Managing Creativity in Small Worlds

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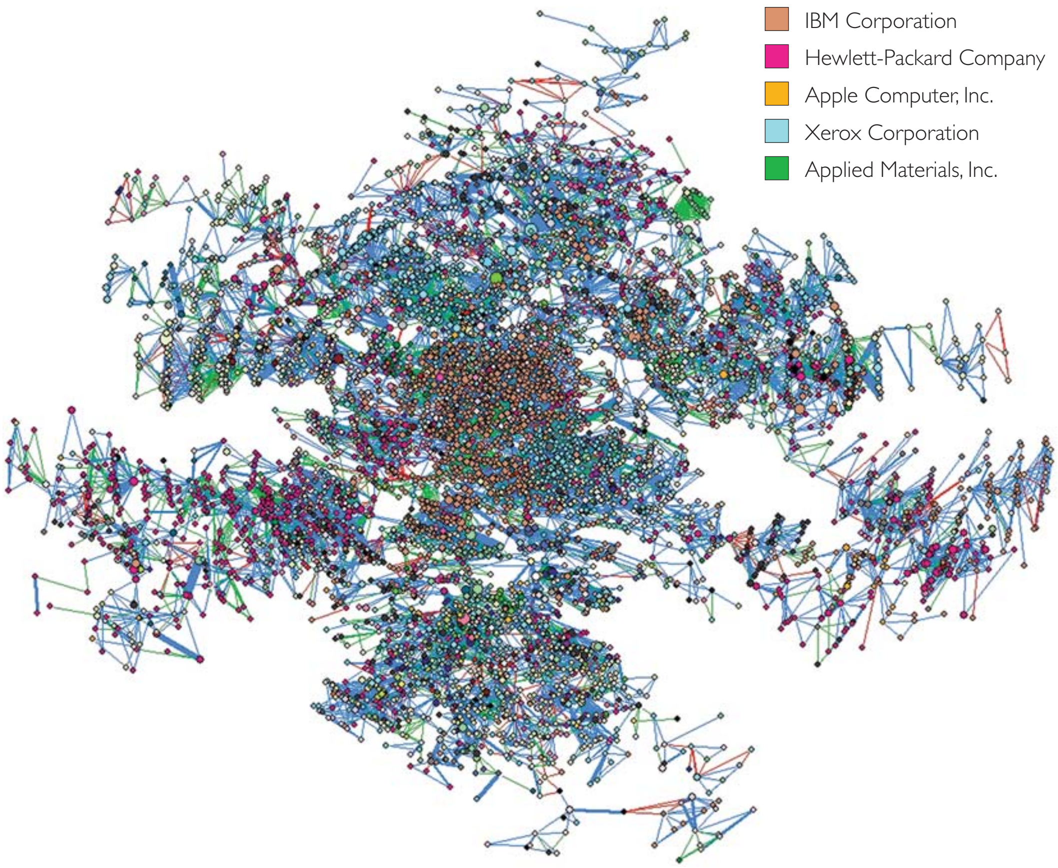
It's no secret that the world is shrinking. The "death of distance" has had a profound impact on invention, innovation, and business, as many before us have noted.[1] Historically, engineers and scientists have worked within local clusters of collaboration that were generally isolated within firms (and even within divisions of firms). However, as inventors have become increasingly mobile, these formerly isolated clusters have begun to aggregate into massively connected networks such as the one illustrated in Figure 1. Both the size and density of this network illustrate today's interconnected, multi-organizational web of technological search and competition, in which information and personnel flow more freely between firms. Firms no longer invent in isolation—they now invent in a small world.

In this article, we define the concept of the small world, describe how small worlds foster creativity, and discuss how firms can profit in a small world. Small worlds, once limited to regions such as Silicon Valley and Boston, are becoming widespread. Given this, managerial attention should focus on identifying, retaining, and enabling *gatekeepers*—technical professionals who span organizational boundaries, accelerating the process of invention by contributing to and capitalizing on interfirm "spillovers" of technical knowledge. The shift of the locus of invention from protected and proprietary silos to porous small worlds only raises the stakes for basic managerial competencies such as execution, flexibility, and strategic recognition of technology-enabled opportunities. By accelerating creativity and spillovers, and thereby heightening the urgency

We would like to thank Kent Bowen, Candace Fleming, Christopher Marquis, Santiago Mingo, Steve Wheelwright, Dennis Yao, and four anonymous reviewers for their feedback; Adam Juda, Jonathan McPhie, and Ivin Baker for their database development; John Elder for his editing assistance; and the Harvard Business School Division of Research for supporting our research.

FIGURE 1. The 7,244 Inventors in Silicon Valley's Largest Collaborative Cluster in the Mid-1990s



IBM's Almaden Valley Laboratory inventors (the tan nodes in the middle of the picture) provided the backbone for the network aggregation process that started in 1989. This process of linkage occurred as inventors moved from university to private employment and moved between firms. In this and all network diagrams, the nodes represent inventors; the colors represent the inventors' firms; and the tie color represents the age of the patent co-authorship, green indicating a collaboration within the past year, blue a collaboration between two and four years previously, and red a collaboration five years previously. Node sizes reflect the importance of the inventors' patents (as measured by the number of prior art citations from future patents) and the width of ties indicates the number of collaborations.

Note: All illustrations in this article have been graphed in Pajek with the Kamada-Kawai/Free algorithm. See V. Batagelj and A.P. Mrvar, "A Program for Large Network Analysis," Connections, 21 (1998): 47-57.

to commercialize inventions, small worlds ultimately make inventors, firms, and economies more productive.

The Research

Although much has been written about psychological and social-psychological influences on creativity,[2] only recently have sociological approaches begun to unravel how immediate and extended collaborative networks might influence creativity. The delay is largely attributable to the difficulty of collecting longitudinal network data and making inferences that can pick apart structural cause and effect. Recent advances in computation and data collection have enabled graphical and statistical analyses of datasets containing millions of individuals and tens of millions of relationships. We have developed a dataset that identifies all co-authorship relationships of U.S. patent inventors from 1975 through 1999. The dataset reveals trends that spill across time and across previously sampled boundaries such as firms and regions.[3] From these representative data—and confirming the arguments in Saxenian's original research that compared the two regions—we identified Silicon Valley and Boston as the most dynamic small worlds.[4] We then interviewed a representative sample of inventors about their social and collaborative networks, career moves and job changes, and creativity. A variety of statistical estimations at the inventor and regional levels of analysis supported our hypotheses.[5] We illustrate and explain our arguments in terms of our patent co-authorship network data, because such data have been shown to be robust conduits for information flow and knowledge transfer.[6]

The Small World of Inventors

People who have just met are often surprised to find that they share many common acquaintances even though they come from very different walks of life. Stanley Milgram, the first to explore these seeming coincidences, investigated the social distance between two people drawn from a large population.[7] He defined distance as the number of indirect linkages between individuals. For example, if Tom knows Dick, Dick knows Harry, and Tom and Harry do not know one another, the social distance between Tom and Harry is two. Drawing a sample from the white pages of Midwest towns and designating a friend in a Boston suburb as a "target," Milgram asked each Midwesterner (who was assumed not to know Milgram's friend directly) to forward a letter to a personal friend who might know the target. Intermediate recipients who did not know the target were asked to forward the letter to friends who might, the process continuing until the letter reached the Boston target. The average number of connections was six, conditional on the letter reaching the target. Milgram's findings passed into urban folklore as "six degrees of separation" until taken up in the late 1990s by Duncan Watts, Steven Strogatz, and Mark Newman at the Santa Fe Institute who, together with other researchers, formally defined the "small world" structure and developed a series of models to explore its properties.[8]

