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Social capital: its relationship to innovation in science and technology

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This paper argues that social capital is a necessary, although not sufficient, enabler of effective public–private partnerships and of a new, more collaborative style of innovation policy, although its significance for science and technology policy, has yet to be assimilated by most policy-makers. The network structure of the biotechnology industry in the United States and the regional-based industrial system in Silicon Valley, California are used to show how social capital affects innovation in science and technology. Two US national policy programs — the Advanced Technology Program and the Manufacturing Extension Partnership — make evident the growing importance of network development. A set of recommendations is given, designed to enhance innovative capacity through the formation of social capital. The central arguments regarding social capital and its relationship to innovation transcend national boundaries, and many of the policy recommendations are important for western European, some East Asian and several other industrial states.

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THE TREND TOWARD inter-organizational linkages in the form of partnerships, alliances, and consortia has contributed to economic revitalization and growth in a number of developed and less developed countries. Many firms, industries, and regions throughout the world that are currently successful have formed productive collaborative relationships with a variety of other firms, laboratories, universities, and governments to take advantage of the benefits of cooperation, which include shared resources, shared staff and expertise, group problem-solving, multiple sources of learning, collaborative development, and diffusion of innovation.

For example, Japanese industries, particularly in automobile manufacturing, machine tools, and electronics, rely at least in part on networks of small and medium-size suppliers for flexible production and new technologies.[1] The economy of Baden-Wurttemberg in Germany is characterized by interdependent groups of small and medium-size firms engaged in the production of auto parts, textile machinery, and machine tools.[2] The flexible, innovative design and production of advanced capital goods such as computer-controlled machine tools, industrial robots, and quality ceramics exemplify the dynamism of high-tech industry networks in the *Terza Italia* in central Italy.[3]

In each of these cases, as well as several others in countries including those as disparate as Denmark, Spain, Taiwan, and Hong Kong, geographically proximate networks include not only small, medium, and, in some cases, large firms but also local and national governments whose social policies encourage a stable supply of labor with requisite skills and knowledge, and whose economic policies both

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remove impediments to non-collusive collaboration and encourage productive partnership.

The contribution to institutional effectiveness of all these relationships measured in terms of economic performance and innovative capacity — horizontally among similar firms in associations, vertically in supply chains, and multidirectionally in links to sources of technical knowledge, human resources, and public agencies — I refer to as 'social capital.' This form of capital, as powerful as physical and human capitals, is the 'stock' that is created when a group of organizations develops the ability to work together for mutual productive gain.[4] The concept is drawn from research that demonstrates the effect of institutional and social arrangements on economic development. It has more recently been extended to explain differences in innovation rates among countries with similar capital, labor, and national resources.[5]

In this paper, I explore the relationship between social capital and innovation in science and technology. This relationship holds across most politico-economic settings as exhibited by the wide range of countries with innovative, collaborative networks. This paper, however, draws case material from recent efforts in the United States to leverage network structures to enhance technological innovation.

I argue that social capital is a necessary, although not sufficient, enabler of effective public–private partnerships and a new, more collaborative style of government policy. The fundamental significance of social capital for innovation, and thus for science and technology policy, while noted by observers at the forefront of thinking in this area, has yet to be assimilated by many US policymakers and captured in the design of policy tools.[6] So far, almost no explicit attention has been directed toward the effect of social capital on innovation, but the relationship is important and has serious implications for science and technology policy.

In contrast to political and economic perspectives that emphasize individualism, closely held information, and autonomy, social capital is derived from those perspectives in which cooperation paradoxically enhances competitiveness, information sharing leads to joint gains, and the importance of reputation and trust ensure reciprocity and fair play within a given network. Adam Smith and other classical economists of the 19th century recognized that any firm needs an underlying fabric of shared values and understanding to make division of labor meaningful.

