circle is a university inventor and a gray circle an inventor at a DBF. There are 599 inventors from universities, 257 from DBFs, and a select group of 23 who have patents assigned to both Boston universities and DBFs. To help locate these few individuals, they are represented by squares. Not surprisingly, these scientists play important bridging roles, connecting the academic and commercial communities, and facilitating the flow of ideas and

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[17] For example, in addition to the relationships we have analyzed here, company board of director linkages, shared experiences as postdoctoral fellows in specific labs, or common mentor-mentee relations also provide avenues for the flow of ideas and resources.

resources from the university lab to commercial development. These scientists are translators in a dual sense - - they are familiar with the mores of both university science and science-based companies, and their research translates from the laboratory bench to clinical treatment.

We also highlight two smaller groups in this co-inventor network. There are fifteen founders of Boston DBFs who have been granted U.S. patents and are located in this main component. Thirteen scientific advisory board members also appear in the main component. In percentage terms, these individuals are quite rare, comprising 1.7% and 1.4% of the main component population, respectively. We label founders with triangles, and SAB members with diamonds. While these individuals are few in number, their critical role as connectors that stitch together the overall scientific network is readily apparent in Figure 9.

[Figure 9 here]

Figure 9 has an expansive center, or pump, that appears to 'supply' the overall network. At the very center of the map is a square, Prof. Robert Langer of MIT, who is the most active co-patentor in our network with 86 co-invented patents, as well as a co-founder of a company and a member of four DBF advisory boards. The group around him is tightly bunched, like a grape cluster. His close collaborators are both university and DBF scientists, a select few scientists who have moved from MIT to companies, and a handful of advisory board members. The traffic out of this central core connects with the rest of the network. [18]

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[18] In a presentation at MIT back in 2001, Powell argued that a critical skill in biotechnology was the ability to be "multi-vocal," that is to be regarded as excellent at both science and commerce, and have one's actions interpreted accordingly by those with more specialized skills. For many companies, this is a challenging task, although those that acquire such capability reap considerable rewards (Powell et al, 2005).

Connected to the central group are five distinctive clusters, which we have labeled. To the north of the 'Langer core cluster,' is group 1, where all inventors have an affiliation with Genetics Institute, a leading Boston DBF in the 1980s that became a division of a succession of large pharmaceutical corporations in the 1990s. Clearly, one reason the large firms had strong interest in GI was its stock of patents. Group 2, the cluster to the far right of the figure, includes inventors from Genzyme, Biogen, and Harvard. This cluster reflects another early founding group, as these two firms are the most notable first-generation Boston DBFs. The small cluster 3 consists of teams of Harvard and MIT scientists. Cluster 4 is an interesting mix of biotech companies that are all tied to MIT through founders. This group of scientists comes from CytoMed, Genzyme, Integrated Genetics, T Cell Science (now Avant), Virus Research Institute, and Transkaryotic Therapies. The very large cluster 5 to the left of the figure is a university group made up of MIT scientists, save for five Boston University inventors. In contrast to the advisory board networks where Harvard faculty played such a central role, the inventor network is dominated by MIT scientists.

Figure 9 also portrays the critical role of a small number of people located in multi-vocal positions as founders, advisory board members, and patentors with both universities and DBFs. Removing the 15 DBF founders and 13 scientific advisory board members from the main component drops connections between clusters 3, 4, and 5 completely. Likewise, removing the 23 individuals who patent across university and industry lines disconnects clusters 1 and 2 from the rest and considerably breaks done the rest of the network. Without these fifty-one individuals (5.6% of the full network), the

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Fiona Murray asked if any scientists are "born multi-vocal," referring to the experience of PhDs and postdocs in a high-profile, well-connected lab such as Langer's who go from his lab to leading positions in firms. We are pleased to present research results that confirm Prof. Murray's intuition.

main component of the inventor network unravels, falling into separate strands. Unlike the previous network visualizations (done at the organizational level), which show a burgeoning field with multiple, independent pathways, Figure 9 is much less robust. The inventor network is highly dependent upon the activities of a select few scientists.[19]

We provide an alternative representation of Figure 9, rotating the flat horizontal network and presenting it vertically, with the most connected individuals at the top in Figure 10. To scale the figure, we use the conventional network measure of betweenness centrality (Freeman, 1979) and array the nodes by standard deviation.[20] Those at the bottom level represent scientists who have a betweenness centrality score that is at the mean of the group or below. Each subsequent level brings the threshold up one standard deviation of betweenness centrality. At the peak we find Prof. Langer, whose betweenness centrality is 19 standard deviations above the mean. Note how over-represented founders, advisors, and inventors who patent with universities and DBFs are in the top echelons. Between 31% and 59% of these individuals are two standard deviations above the mean in betweenness centrality, while only 9% and 10% of the DBF and university scientists are. Figure 10 emphasizes the important role these individuals play in bringing together science and commerce.

[Figure 10 here]

Comparisons Across Networks

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[19] In separate analyses, we have removed the most connected organizations from the overall founder and SAB networks, and the networks remain linked. Only the inventor network is sensitive to the removal of the most connected members.

[20] Freeman's measure of betweenness considers nodes central to the extent that they sit on indirect connections between other organizations and thus can facilitate, appropriate, or impede information and resource flows in a network.

The diverse, cross-cutting linkages that characterize the Boston biotechnology community share common topological features, while showing important differences in institutional detail. Structurally, all the network maps display similar typologies, with a relatively small number of highly connected organizations or individuals at the center, linking a diverse set of less connected organizations. All four networks - - contracts, founders, advisors, and inventors - - are anchored by public research organizations. Given that these four networks are primarily oriented for commercial purposes, the centrality of universities and hospitals is remarkable. One might argue that this involvement reflects the growing commercialization of research universities and hospitals; indeed, an active line of research and commentary makes exactly this claim (Slaughter and Leslie, 1997; Krimsky, 2003). In contrast, we stress that PROs stimulate economic growth precisely because they have largely pursued public science, generating valuable spillovers. Universities contribute most effectively to economic growth when they act like universities and enhance the stock of basic science. Too much attention to commercial prospects, policies of exclusive licensing, or unequal rewards for faculty pursuing proprietary interests make universities vulnerable to corporate capture, and in the long run, render them less consequential (Nelson, 2001; Owen-Smith and Powell, 2003).

The imprint of the different public research organizations varies in interesting ways. In the contractual network, particularly in the 1980s, research hospitals, MIT, Harvard, Tufts, and Boston University were particularly crucial. In the founder affiliation network, MIT and Harvard were the primary source of entrepreneurs. Relatively absent from this network were Tufts and Boston University, which had faculty involved in only a few foundings. On science advisory boards, Harvard was the key contributor of faculty. Research hospitals were active in this capacity as well, highlighting the role SABs play in evaluating clinical efficacy. MIT faculty were also involved, but clearly their energies are more focused on invention. The co-patenting network was dominated by MIT in two key respects, a MIT lab formed the core of the network, and MIT faculty represent more than 66% of all the inventors in the main component network.

We have presented snapshots of three of the networks at two points in time, so we can discern how the relationships evolved as the field of biotechnology matured. The contractual network underwent a dual shift. One transition was from PRO dominance to a more commercial focus, with strong influence by venture capital firms and first-generation biotechs. The second change was from a regional focus to a global focus, with many more alliances with organizations outside of Boston (Owen-Smith and Powell, 2004). The network of founders continued to be dominated by Bostonians, although Figure 4 does show that over time more founders came from outside Boston. When they do, however, they inevitably pair with local founders. Thus, the success of biotechnology in Boston has not been a lure for 'outsiders' to come start new companies there. Rather, established organizations, such as Pfizer, Novartis, and Amgen, have re-located R&D facilities there, hoping to share in, to use Marshall's (1920) felicitous phrase, "the secrets of industry that are in the air." In addition, the established firms want to draw on the rich talent pool in the Boston area, and the fluid labor markets where movement between public and private science is active.