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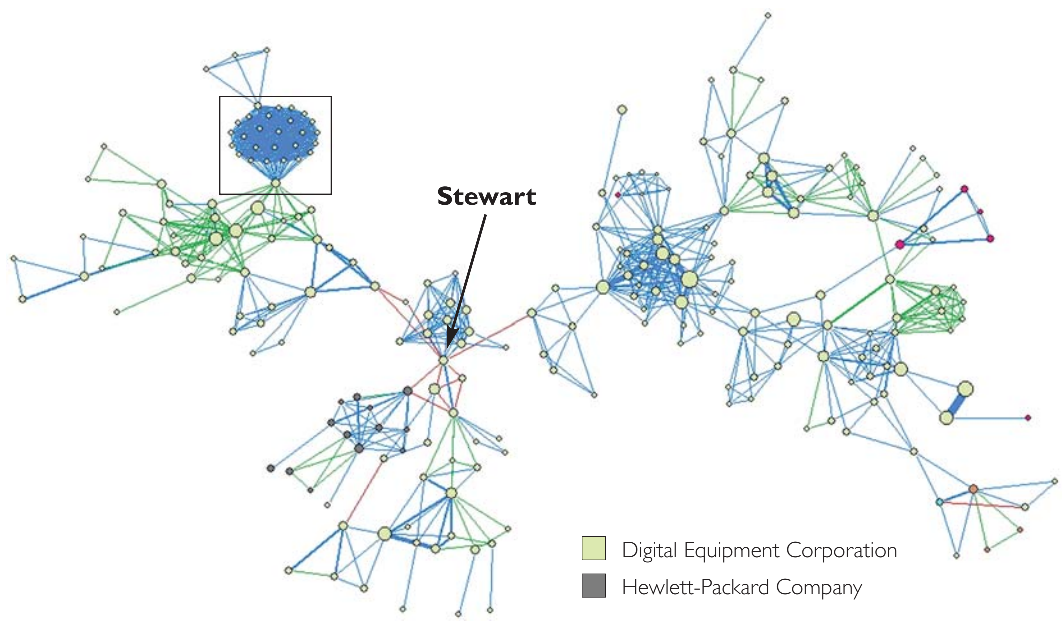
A small world network can be visualized as a "caveman" social structure. Imagine an extended community inhabiting a series of caves which, although not close, are each within walking distance of one or more caves. In such a

FIGURE 2. Inventors in Boston's Largest Connected Cluster circa 1986-1990



Robert Stewart, by facilitating the flow of information among three locally cohesive but insular clusters, turned Digital Equipment Corporation into a small world (though a small world that remained relatively unconnected to other firms). In contrast to Robert Stewart's bridging connection, the box illustrates highly clustered inventors.

community, one would expect a dense network of relationships (or "ties," in network parlance) within each cave, owing to daily interaction among those in closest proximity. Sociologists would describe the internal cave structure of dense, overlapping, and redundant relationships among occupants as a *cohesive cluster*. The upper left box in Figure 2 illustrates a very cohesive cluster of inventors, linked by overlapping collaborative ties.

In contrast to the multiple and redundant ties within caves, fewer ties—possibly none at all—would exist between caves, owing to less frequent interaction among occupants of different caves. If the caves were linked by a few connecting relationships, however, then together the collection of caves would constitute a "small world." These *bridging connections* dramatically reduce social distance because each cave member can now reach a different cave member via a few indirect links. Anyone within a given cave would probably know the local "bridging" person who, in turn, would know a few members of the other caves. Individuals who bridge the caves create a small world; in the absence of such individuals, people remain isolated in their local caves and their worlds remain "large."

Robert Stewart, the node in the middle of Figure 2, is such a bridging person (often referred to as a "gatekeeper").[9] During 1986-1990, he provided the only patent co-authorship connection between three otherwise separate clusters within Digital Equipment Corporation (DEC). He was, in the caveman analogy, the individual who maintains personal connections across three separate caves. He assumed this role because of his expertise in digital design reviews and his ability to identify potential problems within large schematics of digital gates. As a result, many managers asked him for help and valued the fresh perspective he brought from the other groups with which he was in touch.[10] The person at the bottom of the box in Figure 2 also acts as a bridging person, connecting the very cohesive cluster above him and the less cohesive cluster beneath him.

As implied by Figure 2, organizations are the "caves" in the world of invention. People are most likely to work, eat, and socialize with fellow employees of their local organization than with others in their larger organization or profession. Caves often exist within firms (as illustrated by the three clusters at DEC in Figure 2) and generally correspond to the firm's geographical, functional, or divisional organization. While caves can be isolated even within a firm, progressive firms have always created small worlds by connecting the clusters with intra-firm bridging relationships. Thus, small worlds have historically existed *within* some firms, and particularly within creative firms that have encouraged collaboration and communication across their internally cohesive clusters. What has changed is that small worlds now occur *across* firms as well.

How Small Worlds Influence Creativity and Invention[11]

The essence of small world structure is the linkage of locally intense clusters of cohesion by occasional bridging ties; isolated clusters or an overabundance of bridging ties between unclustered or less cohesive inventors are not a small world. This tension between cohesive clustering and bridging connections provides the creative benefits of small worlds. The influence of clustering alone upon creativity has generated a great deal of recent research, with some controversy over whether the influence is more helpful or harmful.[12] Our resolution to this controversy (and explanation for the benefits of small worlds) relies upon differentiating between the seminal generation of an idea and its development and diffusion.[13]

As noted, cohesive clustering occurs when individuals form dense and redundant relationships that do not depend upon a central hub inventor. In such a cohesive configuration, one individual can be removed and the remaining individuals can still communicate with one another through their redundant ties. The previously mentioned upper left hand box in Figure 2 depicts a highly cohesive set of inventors. Most of the inventors work with the same set of local inventors and maintain multiple redundant ties with one another.

The multiple overlapping ties of cohesion engender trust for mainly two reasons.[14] First, unwanted behavior by any individual will become more widely known than it would in a less cohesive group because news will travel quickly and more robustly along the multiple and redundant indirect paths. Second, collective punishment of unwanted behavior will be easier than it would be in a less cohesive group, because the group can coordinate its sanction. In this context, the reputation of an inventor who stole an idea would tarnish more quickly because news of the theft would spread rapidly and redundantly and a consensus to avoid working or sharing with the thief would emerge more quickly.

By engendering trust, cohesive clustering encourages sharing, widespread and lateral communication, and a wide range of other behaviors that facilitate creativity. Invention processes within a cohesive cluster will be more social and iterative; more inventors will contribute to the creative search, take part in the creative breakthroughs, and understand all the components of the creative synthesis. As a result of these behaviors, cohesively clustered structure will greatly enhance the development of an idea. Cohesive structure can also aid the subsequent diffusion of an idea from its original creators to potential adopters. These two benefits of cohesion (more effective development and faster diffusion) occur for three main reasons. First and second, a greater number of clustered inventors will fully understand—and be able to spread—the new technology.[15] Third, it will be easier to mobilize effort and support for development, because more inventors will perceive ownership of the invention, having been intimately involved in its creation.[16]

The downside to clustering is that it makes seminal creativity less likely; clustered inventors will be less likely to come up with a new idea in the first place. Clustering insulates groups from new information, ideas, and opportunities. Isolated groups of inventors go stale and risk vulnerability to groupthink. Consistent with these arguments, our regressions demonstrated that inventors within cohesive clusters are less likely to invent a new idea but the new ideas that do arise are more likely to be developed and adopted by other inventors. Hence, cohesion hurts the initial stage of seminal creativity but helps the subsequent stages of development and diffusion.

Cohesive clusters with bridging connections, however, can escape this fundamental conundrum. Bridging ties counterbalance insularity by bringing in fresh and non-redundant information. The combination of this fresh information with the trust, resource sharing, and robust flow of information within clusters improves seminal creativity in small worlds. Note that it is neither the cohesion nor the bridging ties by themselves that improve seminal creativity—it is their interaction. As an additional benefit, bridging ties also (and independently) enhance diffusion by providing additional connections for the transfer of ideas out of a cohesive cluster.

The combination of bridging ties and cohesion—small worlds—provides for easier diffusion *and* more new ideas to start with. As a result, inventors within small world networks will create more new inventions and those inventions will diffuse more quickly. Since new ideas and technologies provide the basis and trigger for further new ideas and technologies, small worlds lead to a virtuous and self-reinforcing cycle of creativity.