Social capital is derived from those perspectives in which cooperation paradoxically enhances competition, information sharing leads to joint gains, and the importance of reputation and trust ensure reciprocity and fair play within the network

Smith's observation is no less true today. When partnerships and consortia succeed, the glue that holds them together is not simply in the form of contracts that detail every aspect of these complex and dynamic relationships (although contracts are, of course, important). Nor is cohesion to be found exclusively in the information systems that link networks of organizations. A critical 'glue' in the new political economy, characterized by rapid technological change, scarcer resources, and increased global competition, is the trust, or enlightened self-interest, among decisionmakers that makes collaboration feasible.

The dramatic changes that have occurred in private industry throughout the world have constituted a highly compelling challenge to liberals and conservatives to craft a consensus policy that will strengthen civilian science and technology.[7] An effective science and technology policy should aid the ability of the private sector to reconfigure itself in ways that advance rapid technological change and diffuse innovation. It should recognize and support the fact that business and industry are now conducted on the basis not only of strategic alliances and partnerships but also on the basis of networks of learning and innovation.

In the next section I define social capital in some detail and then extend the concept to explain how social capital affects innovation in science and technology. I present two cases of 'best practice' drawn from the United States: the US biotechnology industry and the regional-based industrial system in Silicon Valley, California. Both are highly innovative networks that demonstrate the importance and prevalence of external firm relationships to innovation.

I then describe two national-level US programs designed to support the growing need for consortia development. The Advanced Technology Program (ATP) in the National Institute of Standards and Technology (NIST) of the Department of Commerce provides incentives for the development of new technologies or new applications of technologies. The Manufacturing Extension Partnership (MEP), also sponsored by NIST, is a collaborative effort involving the national and state governments, academic institutions, industry associations, and non-profit organizations. The Partnership focuses on industrial firms with less then 500 employees.

The final section of this paper presents a set of recommendations designed to enhance national innovative capacity through the formation of social capital. Although the recommendations have been developed with the United States as their primary focus, they have relevance for a number of other industrialized countries.

What is social capital?

Like "physical capital and human capital — tools and training that enhance individual productivity — 'social capital' refers to features of social organization, such as networks, norms, and trust, that facilitate coordination and cooperation for mutual benefit."[8] The notion of social capital extends our understanding of 'cooperation' or 'collaboration' in two significant ways. First, linking cooperation to the economic concept 'capital' signals the investment or growth potential of a group's ability to work jointly. Second, the concept identifies the *structure* created from collaborative effort as capital.

Well-functioning partnerships, consortia, and networks are in and of themselves "a form of social capital."[9] Capital is located both in the sharable resources held by individual institutions in a network and in the overall structure, or relationship, among the institutions in a network. For example, a group of scientists who have collaborated on a relatively small scientific project may then use their collaborative ability to propose and complete larger, riskier research projects. They may then further use their network to address the economic revitalization of their community. Their originally small network may be extended to members of the political and business community: small cooperative ventures may grow into more ambitious undertakings as parties learn how to collaborate productively and develop reputations for trustworthiness.

Social capital, like other forms of capital, accumulates when used productively. Traditional economic perspectives that focus on short-term self interest and individual transactions ignore the accretion, or growth, opportunities of cooperation.[10] Closely related to accretion is the self-reinforcing cyclic nature of social relations. Trustful relations tend to be self-reinforcing in the positive direction. Mistrust tends to cycle in the negative direction.

The concept of social capital is relatively simple, yet its opposite was viewed until recently as the common, if unfortunate, order of most economic relations. Consider the 18th century Scottish philosopher David Hume's pessimistic account of human nature:

> "Your corn is ripe today; mine will be so tomorrow. 'Tis profitable for us both that I should labour with you today, and that you should aid me tomorrow. I have no kindness for you, and know you have as little for me. I will not, therefore, take any pains upon your account; and should I labour with you upon my own account, in expectation of a return, I know I should be disappointed, and that I should in vain depend upon your gratitude. Here then I leave you to labour alone; You treat me in the same manner. The seasons change; and both of us lose our harvests for want of mutual confidence and security."[11]

Hume wrote of the dilemma economists typically refer to as the problem of "collective action." Although in most situations all parties would be better off were they to cooperate, collective action theory argues that, in the absence of an overarching authority to enforce appropriate behavior or clear mechanisms to ensure commitment, individuals will tend not to take the risks of cooperation. None achieves the gains from cooperation and all are worse off.