The scientific advisory board affiliation network is, perhaps obviously, more cosmopolitan from the outset. Scientists from Europe and leading U.S. universities and medical centers are well represented, and their presence increases over time. As biotech firms develop medicines for specific therapeutic indications, it is critical for them to recruit thought leaders in that area of medicine, regardless of their physical location. Still, the advisory boards have a very strong Harvard stamp, and a lighter but notable imprint from Massachusetts General Hospital, Dana Farber, and MIT.

Our initial intuition was that the more formal ties, such as the contractual alliances and memberships on scientific advisory boards, would represent more closed relationships and thus less expansive networks. In contrast, we considered the more personal relationships, such as co-patenting among inventors, likely to be more open, given the lack of contractual obligations. Thus, we anticipated that the inventor network would have more open pathways. Interestingly, we find just the opposite results. The inventor network has a very tightly clustered topology, and the removal of a few key participants unravels the network. This type of structure reflects the fact that individual scientists have limits on the number of colleagues, post-doctoral fellows, and students they can collaborate with, and that such collaborations have a repeated games character to them, which deepens existing relations rather than extends collaborations out to new participants. The contractual and SAB networks become, over time, so expansive that their typologies are distinguished by multiple independent pathways, rendering them robust against collapse if several key participants choose to exit. The embeddings of multiple networks create a very dynamic regional economy in biotechnology, with these multiple connections providing ample opportunities for the circulation of ideas and resources.

Implications for High-Tech Regions

Thoughtful analysts of industrial clusters have stressed the extent to which every successful cluster has relatively unique features, thus generalizations across regions are difficult and usually at a very high level of abstraction. We have shown how dependent the Boston biotech community is on personal relations among research scientists, strong ongoing affiliations among universities, hospitals, and firms, and reciprocal flows of ideas and personnel. Replicating this level of connectivity in other areas would be extremely difficult, to mandate it or attempt it with policy levers would be foolish. Not surprisingly, then, biotechnology is a very agglomerated industry, with the lion's share of activity concentrated in a handful of locales.

Nevertheless, it is useful to extend beyond the Boston case and consider which institutional features are essential to the region's success and what elements are idiosyncratic to biotechnology and Boston. We take up that challenge in this section.

How Generalizable is Biotechnology? The life sciences are an unusual science-driven industry, in that basic research done at universities and DBFs continues to be critical to the field's development. Many other technology-based fields have their origins in university or corporate labs, but subsequent development is far removed from the initial discovery process. For example, Gordon Moore, a founder of Intel, argues that the early origins of the semiconductor business in Silicon Valley were not greatly influenced by scientists at Stanford, and that the development of the field owed more to a supply of skilled labor produced by other firms (Moore and Davis, 2001). Whether university science played an important role in the creation of the semiconductor industry is a debatable point, but clearly downstream development was driven by forces of demand and competition. In contrast, biotech firms compete in an environment in which product competition is less intense, product development is extremely protracted (5-10 years to 'produce' a new medicine), and the name or brand of a company has no effect whatsoever on a patient's decision to take a medicine or therapy.

Another way of capturing the institutional idiosyncracies of biotech is to consider how strongly a field like information and communication technology (ICT) is demand-driven, shaped by technological and market opportunities (Bresnahan et al, 2001). Developing new products that have strong complementarities with existing leading technologies is essential in ICT. In contrast, the focus of biotech has been to use novel science to develop first-to-the-world medicines and therapies. These new medicines seldom have any complementarities with existing drugs, and often there is no competing therapeutic regimen for the illness that biotech firms tackled. This absence of "typical" demand features was particularly notable in the early decades of the industry; today as the number of firms has grown and large multinational pharmaceutical companies have entered biotech in a significant way, there is growing competition in specific therapeutic areas. Still, a key force shaping industry evolution is the supply of scientific excellence, which is a primary reason public research organizations continue to exert such a strong influence.

Finally, biotech is unusual in that it is a field where all the relevant skills - - scientific, clinical, manufacturing, legal, financial, regulatory, sales and distribution - - are not readily assembled in a single organization (Powell and Brantley, 1992). As a consequence, organizations turn to collaborations with others in order to combine skills. Complementarities are important in biotech, but at the organizational level, rather than the product market.

Unique features of Boston. Analysts of regional advantage stress that there are relatively few common institutional conditions that typify successful clusters (Bresnahan et al, 2001). Clearly, Boston has several valuable and unique assets. The metropolitan area is home to numerous universities and colleges, and is one of the most educated areas of the United States. The Boston metropolitan area ranks fifth in the U.S. in share of the population over the age of 25 with college degrees and third in percentage with college degrees between ages of 25 and 34 (Glaeser, 2003:5). Thus, there is an abundant supply of well-educated human capital for organizations to draw on, and a rich stock of scientific knowledge generated by several of the world's leading universities.

Yet despite these knowledge assets, Boston has not always been a successful region. Indeed, the city has had to survive shifts from a maritime and fishing center in the early 19th century to a factory town in the late 19th century to a new economy center in the late 20th century.[21] Between 1920 and 1980, Boston's population declined by 25%. In 1980, Boston was a declining city in a middle-income metropolitan area located in a cold climate, with a reputation for high taxes and heavy regulation. By 2000, Boston was a center for information technology, financial services, and biotechnology, and ranked as

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[21] Here, we draw extensively on Glaeser's (2003) fascinating analysis of Boston's economic history.

the 8th richest metropolitan area (and the richest one not located in the New York City region or the Bay Area).

The series of crises and restructurings do not tell a story of constant success, however, but of one obsolescence and recovery. Common to the different eras of reinvention is the supply of skills (Glaeser, 2003). Boston is in many respects a rather insular town, with a distinctive history and accent. The cold weather, stiff taxes, and difficult driving conditions do not attract large numbers of businesses to move there. Unlike regions that have used tax incentives or public initiatives to attract high-tech companies, the Boston area “grows its own.” The attractive inputs for Boston are college students, PhD candidates, and post-doctoral fellows, drawn from all over the world. The availability of an educated work force and the supply of ideas and ingenuity have been Boston’s signature.

Organizational Diversity. A notable feature of the Boston region is the diverse set of organizations involved in the life sciences. Universities, research institutes, hospitals, and small firms combined to get the cluster started in the 70s and 80s, local venture capital was attracted to this activity in the 1990s, and major pharmaceutical concerns established footholds in the first years of the 21st century. This heterogeneity is important in that it promotes experimentation and flexibility. Without a single dominant actor, there is no fixed recipe, instead multiple bets are placed in a milieu that becomes competitive and forward-looking. We have stressed that the dense networks that connect these diverse organizations afford multiple, independent pathways through which ideas and resources can flow, facilitating research progress.

Open Science. Intense competition can lead to rivalrous, cut-throat behavior. In Boston, however, scientific competition created a virtuous cycle, rather than a vicious one, enabling researchers and clinicians to build on the accomplishments of others. The key feature of Boston is the predominance of research organizations committed to norms of open science. Research is published, debated in seminars, and applications are patented. Papers and patents are simultaneously publicly available sources of information and valuable commodities. The strong public science emphasis, even if rooted in private science commercialization efforts, allows ideas to be debated, honed, and utilized by others. Add to this mix the research and clinical focus of top-tier research hospitals and an orientation toward public health is enhanced. The Boston area has been an expansive cluster in large part due to its open science orientation.