The Shrinking World of Inventors

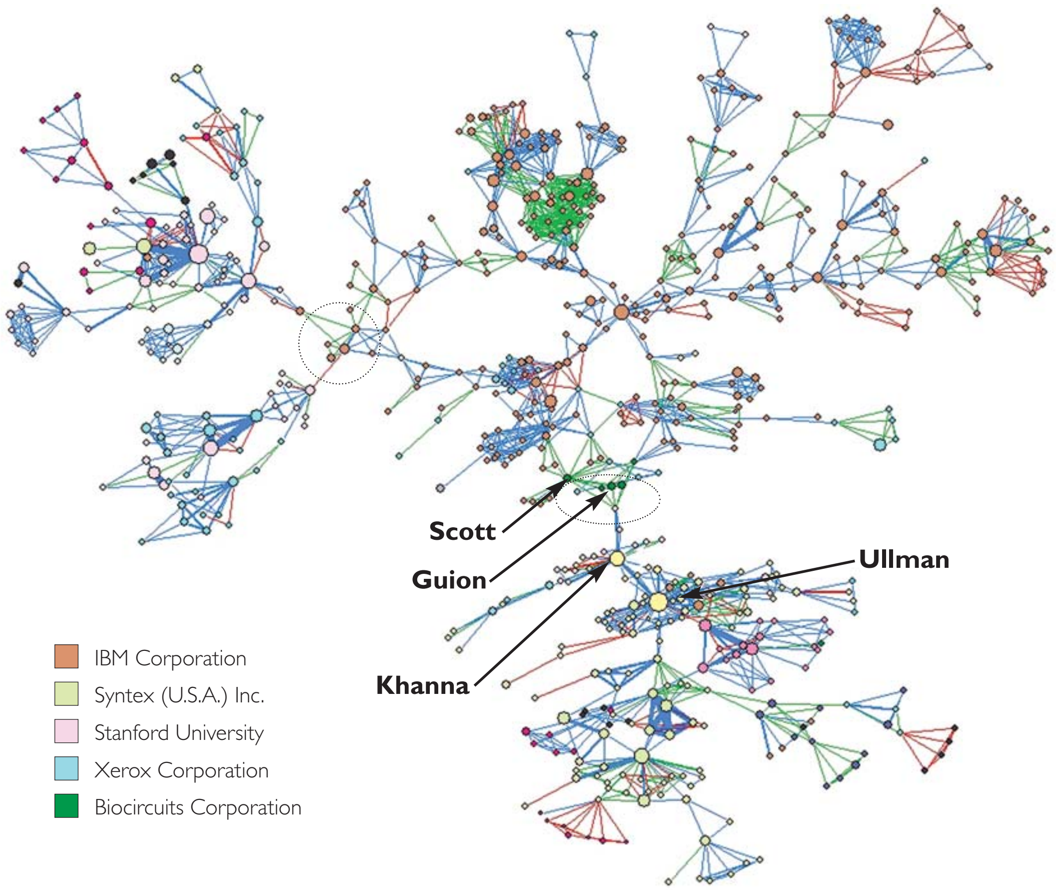
Our data not only demonstrate the creative benefits of small worlds, but also indicate that inventor networks are becoming increasingly connected. As a result, they are "shrinking" and becoming more "small world." Clustering remained relatively unchanged over the time period of our study. Inventors have often invented with small groups of collaborators; while the degree of cohesion varies, its average has been relatively stable. The emergence of small worlds is therefore driven largely by an increase in bridging ties. This increase in ties is driven in turn by increasing inventor mobility; inventors hop between clusters—and thereby connect them—with greater frequency. Consistent with these observations, most of the positive creativity increase at the regional geographic level correlates with the connection of clusters and not with changes in the internal cohesion of local clusters.[17] As mentioned—and of greatest managerial interest—these connections increasingly occur across firm boundaries.

We looked for small worlds across all regions of the U.S. and the focused our fieldwork on the two regions where small worlds emerged most dramatically (Silicon Valley and Boston). Our research corroborated earlier work that demonstrated greater mobility amongst Silicon Valley engineers, particularly in the years prior to 1990.[18] We also found idiosyncratic reasons for Silicon Valley's small worlds and, more importantly, we identified trends that demonstrate that Silicon Valley is no longer unique.

Our systematic data (the purple and orange lines graphed in Figure 5) indicated that Silicon Valley and Boston both became much more connected in the early 1990s. Based on this, we focused on those two regions and developed the series of network illustrations in Figures 1 through 4. These revealed the emergence of small worlds that span firm boundaries first in Silicon Valley and later in Boston. Figure 3 depicts the Silicon Valley network contemporary to the Boston network depicted in Figure 2. Both figures illustrate the largest connected cluster in each region during the 1986-1990 time period (the largest connected cluster is the largest group of inventors who can trace an indirect collaborative path to one another).

In contrast to Figure 2, which shows clusters of inventors primarily within Digital Equipment Corporation, Figure 3 illustrates how small worlds emerged *across* firms. This can be seen by the green ties within the two dotted-line circles. A green tie indicates that the relationship was formed recently; in this case, it indicates a patent co-authorship in 1990. Inspection of Figure 3 indicates that if the circled green ties had not occurred, the largest connected cluster of 1990 would have remained in three smaller and isolated clusters: the large cluster of tan nodes in the middle (IBM Almaden Valley Laboratories), the small cluster of assorted pink and other colors in the upper left (Stanford University and a variety of mostly small firms), and the moderately sized cluster of light green nodes on the bottom (mainly Syntex and associated pharmaceutical firms). Figure 1 illustrates Silicon Valley in 1990-1994 and demonstrates how this process can snowball, aggregating hundreds of isolated clusters into a single dominant cluster within a region. Similar runaway aggregation begins in Boston

FIGURE 3. Inventors in Silicon Valley's Largest Connected Cluster circa 1986-1990

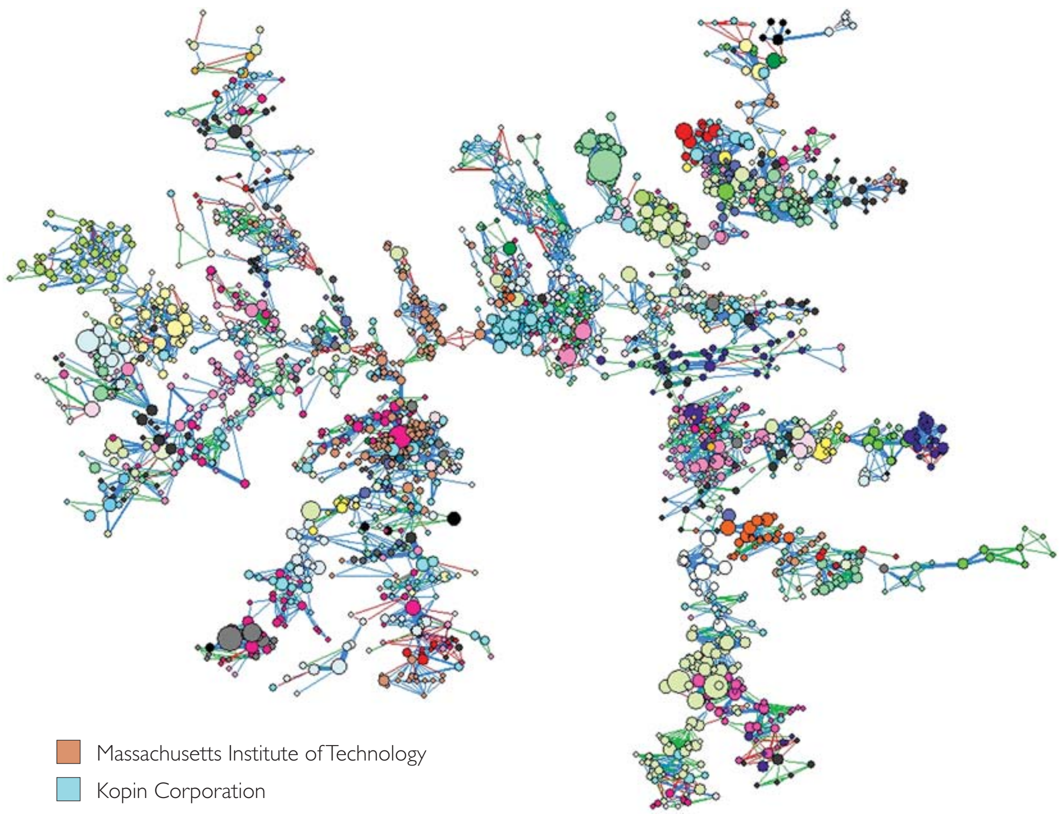


The green ties within the circles highlight the crucial bridging connections that enabled the aggregation of the largest Silicon Valley clusters into a giant cluster in 1990. Pyare Khanna and Edwin Ullman are gatekeepers with high inventive productivity and connections across firm boundaries (indicated by their large nodes and connections to nodes of different colors). Todd Guion worked for Campbell Scott as an IBM post-doc. After leaving for employment at the biotech start-up BioCircuits, Guion invited Scott to collaborate informally. IBM agreed and allowed Scott to maintain full employment at IBM while patenting with the start-up.