Policy experts, drawing on collective action theory, have long argued that the coordination costs associated with interorganizational and interjurisdictional arrangements often exceed the benefits.[12] They have stressed the need for clear lines of authority and strong, centralized governance structures to monitor behavior and to enforce sanctions against inappropriate actions. However, during the past decade or so, social scientists from a variety of disciplines, as well as an increasing number of policy experts, have noted and have sought to explain the proliferation and success of collaborative arrangements in a variety of policy settings. The broad term 'social capital' captures many of the salient properties that allow these arrangements to prosper.

Constituent elements

The constituent elements of social capital are trust, norms, and networks. Trust is developed over time as individuals gain confidence in the reliability of others in a series of interactions.[13] A key property of social capital rests on the transitivity of trust: A trusts C because B trusts C and A trusts B. Thus, relatively large networks may exhibit generalized trust without close personal contact among all members.

Norms of appropriate behavior develop as a social contract is negotiated among actors. Experts have noted that the norm of reciprocity is fundamental to productive relationships. In politics and bureaucratic behavior this norm is well known as the "favor bank."[14] Closely linked to reciprocity is a norm that actors will forgo their immediate self-interest to act not only in the interest of the group but in their own long-term self-interest.[15] Thus, a reputation for trustworthiness, so important in politics and government, is also essential to actors within collaborative networks.

Social capital is preserved by careful selection of network players and strict sanctioning of inappropriate (network-destroying) behaviors. A network develops when a group of individuals or organizations develops reliable, productive communication and decision channels and a more or less permeable boundary to define members.

It is important to note in any discussion of the concept that social capital, like its constituent elements, trust, norms, and networks, is inherently neither good nor bad. It is a tool that may be employed for legal or illegal purposes, for good or ill. Trust allows actors to engage in productive collaboration, but also provides a necessary condition for fraud and other illegal activities. Norms decrease transaction costs and regulate behavior, but when improperly used, they may stifle the creativity and diversity of opinion necessary for solving novel and complex problems.

Networks of firms collaborating to produce new technologies or applications widely report the benefits of cooperation; cartels, unfortunately, also understand the benefits of network approaches to production and distribution. The important point is that social capital is a powerful resource that develops from productive social ties. Its use depends in part on the values and objectives of the actors involved.[16] In those cultures characterized by strong legal systems as well as deeply embedded norms of professional and legal practice, the benefits that flow from social capital outweigh the dangers, given adequate levels of government scrutiny to protect against potential collusive activity.

Foundation for economic development

In fact, within the public policy community, after decades of failure and billions of lost dollars invested in the impoverished nations of the world, development experts have come to appreciate the importance of social capital as the foundation for economic development. Policy experts have documented the importance and extent of rotating credit associations — informal collective savings and loan plans — that prosper throughout the world.[17]

Other researchers have studied the collaborative stewardship of common-pool resources, such as water supplies and grazing areas, that are managed for long-term collective benefit.[18] Experts on urban development in the advanced industrial nations have made the formation of social capital a fundamental element of policies to build and strengthen the social and economic fabric in cities. International relations scholars have documented the extent to which international agreements of many types are developed and adhered to in the absence of overarching authority.

Empirical research on the characteristics of successful cooperative arrangements indicates a set of conditions that aid the formation of social capital. When actors form relationships over a period of time long enough to establish a series of transactions, reputations for fairness and reliability may be built which lead to trustful relations.[19] Successful cooperative arrangements tend to have a limited number of players, which renders information regarding reputations and transactions easily shared within the network. Successful formation of social capital requires that actors value the long-run relationship and its material benefits highly enough to forgo immediate gains.