We emphasize that the public science research community that generates knowledge and the private science commercial regime that produces new medicines are now inextrinsically linked. The intellectual capital of academic and clinical researchers made possible the commercial world of biotechnology in Boston. The vitality of both the commercial and academic communities, however, rests on the public science world remaining committed to the widest possible dissemination of research results.

The growth of biotechnology in Boston has been fueled by the multiple overlapping networks that connect universities, hospitals, and science-driven companies. This community is simultaneously collaborative and competitive. World-class science is intensely rivalrous. The great German sociologist, Max Weber, observed that science is not democratic, but rather an aristocracy of merit (Weber, 1946). The contemporary life sciences represent a new hybrid of science and commerce, in which research spillovers have fueled the emergence of a new industry. The most important lesson we take from our analysis of the Boston biotechnology community is that this productive nexus is deeply dependent upon both organizational heterogeneity and open science.

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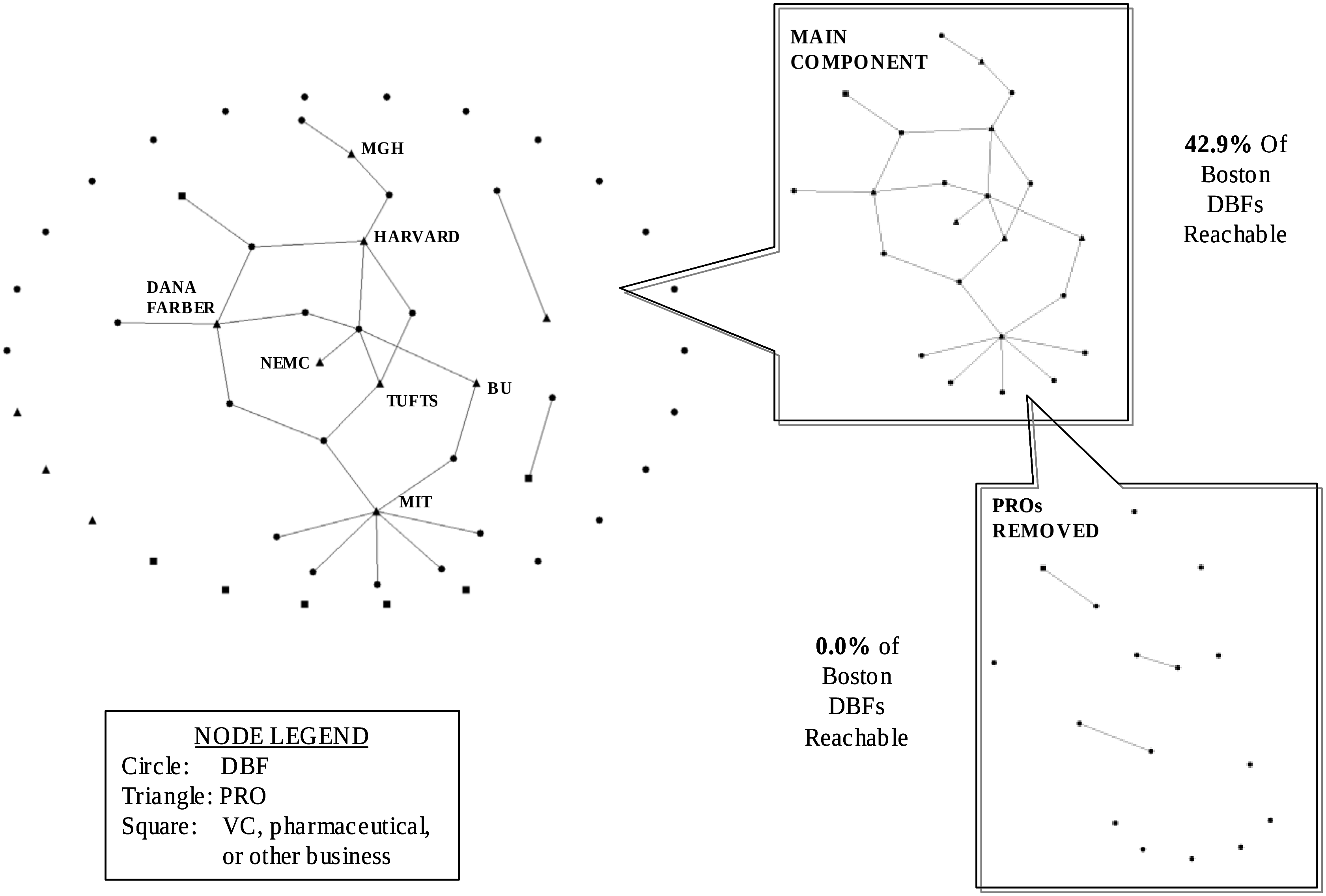
Figure 1. Boston Contractual Network, 1988