three years later and, by 1993, results in the network of Figure 4 with MIT at the center.[19]

Why did small world inventor networks spill across firm boundaries earlier in Silicon Valley than in Boston? The full explanation is complex, multifaceted, and path-dependent, but some answers can be identified.[20] Conventional and unconventional inventor mobility caused the Silicon Valley small world to emerge across firm boundaries. The upper left circle of Figure 3 illustrates conventional mobility—students who left graduate school at Stanford University and took employment at IBM's Almaden Valley Laboratories. The

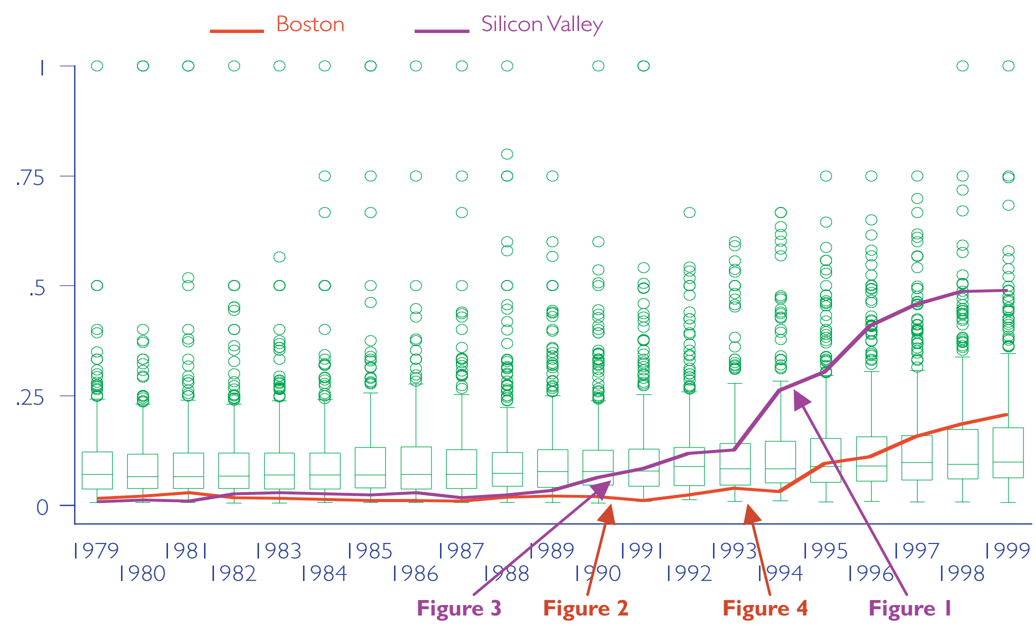
FIGURE 4. Boston's Largest Connected Cluster circa 1989-1993



Boston's largest connected cluster circa 1989-1993, illustrating the region's transition, three years after Silicon Valley's, to a connected, small world structure. MIT, indicated by the light orange nodes, is at the center of the cluster.

lower middle circle illustrates less conventional mobility—recently graduated students who left a postdoctoral program at the same IBM organization for employment at a biotech start-up (dark green nodes in lower middle). These movements linked the central core of IBM's Almaden Valley Laboratories with Stanford University and, through BioCircuits Corporation, with the bottom cluster of pharmaceutical firms. In the latter case, it was not the immediate job movement that indirectly linked IBM's physical sciences to Syntex Pharmaceuticals, but a suggestion by one of the postdocs (Todd Guion) that his former IBM advisor (Campbell Scott) collaborate with the start-up.[21] While IBM did not immediately agree (even though BioCircuits presented no competitive threat to the larger firm), it eventually allowed the collaboration. Ultimately, IBM benefited from its support of the unorthodox collaboration, as Scott indicated[22] that he is now applying the biology he learned at BioCircuits to IBM's move into the life sciences.

FIGURE 5. Box Plot of Proportion of Inventors within the Largest Collaborative Cluster in each U.S. Metropolitan Statistical Area (MSA)

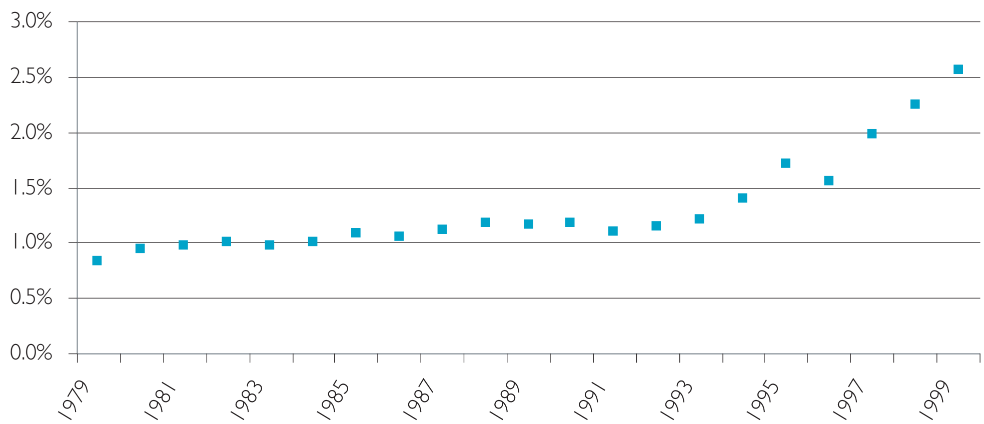


The arrows indicate the timing of each of the network illustrations of Boston and Silicon Valley. Boston and Silicon Valley are highlighted because of their dramatic transitions from "large" to "small" world structure. Regions with extremely high proportions (close to 1) tend to contain only a handful of inventors who all collaborate. Individual circles represent outliers and the horizontal lines within boxes represent the 25th, 50th, and 75th percentiles, respectively.

Our systematic data also demonstrated that these aggregations of clusters were widespread and not limited to Silicon Valley and Boston. The green boxplots in Figure 5 illustrate the proportion of inventors in U.S. regions that are connected into each region's largest connected cluster. It graphs the number of inventors in each region's largest connected cluster, divided by the total number of inventors in that region (essentially Figures 1 through 4 for each of the Metropolitan Statistical Areas (MSAs) in the United States over the years 1979-1999).[23] The increasing average (the middle line in each year's box) and number of outliers (small green circles, mostly in the upper right) illustrate that an increasing proportion of inventors within all regions are connected into their region's largest collaborative cluster.[24]

We also investigated the systematic influence of legal institutions upon mobility and small worlds. Recent work by Gilson has proposed the California proscription of non-compete agreements as the cause of Silicon Valley's greater job mobility.[25] One implication of this research is that greater job mobility results in more connections across firm boundaries and faster network aggregation, and ultimately results in smaller worlds. We tested this non-compete and mobility

FIGURE 6. Proportion of Inventors that Patent with a New Employer



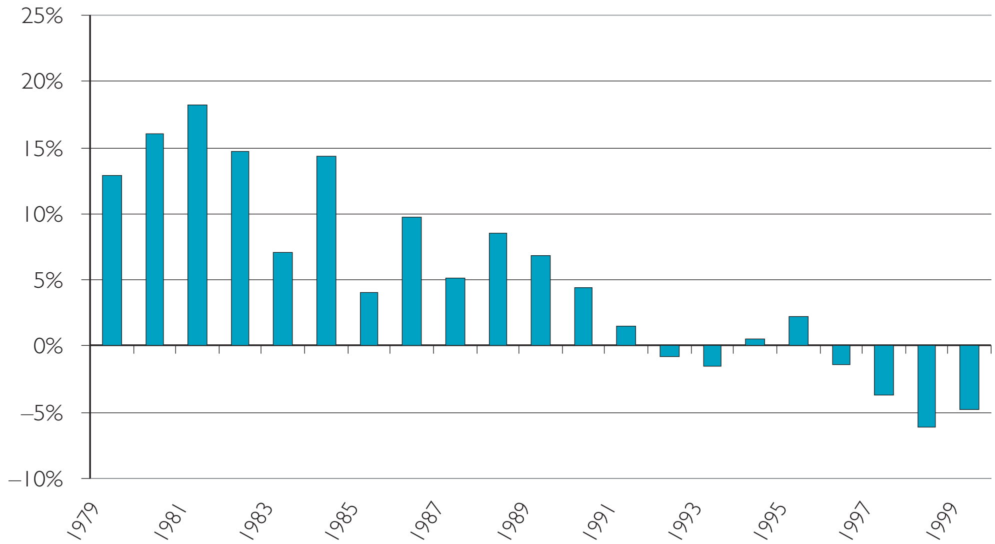
Patented inventor employer mobility within MSAs (box plots are not shown due to the extreme variability of the data). Calculated as the number of inventors that are observed to patent with a new assignee (generally the inventor's employer and typically a firm) in the same region in the given year, divided by the number of unique inventors in that region in a seven-year window bracketing the given year. The data indicate increasing mobility over the time period, though the overall rate remains low, due to the observations of movement being conditional on at least two patents by different firms with the same inventor and in the same region.