The boundaries and objectives of the network must be clearly defined. In some cases, it has been important for participants in the network to define the rules under which they will cooperate. Graduated sanctions must be in place to restrict inappropriate actions

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without destroying the network. Similarly, well-performing networks must develop conflict resolution mechanisms in order to resolve inevitable disagreements.[20] Finally, network sanctions may well require balancing by the positive feedback of intermediate rewards in order to sustain strategic expectations.[21]

How social capital increases innovation

As the pace of technological change has intensified, as economic resources have become more scarce, and as information technologies have made linkages among geographically dispersed actors commonplace, the predominant form of economic organization has been changing. Large, centralized bureaucracies emphasizing division of labor and functional specialization have given way to smaller, leaner organizations in which team-based structures cross functional lines, disrupt traditional hierarchical chains of command, and focus on core functions while contracting with outside firms for other tasks.

Supplier relationships

As an adjunct to internal restructuring, large manufacturers have turned to long-term external supplier relationships for many inputs to the production process as well as a variety of operational and administrative functions. Thus, specialized technological knowledge (and innovation) increasingly reside in small and medium-sized suppliers whose 'research and development' takes place in team-based configurations on the shop floor rather than in corporate laboratories staffed with scientists working on long-range basic research.

Industry experts have noted that the base of technology offerings has increased to the point that it has outstripped the capacity of single firms in rapidly changing industries, such as automobile manufacturing, to remain competent in the technology fields relevant to their business.[22] In addition, the investments necessary to sustain technology development and deployment have increased to the point that single firms often cannot take the level of risk necessary for innovation. For these reasons, supplier relationships have grown in importance. For complex products, suppliers function both as partners and independently to develop and deploy new technologies.[23]

Relationship with government agencies

Another change is found in the relationship of firms to an array of government agencies with jurisdiction over regulation, research and development funding, standards setting, procurement, and other functions that shape the capacity of firms to innovate.[24] A significant effort is being made in a number of countries to reduce the extent of mandatory regulations enforced by primitive sanctions, and to replace them with a growing array of incentives and disincentives intended to induce firm behavior that satisfies public needs while allowing firms to optimize their economic performance.

If government–industry relationships also contribute to the formation of social capital necessary to innovation in science and technology, government must continue to modernize its management, rules, and behavior to contribute. The criticality of innovation to economic performance and competitiveness is one powerful reason to move away from a market economy bounded by hard walls of government regulation to one with permeable boundaries of government incentives and disincentives.

Network structure

The presence of a network of institutions in no way assures collaboration. Many networks are highly discordant, mired in contractual disputes and lack of coordination.[25] However, high-performing network actors learn to collaborate. Firms take advantage of their information-processing capacity through the network form. Unless the network that provides firms with new sources of efficiency and opportunities for innovation is open in structure and efficient in information exchange, little advantage can be gained. Thus the transformation in information networks from hierarchically structured and centrally controlled to highly efficient and flexible peer-to-peer (mesh) network structures has been a key factor in enabling the formation of new sources of social capital.

Compared to large, hierarchical structures, network structures can scan the environment for changes more effectively, interpret environmental change more accurately, and craft responses to change more creatively and adaptively. Better scanning means stronger capacity for timely and accurate problem recognition. Greater effectiveness of interpretation enhances policy and problem formulation, estimation of parameters, and selection from among alternative policy choices. Greater adaptability translates into timely innovation and enhanced alignment of firms, practices, and products with environmental conditions.

Shared information

It should be clear from this discussion that social capital is entirely different from "informational capital."[26] Many observers have noted the importance of shared information to entrepreneurship and economic growth. Although open access to information, notably through the Internet, provides a variety of opportunities, informational capital is not a replacement for social capital.