42.9% Of
Boston
DBFs
Reachable

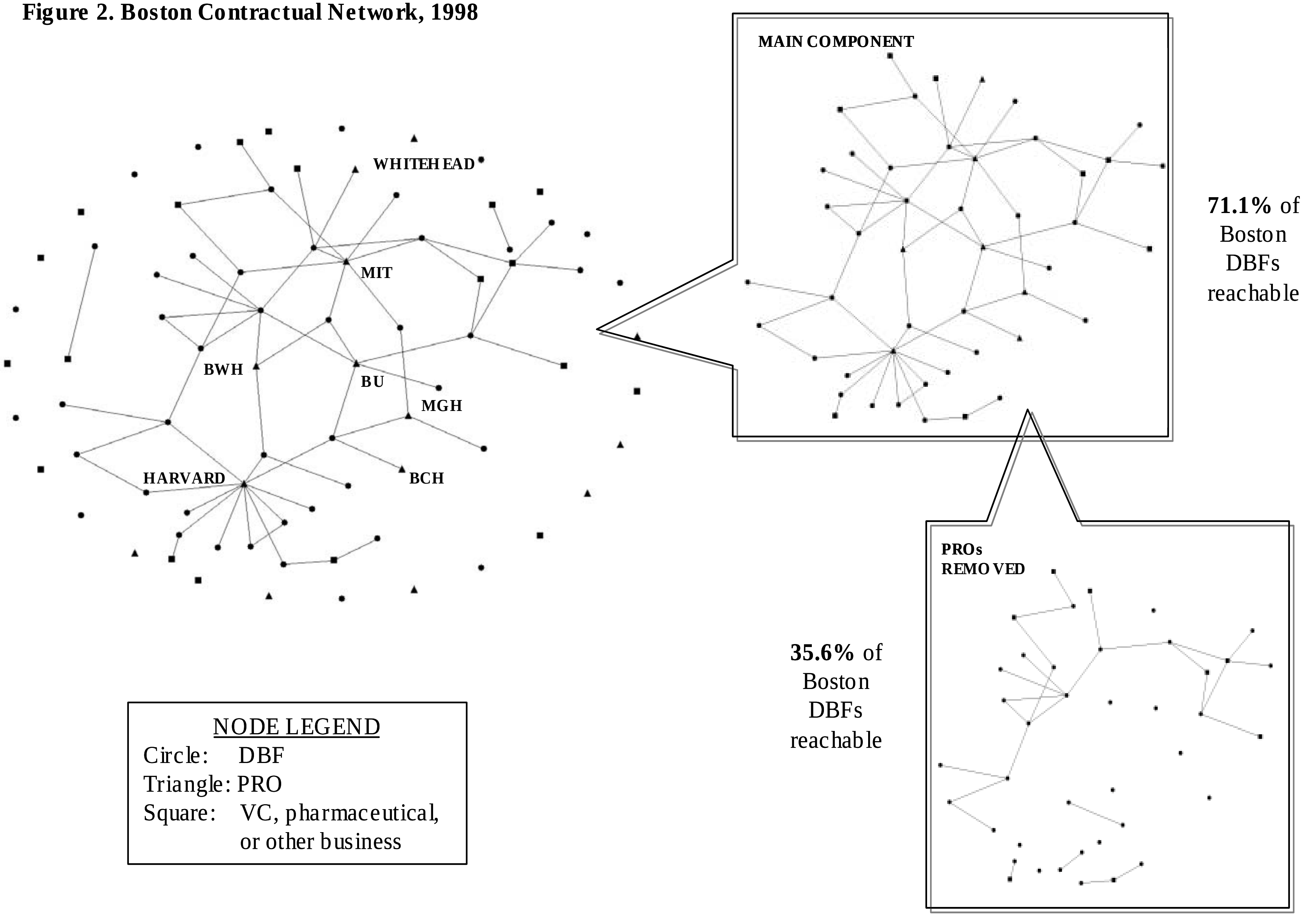
0.0% of
Boston
DBFs
Reachable

NODE LEGEND

Circle: DBF
Triangle: PRO
Square: VC, pharmaceutical, or other business

Source: Owen-Smith & Powell, 2004, p. 11

Figure 2. Boston Contractual Network, 1998



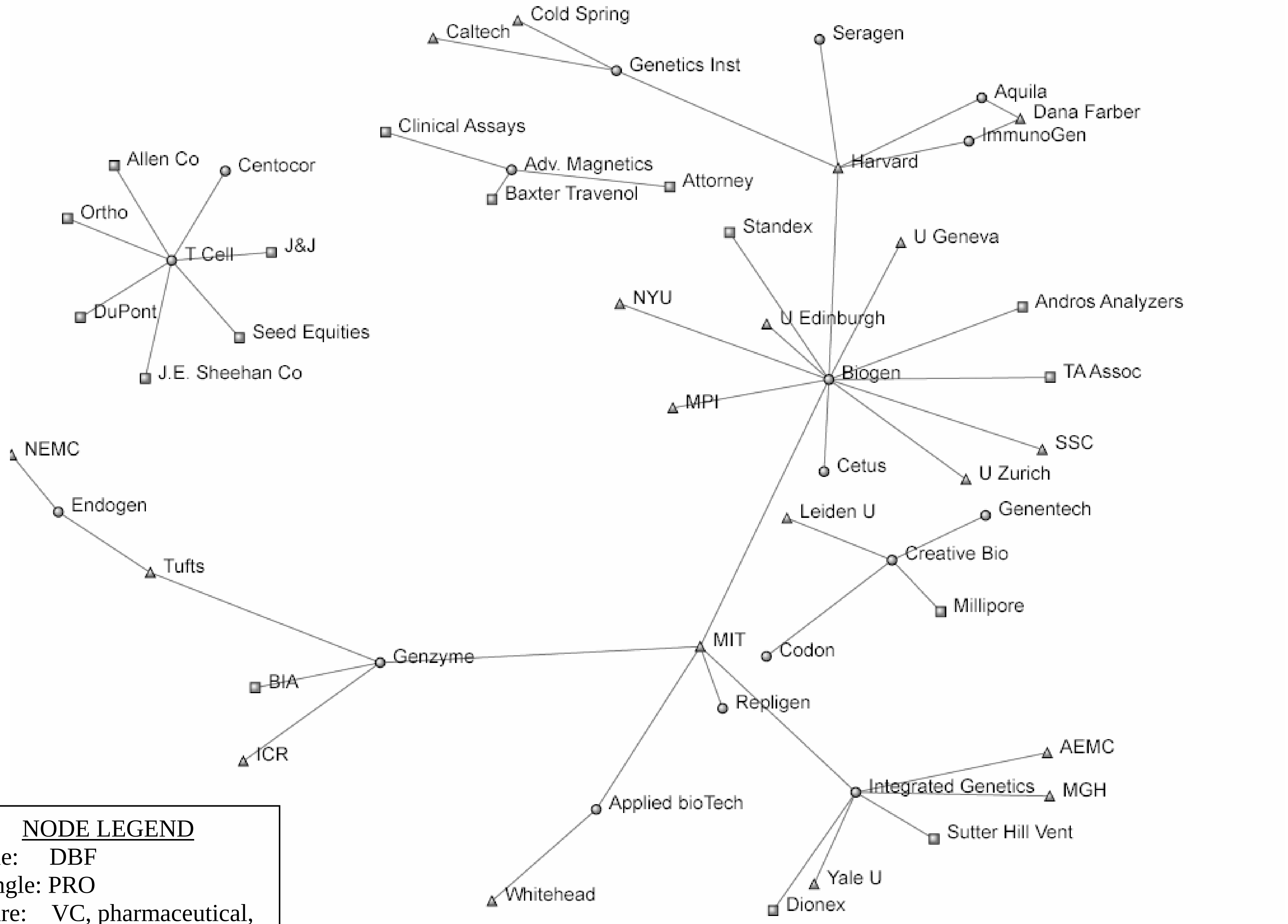
71.1% of
Boston
DBFs
reachable

35.6% of
Boston
DBFs
reachable

NODE LEGEND
Circle: DBF
Triangle: PRO
Square: VC, pharmaceutical, or other business