Note: The U.S. Census Bureau estimates that U.S. individuals move at approximately 6.7 year intervals, hence our selection of seven years for the denominator. See <www.census.gov/population/www/pop-profile/geomob.html> and <http://www.cdc.gov/nchs/fastats/lifexpec.htm>.

hypothesis systematically across all U.S. regions and confirmed that regions that did not enforce non-competes did indeed experience greater inventor mobility across firm boundaries. Surprisingly, we also found that the influence of non-competes has waned over time such that the differences between enforcing and proscribing regions have become indistinguishable.[26]

Figures 6 and 7 illustrate the non-compete and mobility finding. Figure 6 graphs the proportion of patented inventors that change employers in a region. Figure 7 graphs the percentage difference between regions that do and do not enforce non-compete agreements. Both types of regions experienced increased mobility over the observed years, as illustrated in Figure 6, but mobility increased relatively more quickly in regions that enforced non-competes, as illustrated in Figure 7. At the start of the time series, mobility in regions (such as Silicon Valley) that did not allow enforcement of non-competes was 10-15% greater; by the end of the series, there was actually greater mobility in regions (such as Boston) that allowed enforcement of non-competes. In summary, Silicon Valley networks aggregated first for a variety of reasons, including but not limited to greater inventor mobility. More importantly, inventors are becoming more mobile in all regions, such that small worlds are becoming more common. Managers therefore cannot rely upon their location in states that enforce non-competes to retard employee mobility.

FIGURE 7. The Decreasing Effect of Noncompete Enforcement on Inventor Mobility



The percentage difference in patented inventor employer mobility within MSAs, between regions that do and do not enforce non-compete agreements. In the early years of the time series, inventors were much more mobile in regions (such as Silicon Valley) that did not enforce non-compete agreements. By the end of the time series, inventors were more mobile in regions (such as Boston) that did enforce the agreements.

Data beyond patents also indicate that there is greater professional mobility[27] and that the world of individuals who do not hold patents is also "shrinking." Scientists increasingly act as free agents, taking temporary employment in different laboratories.[28] Linking mechanisms besides worker mobility have also become more common, including strategic alliances[29] and consulting professionals who patent with more than one firm.[30] Engineers increasingly participate in open innovation communities as a way to increase their skills, enhance their external reputations, and facilitate movement between firms. The U.S. Bureau of Labor Statistics estimates that between 1995 and 1999, 13.3% of workers were "contingent," and even this high number does not count those employed by temp firms. At Microsoft, between 8,000 and 12,000 temporary workers, roughly one-third of Microsoft's total work force, were affected by the 1999 settlement of *Vizcanio v. Microsoft* which enhanced temporary workers' permanent benefits.[31] Informal estimates of Silicon Valley's contingent work force range between 15% and 30%. As a testament to the (perhaps obsessive) professionalism of contingent engineers, an entire software product, a graphing calculator later adopted and released by Apple, was written illegally within corporate walls by laid-off temporary contractors.[32]

Managing Inventors in Small Worlds

Small worlds create anxiety for many managers. Given the expense of hiring and training scientists, inventors, and other creative professionals, managers understandably resent their diminished ability to appropriate returns on those investments due to short job tenures and information spillovers. Such concerns are only magnified when technical professionals move in packs, such as groups of "Netscapees" that form the engineering backbones of many Silicon Valley start-ups. "We're probably the largest single collection of people who were originally involved in Netscape engineering," said Jim Everingham, now the CTO of LiveOps. "It's the same team, and we love to work with each other."[33]

Firms whose chief assets reside inside their employees' heads, rather than in physical or capital investments, are acutely aware of the leverage gained by their inventors in the knowledge economy.[34] In a case familiar to us, a software engineer invented a technology that promised to create an entirely new business model for a struggling start-up. When the company's general counsel approached him about patenting the invention, he refused unless the IP rights were assigned to him personally instead of to the company. When threatened, he said, in effect: "Fine. I have a better idea for a company than anyone here and I'll go do it myself." Management ultimately agreed to give him IP ownership of the invention in return for licensing it back to the company.[35]

Thus framing the flow of information as an expected *loss* of people and ideas, the instinctive managerial response for many is to "plug the dike." Some managers, attempting to replicate the benefits of an earlier era, sequester their inventors; one CEO indicated that he intentionally kept his inventors in silos, to minimize their awareness and understanding of outside opportunities.[36] Others seek IP protection through strict non-disclosure and non-competition agreements and accompanying threats of legal action. Yet intimidated unhappy inventors are uncreative inventors, particularly if pressured by extrinsic threat; they will be far more creative if internally motivated by the learning and challenge at hand.[37] Worse, inventors who feel suffocated are more likely to leave, possibly for a competitor. While most inventors sign non-compete agreements, these appear to be having less influence within regions, as illustrated by Figure 7. Moreover, top talent might not hesitate to relocate across state lines, out of legal reach. In a recent conversation, a manager at a Boston-area Web-search firm was aghast to hear that his chief scientist could be snapped up by West Coast competitors with no legal recourse.[38] Thus, a firm that clamps down on technical professionals will be less able to hire or retain elite inventors.[39]

But managers should not assume the worst when managing invention in a small world. To begin with, managers should remember the typical human bias of valuing losses more heavily than gains.[40] Because complex tacit knowledge does not diffuse easily, managers need only be concerned about IP loss if an engineer takes codified and well-articulated knowledge and immediately pursues the original firm's ideas. (To restate the idea visually, only the simplest of ideas would diffuse across the humungous network of Figure 1; more complex ideas and technologies would stop after a few links.)[41] Instead, management should look for ways to maximize the *inflow* of information, invent creatively with that information, quickly identify the most promising ideas, and exploit those ideas more quickly than their competitors. The keys to accomplishing these objectives are: to identify, enable, and motivate the elite inventors who span organizational boundaries; and to leverage increased creativity externally or internally—if the former, through supporting the inventor in a start-up effort and/or licensing; and if the latter, through faster execution, better product development, more effective marketing, more efficient manufacturing, and smarter strategy. Since most research on innovation addresses the latter set of challenges,[42] and since this work generally applies to inventions created within small worlds, we focus on managing the elite inventor.

Identify the "Gatekeepers"

The first step in managing inventors in a small world is to map the organization's social capital—to identify the key bridging connections to the outside world of universities, associations, and other firms.[43] Bridging inventors were first identified 30 years ago as technical *gatekeepers.*[44] Managers' intuition in identifying gatekeepers has been shown to be reasonably accurate.[45] Gatekeepers often hold advanced degrees, enjoy deep technical respect from their peers, work closely with other gatekeepers (both within and outside of the firm), and move into management positions. While all the identified individuals in our graphs are gatekeepers and elite inventors, Pyare Khanna and Edwin Ullman (represented by the two large yellow nodes in Figure 3) provide the most preeminent examples. Both hold Ph.D.s, publish prolifically in the scientific literature, and have worked in multiple firms or across boundaries of firms.[46]

The best gatekeepers invent, communicate, and exploit their boundary-spanning positions to keep abreast of current developments, problems, and breakthroughs. They both consume and contribute to the scientific literature; they translate important external results for their colleagues; and they identify trends, threats, and opportunities for their firms. Managers should remain wary of gatekeepers who actively control information. Instead, gatekeepers should use their awareness and brokerage of different clusters to join disconnected individuals who have the potential for fruitful collaboration.[47] Forming simple connections between isolated clusters is relatively straightforward, but the key is to encourage fruitful collaborations. (In this respect, the best gatekeeper is one who continuously makes new connections and solidifies the most promising introductions, leaving cohesive clusters in his or her wake.)