Social capital provides decisionmakers with far more important information benefits than access to the Internet. Useful access involves understanding who will benefit from specific information. It also involves screening information for accuracy, importance, and implications. Collaborative networks perform this critical screening function.[27]

Social capital encompasses not only shared access to vast amounts of timely information but many positive properties of interdependence: shared values, goals, and objectives; shared expertise and knowledge; sharing of work, decisionmaking, and prioritization; shared risk, accountability, and trust; and shared rewards.[28] Social capital increases the ability to build and use informational capital because trustful relationships increase information flows and bring richer meaning to information.

Actors in a collaborative network exhibit an efficient form of collective learning. They learn of new technologies, opportunities, the outcome of transactions, and challenges more quickly because of the density of interaction within the network. Learning is of a higher quality because it is subject to discussion and debate among horizontal counterparts whose perspectives and backgrounds may differ. For this reason, geographic regions that include highly adaptive industry networks have been termed "learning regions."[29]

By contrast, vertically organized firms and their supply chains with few horizontal connections tend toward characteristics that adversely affect information-processing capacity: inward, insular focus; unproductive levels of vertical integration within large firms and bureaucracies; unproductive levels of secrecy and organizational loyalty that dampen information sharing within and across professions; norms of institutional stability and autonomy that fit poorly with a turbulent economic, technological, globally competitive environment; authority centralized at unproductive levels; and predominantly vertical flows of information, which tend to be slower, biased, and thus less reliable. Regions characterized by firms with these properties cannot innovate as effectively as a collaborative network. In fact, attempts at partnerships and consortia under these conditions of low trust lead either to failure or to poorly performing, noncollaborative networks.

Electronic interface

Understanding the differences in information processing in large, vertically integrated hierarchies versus more horizontal network structures is critical to understanding how social capital is built and maintained in the latter, and how it leads to greater innovation potential. Differences in environmental

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scanning, information flows, and relative lack of bias aggregate to a greater capacity to innovate in the network form than within a hierarchy. Dense social networks can encourage experimentation and entrepreneurship among actors because of the mix of collaboration and competition within the network. Network members compete fiercely but also collectively process and share information about environmental changes including markets, regulations, technologies, and opportunities.

Interorganizational networks, partnerships, and consortia could not function to the extent and at the levels of interaction now typical without an electronic interface. However, the promise of information technologies to bring about vast changes in the structure, systems, and management of business and industry, far beyond those discussed in this paper, has yet to be achieved.[30] Researchers consistently note the resistance of systems and structures to change even in the face of the great potential for increased efficiency offered by new information technologies. The ability to collaborate both within and among firms and other organizations appears to be a necessary condition for firms to take advantage of new technologies rather than resisting change.

The explosive growth of Internet use prompts another question: Does social capital have to be built face-to-face? Currently, experts disagree regarding the importance of face-to-face interaction for the formation of trust and collaboration. Technology researchers celebrate the ability of information technology to make distance and time constraints virtually meaningless. However, most of the research that has been conducted on industry networks notes the importance of geographic proximity. More empirical study is required to understand the potential for developing social capital in geographically dispersed networks.

In spite of the need for continuing research efforts, the responsibility of national governments to invest in information infrastructure is clear and relates importantly to the ability of researchers in science and technology to collaborate in a variety of ways.[31] The more difficult investments in information infrastructure are not hardware but software and institution-building to enable industry restructuring and partnerships, to enhance education and training at all levels, and to make the resources of libraries and information services available throughout and, increasingly, among nations.[32]

Dynamics of collaboration in networks

The two illustrations from the United States that follow present examples of high-performing network structures that have developed significant levels of trust. The first case describes the ways in which firms in the US biotechnology industry form partnerships to remain at the forefront of research and development. The second case outlines the dynamics that undergird regional industrial systems, exemplified in this case by the semiconductor industry in Silicon Valley, California.