Source: Owen-Smith & Powell, 2004, p. 14

Figure 3. Founder Affiliation Network, 1984



NODE LEGEND

Circle: DBF
Triangle: PRO
Square: VC, pharmaceutical, or other business

Figure 4. Founder Affiliation Network, 1997

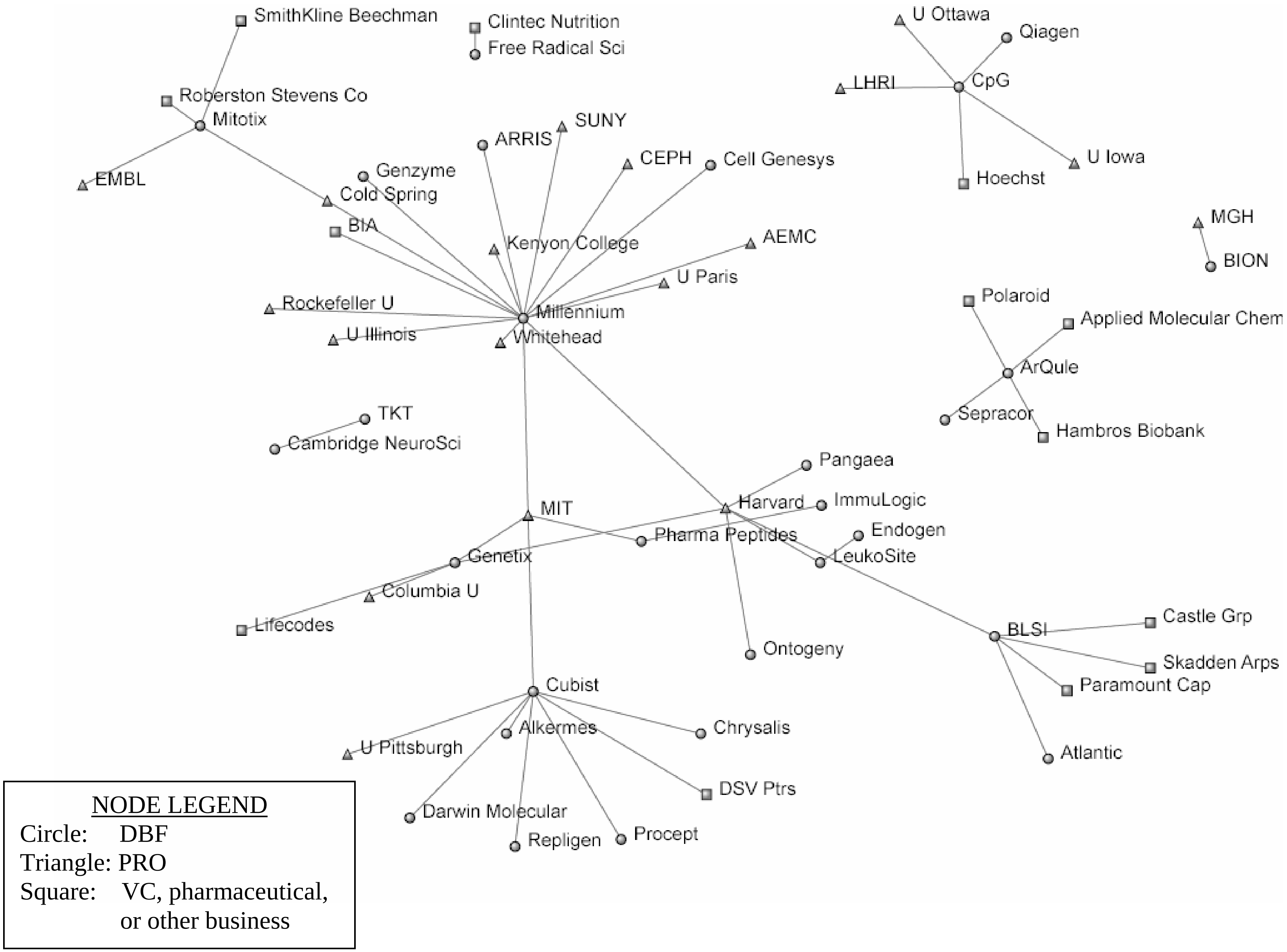


Figure 5. Founder Affiliation Network, Only Nodes with Two or More Links – 1978-2003

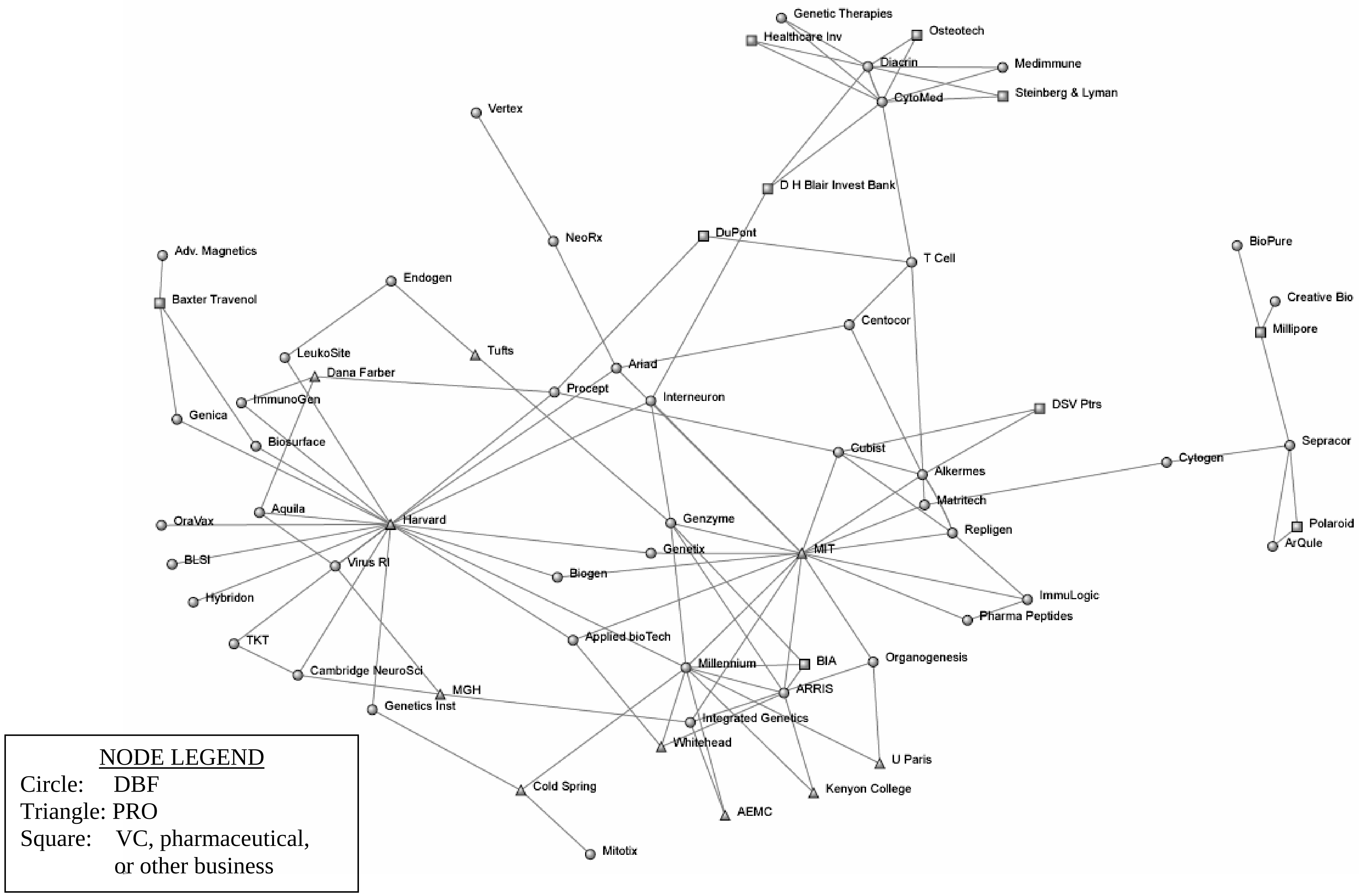
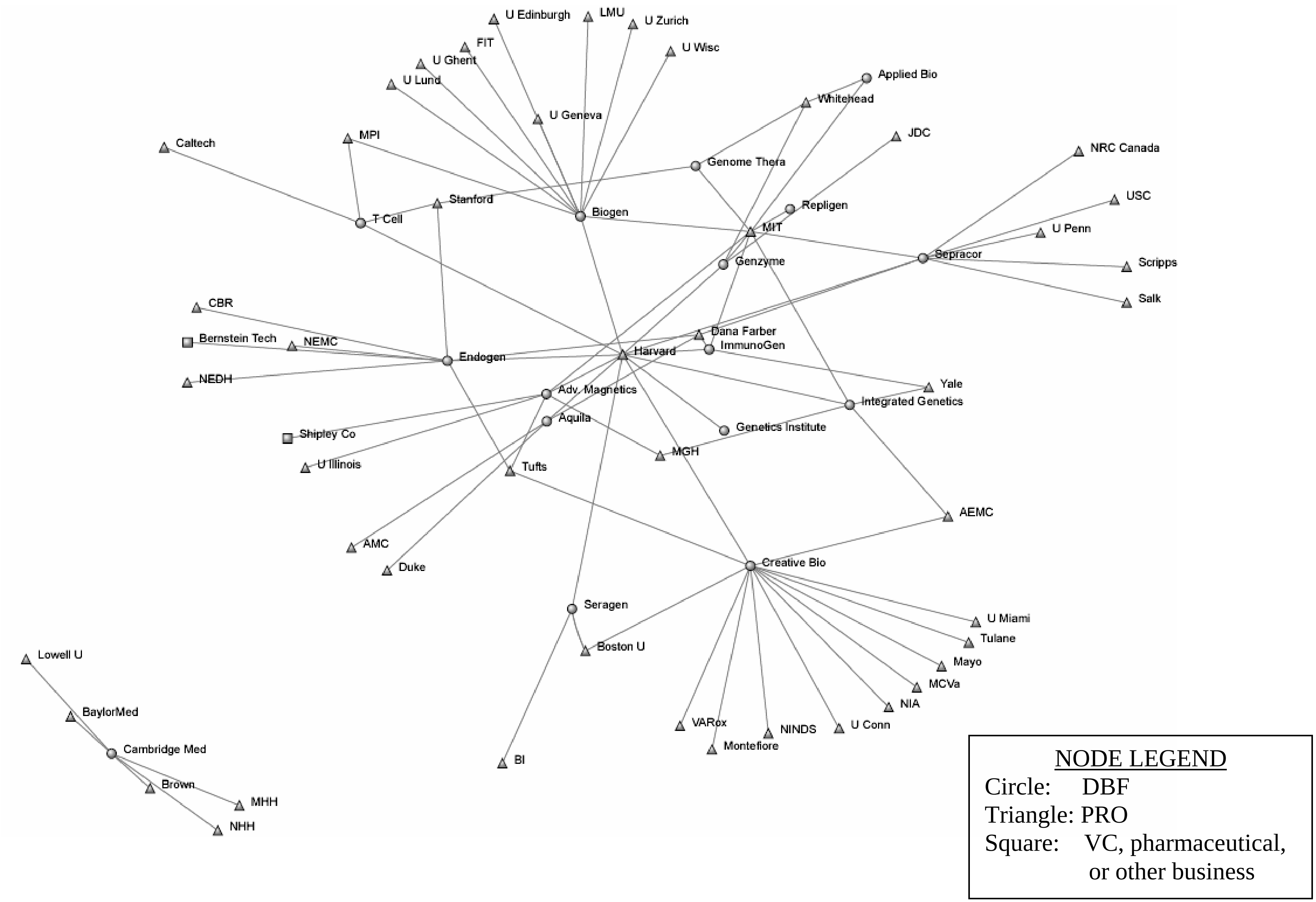