No research has yet considered whether gatekeepers can be developed from scratch. We suspect that the process would be very difficult, due to the simultaneous requirement of fundamental and difficult-to-teach technical and communication skills. Fortunately, gatekeepers appear to be a fundamental part of every technological and scientific community. If management feels that the firm lacks sufficient gatekeepers, it can probably hire additional gatekeepers from the larger community. Managers of peripheral firms should pay particular attention to the role of academic inventors like those in Figure 3. Such young inventors can move a firm closer to the core and creative ferment of a small world.

Care and Feeding of Gatekeepers

Gatekeepers are gifted and unique individuals but pose particular human resource challenges. Because they can be so creative and aware of technological opportunities, they can sometimes paralyze the firm with possibilities. Rather than focus on and explain the most important threats or opportunities, unskilled gatekeepers generate unfiltered, unprioritized lists of ideas, "randomizing" fellow employees and disrupting meetings. Such behavior can distract the firm from timely execution of product development and current strategy and ultimately makes the gatekeeper less effective, since he or she is more likely to be ignored in the future. Consistent with the possibility of randomizing fellow employees, gatekeepers are often better at generating ideas than bringing them to fruition. (To complete the story of the inventor who demanded ownership of his IP, he eventually left the firm—with the result that neither the firm nor the inventor has commercialized his creative breakthrough.)

While there are probably psychological factors that cause this inability to follow through, including an innate preference for creativity over refinement and elaboration, our research highlights the importance of purely structural influences. To illustrate this, consider the common challenge of attempting to transfer a gatekeeper's idea into manufacturing. This is often difficult because the unique bridging position that made the gatekeeper creative in the first place also means that he or she is the only person who understands all sides of the idea. In contrast, when an invention arises within a cohesive cluster, almost everyone within the cluster understands the idea and can explain it to others. In other words, the very position that makes gatekeepers creative makes them less able to diffuse that creativity to others. Much of this effect is purely structural—embedding a gatekeeper in a cohesive cluster will ameliorate some of the problems but also make him or her less likely to come up with new ideas.[48] Clearly, the creative conundrum of cohesive collaboration must be addressed outside of the structure, perhaps through more careful management (often not popular with gatekeepers) or through incentives for the completion and transfer of ideas and/or products.

If such problems can be managed, gatekeepers can create significant commercial opportunities. The ability to establish a legitimate presence in a technological or scientific community, without giving away all of the company jewels, remains limited to prolific and sensitive inventors. If such individuals also have good communication skills and a strategic appreciation of corporate objectives, they become exceptionally valuable and should be treated accordingly. Yet treatment rarely scales with the creative importance of an individual. Awards for patents tend to be modest and take little account of the quality or magnitude of the contribution (which are understandably difficult to estimate at the time of the patent grant). Dual-career ladders compare poorly to the monetary and status rewards of line management promotions. Ironically, executives accustomed to setting sales compensation plans with aggressive accelerators are often reluctant to bestow equivalent rewards on star gatekeepers. Such reluctance is parochial and ultimately ineffective in a small world setting.

Gatekeepers create the greatest value for their firms if they can contribute to corporate strategy. Most importantly, senior gatekeepers are in the best position to assess the threat or opportunity posed by an external breakthrough. Such individuals can foresee discontinuous or disruptive change[49] from much greater distances. Their early warnings and technical insights can greatly increase the firm's ability to meet and profit from the change. Such senior gatekeepers should have strong and direct influence on corporate strategy through the chief technology (or science) officer. Ideally, these officers are themselves the best gatekeepers in the firm and should not be overly burdened with administrative tasks that detract from their focus on inventive processes and external technology developments.

Managers should remain realistic about their abilities to retain gatekeepers. Like star athletes or academics, gatekeepers can always exploit a variety of opportunities, both within and outside of their current employer. While keeping gatekeepers within a firm is always an attractive option, managers should be open to less conventional opportunities; gatekeepers may be better employed in developing a new technology at a start-up, particularly if they invented it and are passionate about its development. For example, many competitive start-ups occurred in the early auto industry because an incumbent refused to support the development of an inventor's idea.[50] Rather than losing an outstanding individual and generating ill will, firms should consider funding a gifted inventor, particularly if the technology and business model complement the firm's strategy.[51] For example, a disruptive technology might best be initially pursued outside of an incumbent firm; if that development proves successful, the original firm is then in a much better position to take advantage of the success (through return on an investment, ease of acquisition, or purchase of technology or product).

Exploit the Fishbowl

Managing in a small world is akin to managing in a fishbowl: besides learning about the firm's breakthroughs more quickly, everyone sees (or hears about) a firm's human resource practices as well—all the more so in a world with e-mail, Internet chat groups, and blogging. Firms that constrain their gatekeepers too aggressively will quickly gain a repressive reputation and be less able to retain or hire top creative talent. In contrast, a firm that becomes known for its enlightened hiring practices can benefit enormously; for instance, Cisco's reputation for not suing ex-employees not only may help employee retention, but may help to facilitate acquisitions as well, since executives at the acquired firm realize they can leave without fear if the merger doesn't work. More generally, the presence of an escape route increases the credibility of a firm's promises, which can in turn increase an inventor's commitment to a firm.[52]

Small world fishbowls are transparent and firms should take advantage of that. Individuals build widespread reputations in a small world fishbowl, which makes it easier for management to identify and assess prospective hires and find the expertise they need. Careful and selective hiring is all the more essential in a fishbowl, since a bad match between the firm and inventor only results in ill will and a disgruntled former employee who then has a wide scope for badmouthing the firm. Fishbowls elicit greater effort and higher quality output from creative professionals, because more people see—and judge—their work. Finally, fishbowls make it less likely that a former employee will peddle proprietary secrets, because such behaviors become widely known. Malfeasance in a fishbowl will at the very least impair an individual's reputation and, to the extent that the transgression is more likely to become widely known, will increase vulnerability to legal recourse.[53]

Never Stop Hiring Someone

Once hired, an employee has traditionally been viewed as an asset or resource, with the firm enjoying leverage once the employee has signed the requisite employment agreements. In an era of increased inventor savvy, however, companies must constantly compete for talent, *including the talent they have already hired*. Conventional means of doing this include promotion into management (though gatekeepers can rarely stay sharp technically if they become overburdened by business or administrative tasks) and higher pay (for example, from 2001 to 2003, eBay's chief technologist earned more than twice as much as its CEO).[54] Many scientists, engineers, and other creative professionals value "horizontal" growth as well as financial rewards and "vertical" promotions. They accomplish horizontal growth by extending their reputations among peers who tend to be widely scattered throughout companies, universities, and other organizations and enterprises. As demonstrated by the popularity of open-source projects such as Mozilla and Linux, the opportunity to develop technical status, both within and outside of the firm, provides intrinsic motivation to technical professionals.[55]

Publishing in scientific journals and presenting at conferences also motivates technical professionals, yet many companies either censor or disallow outside publication. It is easy to overestimate the damage of disclosure via publishing. PageRank, the heart of the original Google search engine, has been openly and extensively described in a number of publications,[56] yet Google (up until now) has maintained its commercial advantage. This example illustrates the difficulties of turning ideas into successful products; even after a breakthrough algorithm has been invented, there remain formidable implementation challenges, including writing the code, porting it to enough machines to demonstrate its credibility, scaling it up to commercial viability, and finding paying customers. The analog of this advantage in physical technologies is the crucial role of tacit "bench knowledge" in the replication of results. Inventions in biotechnology and nanotechnology often require complex physical processes that are difficult to replicate without detailed documentation (far more than is required or expected for peer-reviewed publication) or direct social interaction. Because scientists are generally more interested in credit for the algorithm or results than in documenting nuanced tacit details, inventors and their firms both win. Encouraging scientists and engineers to publish can also benefit firms financially; one study showed that scientists allowed to publish will on average accept lower salaries.[57]

Publishing's outward information flow also increases the likelihood of inbound information flow.[58] Because technical professionals prefer to interact with bright colleagues who can bring something to the table, managers intent on being in the ferment of ideas must give their own professionals permission to share. Chuck Morehouse, a director at Hewlett-Packard Laboratories, explained: "One of the things that HP needs to do just to keep its own people alive and healthy is to participate in the scientific community. That helps us attract the best students and keep our own people alive and vibrant."[59] Of course, participation in scientific communities needs to be carefully defined and regularly discussed to ensure that sensitive material remains confidential or receives protection prior to being shared. As part of an open publication strategy, management should also ensure that technical professionals with outside contacts are aware of intellectual property laws, corporate strategies, and competitors.