Biotechnology industry: learning networks

The biotechnology industry in the US provides a cutting-edge example of new forms of industry operation that demand an intensive level of external collaboration. The traditional view of technological development and industry structure holds that technologies follow a typical life cycle whose character shapes the form of an industry. In industries as diverse as high technology, heavy manufacturing, and utilities, the trajectory of technological development and change, and its effect on industry structure have been viewed by scholars as roughly similar.

Within an early experimental period during which technologies are young, many firms compete and exhibit high turnover rates. As the dominant technologies for the industry take shape, those firms that best exemplify the leading technologies build economies of scale and are able to adopt the most efficient process technologies and market-scale economies, thereby blocking new entrants to the field. As the industry matures, less efficient firms are driven out of business by market forces, while a small number of leading firms, traditionally viewed as the most efficient, remain.[33]

However, under conditions by which "new discoveries create technological discontinuities or radical breaks from previously dominant methods," leading firms may lose their traditional advantage, and new ways of doing business may emerge that better exploit the new technologies.[34] Biotechnology is an industry characterized by radical, or discontinuous, technological advances.

> "Biotechnology represents a competence-destroying innovation because it builds on a scientific basis (immunology and molecular biology) that differs significantly from the knowledge base (organic chemistry) of the more established pharmaceutical industry."[35]

Thus, one would expect that the traditional model would not hold, but that instead many firms would continue to compete over a longer period of time.

Many experts regard strategic alliances to be the foundation for inter-firm collaboration in business and industry. Whereas large firms in the past maintained in-house research and development laboratories to retain dominance in their core technologies, firms increasingly have externalized this function through cooperative agreements with other firms, research laboratories, and universities. Most experts explain the rise in consortium activity as attempts to reduce the cycle time of innovation, to reach new markets and technologies, to share risks and gain complementary competencies.[36]

However, other researchers have argued that, when the knowledge base that supports an industry is hard to comprehend, still emerging, and distributed across several organizations, then collaboration among firms, universities, and national laboratories will reflect a strong and fundamental interest in "access to knowledge" rather than simply with strategic calculation, resource sharing, or transaction cost reduction.[37] Internal expertise remains necessary to evaluate external research and development, but external relations facilitate access to new information and expertise that is not easily built within the firm. The biotechnology industry exemplifies this concern with knowledge access. The shape of the industry provides strong evidence for the effect of social capital on innovation.

The birth and early development of the US biotechnology industry occurred during the 1980s and early 1990s. The National Institutes of Health (NIH) played a vital role in the formation of the industry by its support of $65 billion of scientific research through universities and their buffer institutions.[38] National-level support comprised the funding source of initial biotech firms and remains a continued source of sustenance.

One of the striking aspects of this industry is the range and number of formal interorganizational collaborations among firms, research laboratories, and universities. For example, a detailed study of collaboration in the most research-intensive segment of the industry, human therapeutics and diagnostics, found that the percentage of firms with formal ties to other biotech firms increased from 74% in 1990 to 86% in 1994.[39]

Measurement of formal ties underestimates the extent to which these firms collaborate. A complete portrayal of the degree of extra-firm associations would have to include not only formal interorganizational arrangements but also informal alliances and professional interactions among scientists from different organizations. Such informal, professional interactions are numerous.

The same study found that, in the biotechnology industry, older firms possess a greater number of formal collaborative relationships than younger firms. Those firms that collaborate externally tend to be older and much larger than firms without ties, and the disparity in size grows slightly during the half decade studied. Firms with no external ties tend to be very small and the percentage of isolated firms decreases by 50%, from 62 to 31 firms, during the five-year period.[40] Although the number of formal external relationships grows only slightly, on average, network measures of centrality and closeness indicate that firms strengthened their existing connections substantially during this time period.