Figure 6. SAB Affiliation Network, 1984



NODE LEGEND
Circle: DBF
Triangle: PRO
Square: VC, pharmaceutical, or other business

Figure 7. SAB Affiliation Network, 1997

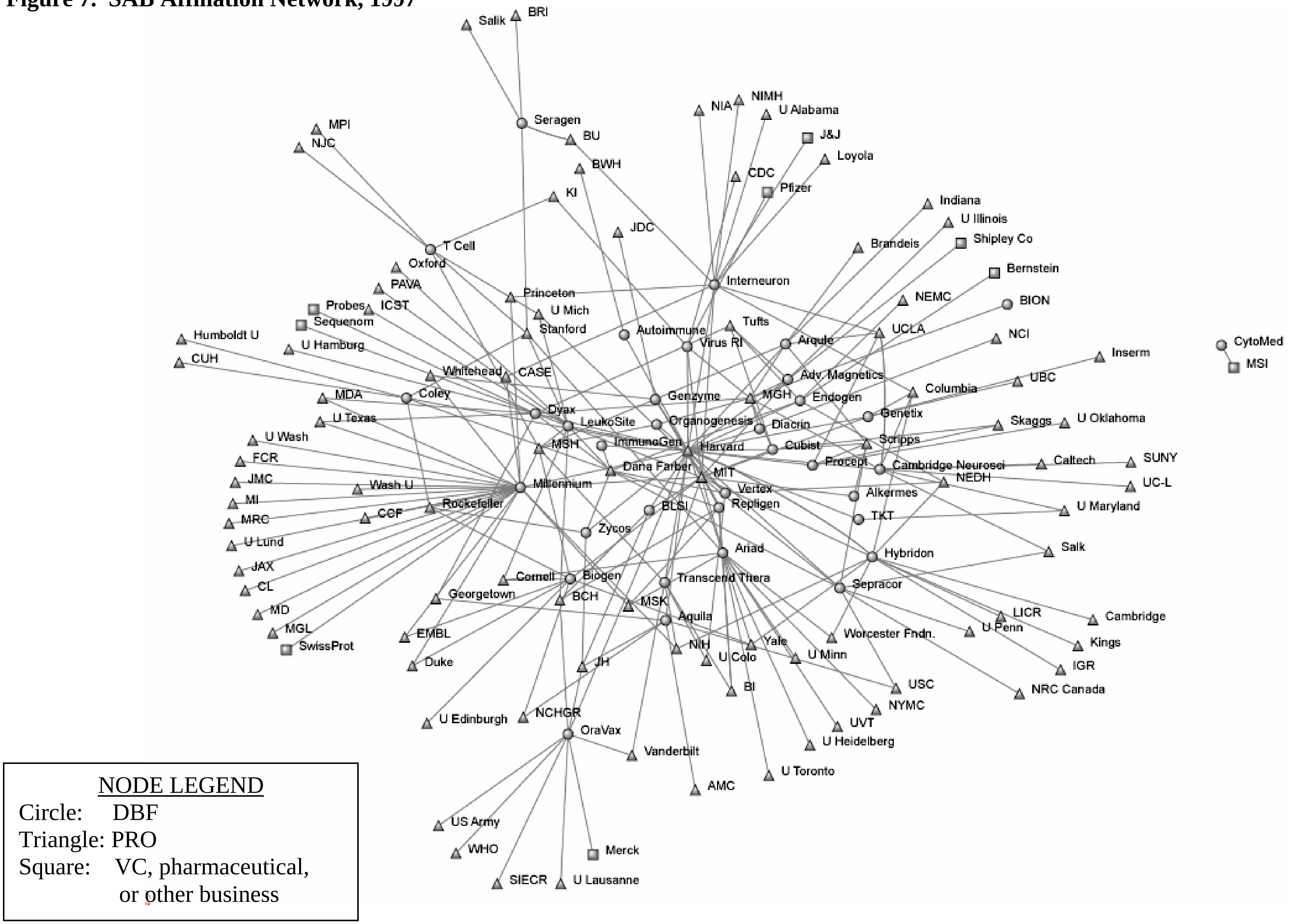


Figure 8. SAB Affiliation Network, Only Nodes with Three or More Links – 1978-2003