While we hesitate to generalize based on (even methodically sampled) fieldwork, we found the experience of the gatekeepers in our diagrams to be consistent with our managerial prescriptions.[60] One of the gatekeepers stayed at a traditionally managed firm until the firm went bankrupt (part of the reason for the bankruptcy was the firm's poor estimation of external technology trends). Another gatekeeper's early jobs were at conventionally managed firms; since then he has been relatively mobile even by Silicon Valley standards and continues to manage in the fashion of his early experience (that is, he does not follow our prescriptions). Two other gatekeepers have been allowed to publish and collaborate externally; one of them spent over ten years at a single firm and the other is still at his original firm more than 30 years later.

Small Worlds: The New Inventive Basis of Innovation

The world of invention is shrinking due to the increasing connectivity of collaborative relationships between creative professionals. Small worlds can greatly enhance creativity by affording insular clusters of collaboration access to new information, but they can also increase the likelihood that firms' competitors will more quickly learn about any breakthroughs. To prosper in small worlds, firms must embrace, exploit, and trust their professionals' connectedness. Managers need to identify their key gatekeepers, recognize them with financial rewards and status, support the development of their reputations, and include them in deliberations about corporate strategy. The alternative—conventional strategies of restricting information flow and access to personnel—will alienate the firm's inventors and make it more difficult for the firm to attract elite inventors and maintain a creative edge in the future.

Ironically, cheap creative opportunities increase the value of an enterprise's non-creative complementary assets.[61] By improving creative processes for all firms, small worlds increase the importance of the management functions that identify, leverage, and support creativity. Firms that excel at product development or manufacturing or marketing can multiply the value of these assets by hiring the best inventors, motivating them with challenging work, placing them within small world networks, and doing a better job of leveraging their increased creativity.

Small worlds are fast-paced Darwinian environments in which ideas are cheap, knowledge flows freely, and talent seeks opportunity. Hewlett-Packard Senior Research Fellow Stan Williams describes his firm's small world: "Ideas are a dime a dozen. What's hard is taking an idea and turning it into something real. That's what we need talented people for."[62] Firms succeed in a small world not by surrendering leadership to their top geeks, but by helping their gatekeepers build external networks and heeding their advice about technological opportunities and competitive threats. As has been demonstrated in Silicon Valley, small worlds make it difficult for firms with conventional views of creativity to survive. They raise the bar of success by accelerating invention and the urgency of commercializing good ideas, to the ultimate benefit of all the firm's stakeholders.

Notes

1. H. Chesbrough, *Open Innovation: The New Imperative for Creating and Profiting from Technology* (Boston, MA: Harvard Business School Press, 2003).
2. For entry points into the psychology and social-psychology literatures, see T. Amabile, *Creativity in Context* (Boulder, CO: Westview Press, 1996); D. Simonton, *Origins of Genius: Darwinian Perspectives on Creativity* (New York, NY: Oxford University Press, 1999); P. Paulus and B. Nijstad, *Group Creativity* (Oxford: Oxford University Press, 2003). For structural perspectives, see R. Burt, "Structural Holes and Good Ideas," *American Journal of Sociology*, 110 (September 2004): 349-399; B. Uzzi and J. Spiro, "Collaboration and Creativity: The Small World Problem," *American Journal of Sociology*, 111 (September 2005): 447-504.
3. L. Fleming, C. King, and A. Juda, "Small Worlds and Regional Innovation," *Organization Science*, under revision.
4. Saxenian made the original argument for denser networks in Silicon Valley and was the first to identify and document many of the phenomena we studied. See A. Saxenian, *Regional Advantage* (Cambridge, MA: Harvard University Press, 1994).
5. See L. Fleming, S. Mingo, and D. Chen, "Brokerage and Collaborative Creativity," Harvard Business School working paper, 2005. While the regional analyses revealed a positive though inconsistently significant small world interaction, the individual-level analyses demonstrated a robust positive interaction. Though the two results are consistent, we rely much more heavily upon the latter research, because it was randomly sampled to avoid network auto-correlation and instrumented to control for endogeneity.
6. J. Singh, "Collaborative Networks as Determinants of Knowledge Diffusion Patterns," *Management Science*, 51/5 (May 2005): 756-770.
7. J. Travers and S. Milgram, "An Experimental Study of the Small World Problem," *Sociometry*, 32 (1969): 425-443.
8. D.J. Watts and S.H. Strogatz, "Collective Dynamics of 'Small-World' Networks," *Nature*, 393 (1998): 440-442; D.J. Watts, *Small Worlds: The Dynamics of Networks between Order and Randomness* (Princeton, NJ: Princeton University Press, 1999); M.E.J. Newman, A.L. Barabasi, and D.J. Watts, eds., *The Structure and Dynamics of Complex Networks* (Princeton, NJ: Princeton University Press, 2003).
9. See T. Allen, *Managing the Flow of Technology* (Cambridge, MA: MIT Press, 1977).
10. Robert Stewart, interview by first author, Cambridge, MA, June 17, 2004.

11. The idea that small worlds improve creativity has recently been an area of intense research activity, though our research proposes and demonstrates novel mechanisms that are contrary to some of those previously argued. For example, see A. Hargadon, *How Breakthroughs Happen: The Surprising Truth About How Companies Innovate* (Boston, MA: Harvard Business School Press, 2003); Uzzi and Spiro, op. cit.; Melissa A. Schilling and Corey C. Phelps, "Interfirm Collaboration Networks: The Impact of Small World Connectivity on Firm Innovation," December 2005, <http://ssrn.com/abstract=564422>.
12. See D. Obstfeld, "Social Networks, the Tertius Iungens Orientation, and Involvement in Innovation," *Administrative Science Quarterly*, 50/1 (March 2005): 100-130; Uzzi and Spiro, op. cit.; Burt, op. cit.
13. Fleming, Mingo, and Chen, op. cit.
14. J.S. Coleman, "Social Capital in the Creation of Human Capital," *American Journal of Sociology*, 94 (1988): S95-S120.
15. Michael Porter has written extensively about the benefits to regional competitiveness of clustering specialists in a field. Porter's theory of clusters was introduced in Michael Porter, *The Competitive Advantage of Nations* (New York, NY: Free Press, 1990) and later developed in several articles including Michael Porter, "Clusters and the New Economics of Competition," *Harvard Business Review*, 76/6 (November/December 1998): 77-90; Michael Porter, "Location, Clusters, and Company Strategy," in G. Clark, M. Gertler, and M. Feldman, eds., *Oxford Handbook of Economic Geography* (Oxford: Oxford University Press, 2000).
16. See Burt, op. cit.; Obstfeld, op. cit.
17. Fleming, King, and Juda, op. cit.
18. See Saxenian, op. cit.; P. Almeida and B. Kogut, "Localization of Knowledge and the Mobility of Engineers in Regional Networks," *Management Science*, 45 (1999): 905-917.
19. In both regions, in the years before the small worlds grew to encompass more than one predominant organization, the dominant organization in the largest cluster changed several times. In Silicon Valley, dominance alternated between Raychem and IBM; in Boston, between DEC and MIT.
20. For greater detail, see L. Fleming, L. Colfer, A. Marin, and J. McPhie, "Why the Valley Went First: Agglomeration and Emergence in Regional Inventor Networks," in W. Powell and J. Padgett, eds., *Market Emergence and Transformation* (Santa Fe, NM: Santa Fe Institute, forthcoming); L. Fleming and K. Frenken, "The Evolution of Inventor Networks in the Silicon Valley and Boston Regions," *Advances in Complex Systems* (forthcoming).
21. For a description of a similar postdoc program at Syntex (coincidentally, the predominant firm on the other side of the IBM-pharmaceutical bridge depicted in Figure 3), see A. Kornberg, *The Golden Helix: Inside Biotech Ventures* (Sausalito, CA: University Science Books, 1995).
22. John Campbell Scott, interview by first author, Santa Clara, CA, May 12, 2003.
23. We define regions using the conventional Metropolitan Statistical Area designation. Boston is region 1120 and Silicon Valley is region 7400. See U.S. Census Bureau, "Reference Resources for Understanding Census Bureau Geography," <www.census.gov/geo/www/reference.html>, accessed April 13, 2004. Different regional definitions and window sizes did not substantively influence the observed processes of network aggregation.
24. While our focus is upon regional differences in small worlds, we strongly suspect variance across industries as well. For example, industries with stronger academic ties are probably more small world, and different academic fields probably have different clustering and small world properties. See M. Newman, "The Structure of Scientific Collaboration Networks," *Proceedings of the National Academy of Sciences*, 98 (January 16, 2001): 404-409. Current research attempts to describe the industrial differences in collaborative structure and inventor mobility.
25. R.J. Gilson, "The Legal Infrastructure of High Technology Industrial Districts: Silicon Valley, Route 128, and Covenants Not to Compete," *New York University Law Review*, 74 (1999): 575-629.
26. We suspect this happened due to the weakening of mutual loyalty (the "psychological contract") between employers and employees and are developing more direct tests of this hypothesis.
27. "Centrifugal Forces: Americans Are Still Restless in the Midst of Plenty," *Economist*, July 16, 2005, pp. 4-7.
28. T. Gura, "Joining a Trend, Scientists Increasingly Say 'Call My Agent,'" Science, 303 (2004): 303-305.