As firms age and grow in size, they do not decrease the number and diversity of external ties although clearly they are large enough to move several R&D activities in-house. Nevertheless, although network centrality appears to be necessary for firm success, it is not a sufficient condition. In other words, all the successful biotech firms in this study are highly active collaborators and none of the isolated firms was successful. However, some actively collaborative firms do not succeed. In general, though, the more network R&D activity engaged in by a firm, the greater the likelihood that the firm becomes a central, and highly successful, player in the industry network.[41]

In fields in which knowledge is distributed across a wide range of organizations and scientific and technological knowledge is critical to competitiveness, innovation is located in the network rather than within individual firms. A zero-sum depiction, in which a firm gains only at the expense of others, inaccurately portrays the situation of most industries affected by the rapid pace of technological and scientific change. It is far more accurate to view the external relationships in terms of a positive-sum game in which joint gains, or wins, are realized which disadvantage no firm in the network.

Few would suggest that the biotechnology industry is not characterized by fierce competition. Nevertheless, the basis for competition is more accurately described in terms of competing networks of firms rather than rivalries among individual firms. The collaboration required to stay abreast of technological and process advances, rather than diminishing competition, merely changes its character.

Finally, the structure and development of this knowledge network cannot be understood fully without reaching far beyond the small biotech firms into the universities and the NIH government laboratories.[42] The government role in positioning universities and NIH to spin off biotech firms is critical. Decades of biotech research funded by NIH (10% in-house, 90% outside contracts) created the capability and strongly influenced the institutional structure described here.

Regional network-based systems: Silicon Valley

Many industries have developed social capital through external relations with other organizations to increase their ability to innovate and to absorb innovations. Experts have documented the unprecedented competitive success of networked systems of industrial production.[43] To date, proximity has provided a powerful aid to realizing these advantages. Examples of such systems, as noted at the beginning of this paper, have existed historically and are currently found in a growing number of countries. These include, but are no means limited to, the *keiretsu* of Japan, the Baden-Wurttemberg region of Germany, the technopoles in France, the *Terza Italia* of central Italy, and Regional Development Authorities in the United Kingdom.

One of the better-known examples of a high-performing industry network is the computer industry of Silicon Valley, California. The professional culture is highly collaborative. Non-proprietary professional and technical information typically is shared among employees and companies. Professionals regularly telephone and e-mail one another for assistance concerning specific technical problems. Professionals meet socially and discuss technical issues. Employment mobility of professional employees is unusually high relative to other industries. Nevertheless, among competing firms and professionals, the level of competition is fierce.[44]

Three different, but highly interrelated, structures — firm, industry, and institution — work together in Silicon Valley and explain the high levels of efficiency, adaptability, and innovation within this setting.[45] The system exhibits congruence, or alignment, among the internal firm structure, the organization of the network, and the wider institutional structure in the region that supports the industry.

At the level of the firm, typically the management structures are aligned with the use of advanced information technologies. These include a short chain of command and stronger horizontal coordination through the use of cross-functional teams, a fairly fluid division of labor, decision-making devolved to the lowest feasible levels, task specialization that reflects job enrichment available through use of workstations and reengineered business processes, and organization by business unit rather than by function. These organization-level structural characteristics enable greater flexibility, increased capacity to absorb innovation, and more efficient use of human and technical resources than those structures associated with traditional hierarchical forms.

At the industry level, networked systems exhibit low levels of vertical integration because of the high degree of outsourcing for inputs that occurs. By contrast, there are a greater number and type of linkages among producers, suppliers, and customers within and across related sectors, forming a rich system of interconnections among network nodes.

The broader institutional structure in which the industry network is embedded plays a critical role in the economic viability of the network. Stanford University plays a much more central role in this network than simply as supplier of research and researchers to industry. Stanford spawned Hewlett-Packard, one of the Valley's central firms, as well as many other firms. Firm leadership, as well as several venture capitalists, have strong ties to the university and, thus, to one another. In many ways, Stanford University is the chief influence on the culture of Silicon Valley. The Massachusetts Institute of Technology and the banks of Boston played similar roles in shaping the culture of the high-tech industry along Route 128 in Massachusetts.[46]

The stronger horizontal coordination of management in Silicon Valley gives increased capacity to absorb innovation, and more efficient use of human and technical resources than the structures associated with traditional hierarchical forms