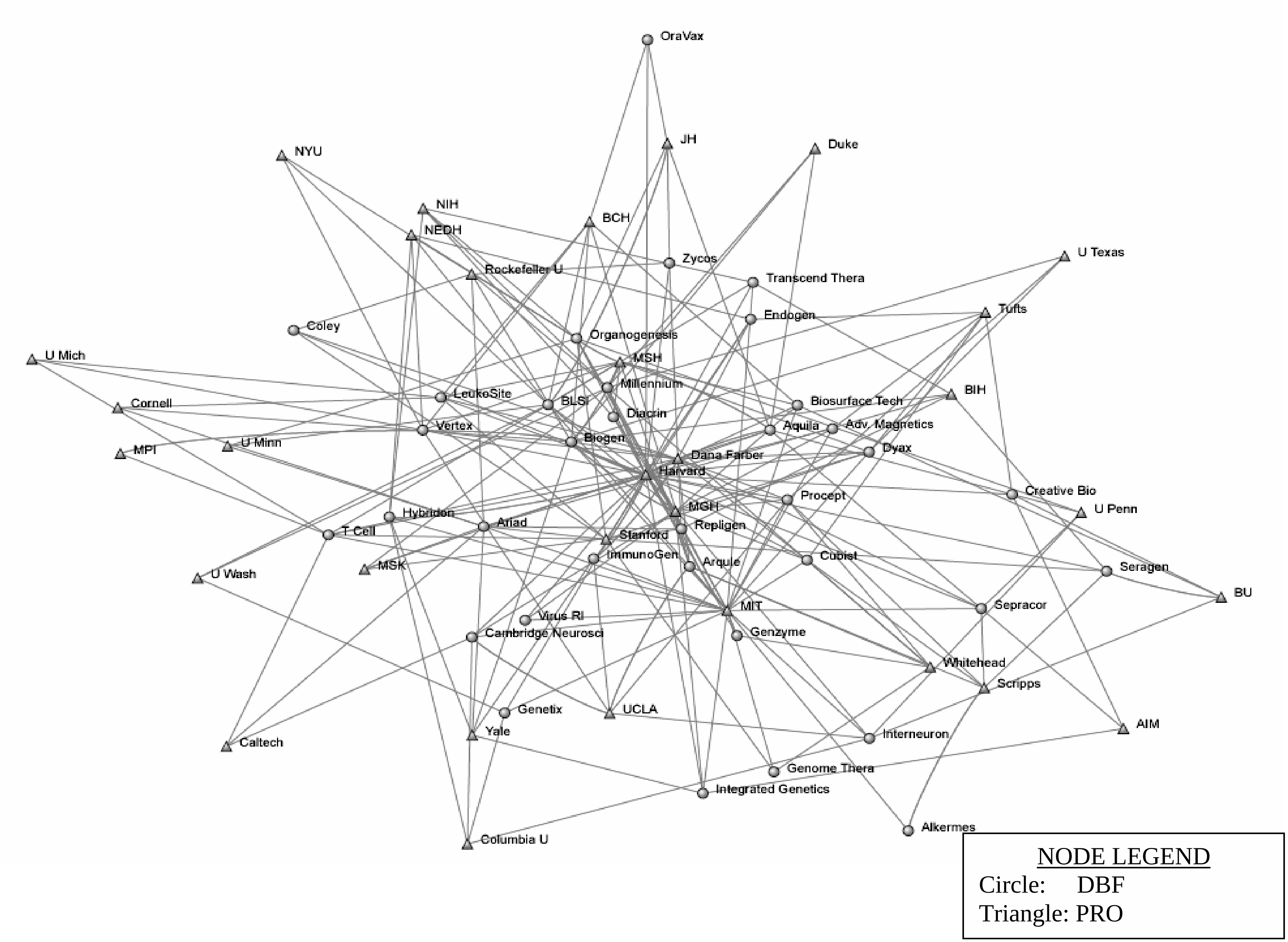


Figure 9. Boston Patent Co-Inventor Network, 1976-1998

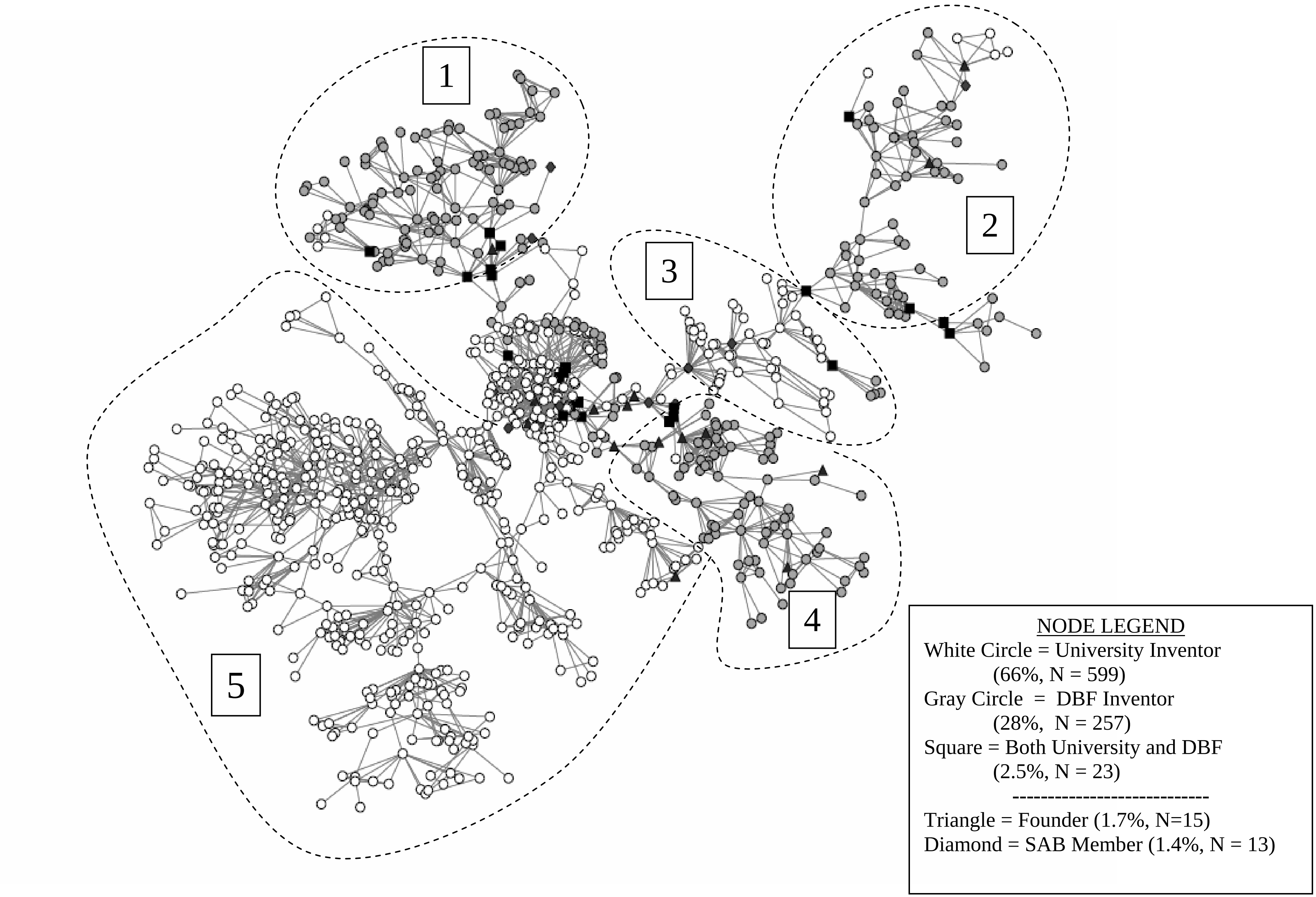
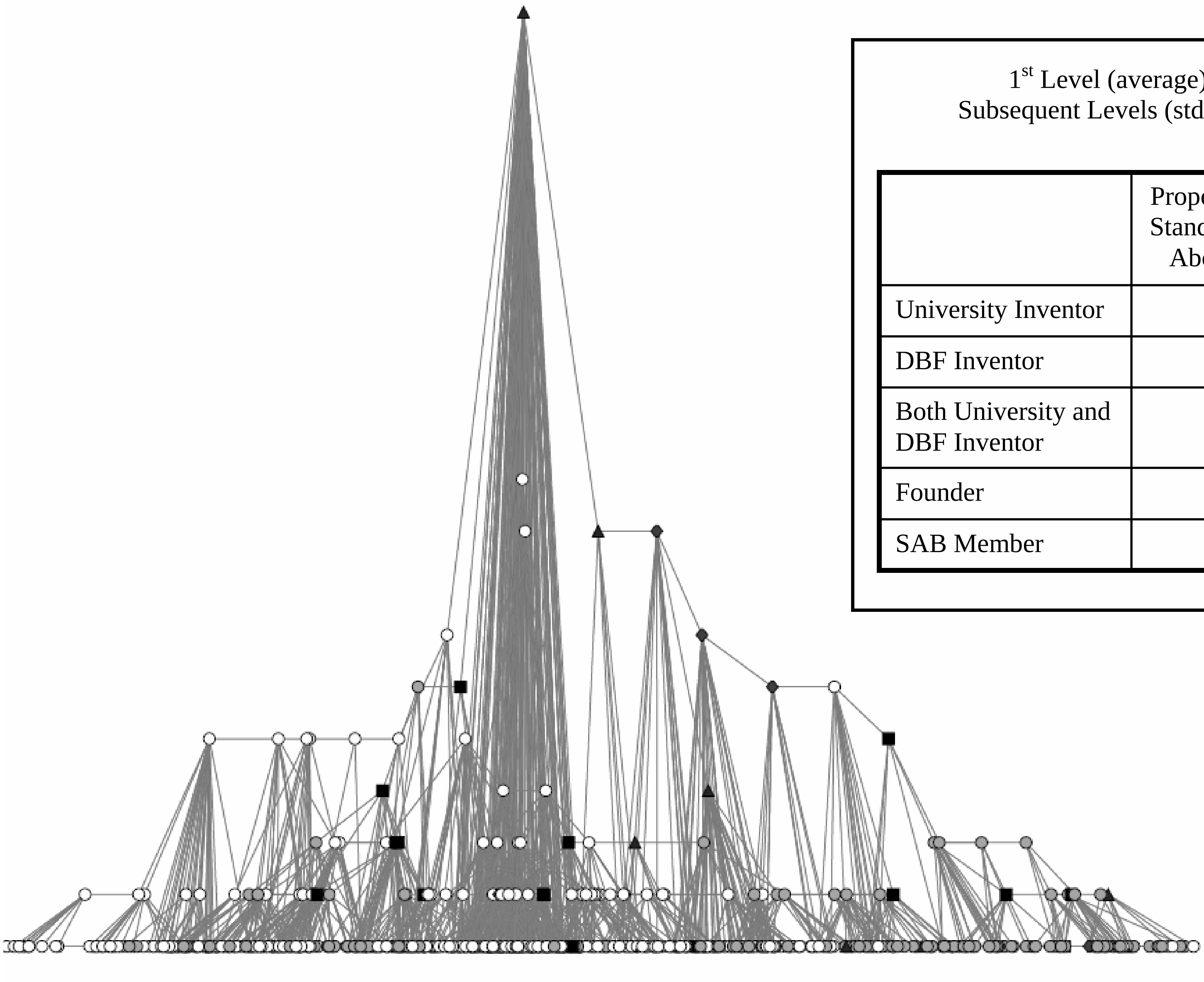