29. R. Gulati and M. Gargiulo, "Where Do Interorganizational Networks Come From?" *American Journal of Sociology*, 104 (1999): 1439-1493.
30. L. Fleming and A. Juda, "A Network of Invention," *Harvard Business Review*, 82/4 (April 2004): 22.
31. S. Barley and G. Kunda, *Gurus, Hired Guns, and Warm Bodies: Itinerant Experts in a Knowledge Economy* (Princeton, NJ: Princeton University Press, 2004).
32. For an entertaining story of subterfuge, obsession, and ultimate victory for the geeks, see R. Avitzur, "The Graphing Calculator Story," <www.pacifict.com/Story/>, accessed July 4, 2005; S. Levy, "They Hacked Real Good, for Free," *Newsweek*, January 10, 2005.
33. See <http://news.com.com/Where+are+Netscapes+pioneers+today/2100-1032_3-5406730.html> and <http://ex-mozilla.org> for biographies of more than 900 ex-Netscape employees.
34. The bursting of the technology bubble aside, we believe (though we lack systematic evidence) that power remains with high-powered inventors, as evidenced by Microsoft's inability to retain Kai-Fu Lee after he announced plans to defect to Google.
35. Though we cannot directly cite the firm involved, we fictionalized the true story in L. Fleming and M. Marx, "Barry Riceman at NetD," Harvard Business School Case Study No. 606-090. Whether or not the inventor was justified remains unclear; engineers can leave a firm with their ideas "before an inventive concept has taken on a concrete, tangible form," according to R. Merges, "The Law and Economics of Employee Inventions," *Harvard Journal of Law and Technology*, 13/1(Fall 1999), pg. 3.
36. Fleming, Colfer, Marin, and McPhie, op. cit.
37. Amabile, op. cit.
38. Michael Souza, interview by second author, March 21, 2005, Cambridge, Mass.
39. Intel provides a counterexample—a successful firm that has pursued an aggressive litigation strategy. Hyde describes the hiring problems that accompany this strategy. See A. Hyde, *Working in Silicon Valley: Economic and Legal Analysis of a High Velocity Labor Market* (Armonk, NY: M.E. Sharp, 2003). Formal economic models that demonstrate the benefits to firms of greater mobility include B. Anand, A. Galetovic, and A. Stein, "Incentives versus Synergies in the Markets for Talent," Harvard Business School working paper, 2004; R. Lewis and D. Yao, "Innovation, Knowledge Flow, and Worker Mobility," Fuqua School of Business working paper, 2003.
40. A. Tversky and D. Kahneman, "The Framing of Decisions and Psychology of Choice," *Science*, 211 (1981): 453-458.
41. See M. T. Hansen, "The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits," *Administrative Science Quarterly*, 44/1 (March 1999): 82-111; Singh, op. cit.
42. For particular emphasis on the development of business models in an open and increasingly connected environment, see H. Chesbrough, *Open Innovation: The New Imperative for Creating and Profiting from Technology* (Boston, MA: Harvard Business School Press, 2003); M. Iansiti and R. Levien, *The Keystone Advantage: What the New Dynamics of Business Ecosystems Mean for Strategy, Innovation, and Sustainability* (Boston, MA: Harvard Business School Press, 2004). For more general works on technology and strategy, see S. Wheelwright and K. Clark, *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality* (Boston, MA: Harvard Business School Press, 1992); S. Thomke, *Experimentation Matters* (Boston, MA: Harvard Business School Press, 2003).
43. Although bridging inventors can connect firms internally as well (as illustrated by Stewart in Figure 2), this article is concerned with the more important, challenging, and increasingly common problem of managing across firm boundaries.
44. Allen, op. cit.; M. Tushman, "Special Boundary Roles in the Innovation Process," *Administration Science Quarterly*, 22/4 (December 1977): 587-605.
45. Allen, op. cit.
46. Pyare Khanna, interview by first author, Fremont, Calif., July 10, 2003.
47. See Obstfeld, op. cit.
48. For the first stage of idea generation, 60% of the effect remained after controlling for the inventor with fixed-effects models (such models assume that the inventor's innate intelligence or creativity remains fixed over his or her lifetime). For the second stage of idea diffusion, between 70% and 80% of the effect remained after estimating fixed-effects models. An instrumented version of the structural variable also returned similar results. Hence we inferred that most of the effects are due to differences in collaborative structure.

49. See C. Christensen, *The Innovator's Dilemma* (Boston, MA: Harvard Business School Press, 1997); M. Tushman and C. O'Reilly, *Winning through Innovation: A Practical Guide to Leading Organizational Change and Renewal* (Boston, MA: Harvard Business School Press, 1997).
50. See S. Klepper and P. Thompson, "Spin-Off Entry in High Tech Industries: Motives and Consequences," Carnegie Mellon University working paper, 2006.
51. This has become more common lately. See J. Lerner and Paul Gompers, "The Determinants of Corporate Venture Capital Success: Organizational Structure, Incentives, and Complementarities," in Randall Morck, ed., *Concentrated Ownership* (Chicago, IL: University of Chicago Press for the National Bureau of Economic Research, 2000), pp. 17-50.
52. See Anand, Galetovic, and Stein, op. cit.; Merges, op. cit.
53. Trade secret law remains enforceable, to varying degrees, in all states. See Hyde, op. cit.
54. Hoover's online database.
55. K.R. Lakhani and R. Wolf, "Why Hackers Do What They Do: Understanding Motivation and Effort in Free/Open Source Software Projects," in J. Feller, B. Fitzgerald, S. Hissa, and K. R. Lakhani, eds., *Perspectives on Free and Open Source Software* (Cambridge, MA: MIT Press, 2005).
56. See <http://dbpubs.stanford.edu:8090/pub/showDoc.Fulltext?lang=en&doc=1999-66&format=pdf&compression=>, among other sites.
57. Scott Stern, "Do Scientists Pay to Be Scientists?" *Management Science*, 50 (2004): 835-853.
58. W. Cohen and D. Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly*, 35/1 (March 1990): 128-152.
59. Chuck Morehouse, director of Hewlett-Packard's Information Access Laboratory, interview by first author, Palo Alto, CA, June 18, 2005.
60. We do not specify the particular inventors in these cases out of respect for their privacy.
61. D. Teece, "Profiting from Technological Innovation," *Research Policy*, 15 (1986): 285-305.
62. Stan Williams, director of Hewlett-Packard's Quantum Science Research Group, interview by first author, Palo Alto, Calif., June 18, 2005.