Figure 10. Betweenness Centrality Distribution of the Patent Co-Inventor Network, 1976-1998



1st Level (average): 0.01
Subsequent Levels (std dev): 0.04

	Proportion at least 2 Standard Deviations Above the Mean
University Inventor	10%
DBF Inventor	9%
Both University and DBF Inventor	59%
Founder	33%
SAB Member	31%

APPENDIX I: Abbreviations of Names in Network Images*

Abbreviation	Formal Name, Location
AEMC	Albert Einstein Medical College, NYC
AMC	Animal Medical Center, NYC
Aquila	Cambridge Biosciences, Aquila Biopharm, Boston
Baylor Med	Baylor College of Medicine, Houston TX
BCH	Boston Children’s Hospital
BI	Beth Israel Hospital, Boston
BLSI	Boston Life Sciences Inc.
BMS	Bristol-Myers Squibb, NYC
BRI	Biometric Research Institute, Arlington VA
BU	Boston University
BWH	Brigham and Women’s Hospital, Boston
CASE	Case Western Reserve University, Cleveland OH
CBR	Center for Blood Research, Boston
CCF	Cleveland Clinic Foundation
CDC	Centers for Disease Control, Atlanta GA
CEPH	Centre d’Etude du Polymorphisme Humain, France
CL	Channing Laboratory, Boston
Cogito	Cogito Learning Media, Boston
CSHL	Cold Spring Harbor Laboratories, NYC
CUH	Charité University Hospital, Berlin
DRCR	Damon Runyon Cancer Research Fund, NYC
EMBL	European Molecular Biology Laboratories, Heidelberg
FCR	Frederick Cancer Research and Development Center, National Cancer Institute
FIT	Federal Institute of Technology, Zurich
Genome Thera	Collaborative Research, Genome Therapeutics, Boston
HCA	Columbia/Health Corporation America, Nashville TN
ICR	Imperial Cancer Research, London
ICST	Imperial College of Science and Technology, London
IGR	Institut Gustave-Roussy, Desmoulins, France
J&J	Johnson and Johnson, New Brunswick NJ
JAX	Jackson Laboratories, Bar Harbor ME
JDC	Joslin Diabetes Center, Boston
JH	Johns Hopkins University, Baltimore MD
JMC	Jefferson Medical College, Philadelphia PA
KI	Karolinska Institute, Stockholm
Kings	Kings College, London
LHRI	Loehs Health Research Institute, Ottowa
LICR	Ludwig Institute for Cancer Research, New York
LMU	Ludwig Maxilians-Universität-München
Mayo	Mayo Clinic, Rochester MN
MCVa	Medical College of Virginia

MD	Max Delbruck Center, Berlin
MDA	M.D. Anderson Hospital, Houston TX
MGH	Massachusetts General Hospital, Boston
MGL	Mammalian Genetics Lab, Great Falls MT
MHH	Methodist Hospital of Houston
MI	McLaughlin Institute
Montefiore	Montefiore Hospital of Houston
MPI	Max Planck Institute
MRC	Medical Research Council, UK
MSH	Mt. Sinai Hospital, NYC
MSI	Molecular Simulations Institute
MSK	Memorial Sloan Kettering, NYC
NCHGR	National Center for Human Genome Research
NE Nuclear	New England Nuclear, Boston
NEDH	New England Deaconess Hospital, Boston
NEMC	New England Medical Center, Boston
NHH	National Heart Hospital, London
NIA	National Institute on Aging
NINDS	National Institute of Neurological Disorders and Stroke
NJC	National Jewish Center
NRC-Canada	National Research Council of Canada
NYMC	New York Medical Center
Ortho	Ortho Biologics, a division of J&J
PAVA	Palo Alto Veterans Association Hospital
SALK	Salk Institute, La Jolla CA
Scripps	Scripps Research Institute, La Jolla CA
SIECR	Swiss Institute for Experimental Cancer Research
Skaggs	Skaggs Institute, La Jolla CA
SSC	Swiss Science Council
SUNY	State University of New York
T Cell	T Cell Sciences, Avant, Boston
TKT	Transkaryotic Therapeutics, Boston
U Colo	University of Colorado
U Conn	University of Connecticut
U Mich	University of Michigan
U Minn	University of Minnesota
U Penn	University of Pennsylvania
U Vt	University of Vermont
U Wisc	University of Wisconsin
UBC	University of British Columbia
UCL	University College – London
USC	University of South Carolina
VA Rox	Veterans’ Admin. Hospital, W. Roxbury MA
Virus RI	Virus Research Institute, Boston
Wash U	Washington University, St. Louis MO
Worcester Fndn.	Worcester Foundation for Biosciences, Worcester MA

WHO	World Health Organization

* For biotechnology companies, we have dropped second names such as Pharmaceuticals, Biologics, and Technology, and shortened companies whenever possible. In the case of merged companies, or those with name changes, we include a shortened version of their most familiar name.