Some, but not all, of the norms that comprise social capital have been codified into legal arrangements. Contracting devices critical for scientific and technical innovation in a network environment include cross-licensing, second-sourcing arrangements, technology agreements, and joint ventures. The federal government has played a key role here. It catalyzed cross-licensing through judicial decisions made during the anti-trust suit against AT&T. Second-sourcing arrangements were originally required by the Department of Defense to ensure supply. The arrangements, however, quickly spread beyond military contracts and some of the second-source firms became innovators in their own right. These legal instruments spread innovation and risk by pooling resources.

Educational systems at all levels ensure a supply of skilled labor and provide training, retraining, and development of technical staff. At the graduate school level, these systems produce basic and applied research and researchers. The inclusion of a first-rate research university or laboratory in the network, like Stanford University in Silicon Valley, greatly strengthens the potential for scientific innovation. Strong networks or partnerships among government, universities, and industry help to ensure the supply of scientists and technical experts, a critical component of national competitiveness.

These partnerships also ensure the continued high quality of scientists and technical experts by translating new ideas, technologies, and methods from universities to industry and from industry to universities. In the case of Silicon Valley, the system benefits from the strong supporting role played by other institutions of higher learning. State and community college systems, through strong, focused engineering and technical training programs, supply and sustain high-quality technical employees able to function effectively in a networked environment.

The case of Silicon Valley, an exemplar of a regional network-based industrial system, exhibits many of the properties that underlie national advantage. The firms and other players within the network tend to become mutually reinforcing, with beneficial interactions flowing in all directions. The ability of a well-functioning network exceeds the aggregate abilities of the individual nodes. The network attracts related industries and grows into a 'cluster' of associated industries. Research comparing national advantage in a variety of industry sectors demonstrates that this clustering of industries, with all the benefits of collaboration associated with the network form, is highly correlated with national competitive advantage.[47]

Building social capital through S&T policy

Many aspects of federal science and technology policy may be used to advance interorganizational relationships. This section summarizes the chief components of two US policy programs that build social capital. Although neither the Advanced Technology Program (ATP) nor the Manufacturing Extension Partnership (MEP) have as their primary focus the construction of collaborative efforts, both contribute to linkage in substantial ways.

Enabling cooperation

Many benefits of network-based arrangements have been produced as positive, if largely unintended, consequences of the US Department of Commerce's Advanced Technology Program.[48] The ATP funds, on a cost-shared basis, research to create industrial technology that is considered too risky for firms to fund on their own but which, if successfully developed, would be of net benefit not only to the firm but also to the nation.

Although selection criteria presently are under intense debate, at this writing the program selects awardees by a competitive process using well-defined criteria, none of which is meant to favor consortia over single firms. Advanced Technology Program projects are selected on two criteria:

- they must be technically sound and promise high value if successful; and
- if technically successful they must be judged likely to possess low business risk.

Consortia typically pool business risk, and technologies of interest to more than one firm tend to be of broader interest than those pursued by single firms. For these two reasons, indirect incentives in ATP would tend to give joint ventures a broadly based advantage over single firms, although single firms are by no means excluded.

As this paper argues, the development of new technologies increasingly comes about through broad-based, multi-party cooperation. If social capital inheres in the structures that are developed through consortium efforts, the long-term benefits to the nation in terms of increasing innovative capacity should accrue more strongly through support to consortia than to single firms. In each case evaluated by ATP, some value should be estimated for the potential long-term benefits of creating collaboration that extend beyond the estimated direct value of the proposed project.

ATP awardees responded overwhelmingly that the chief benefit of collaboration has been the stimulation of creative thinking by pooling expertise: firms also value the ability to commercialize products more quickly and to save time in general

A survey of 115 ATP awardees who received their awards during the 1990–92 period provides insights into the benefits of ATP as perceived by firms in the program. One of the key benefits, from the perspective of participant firms, was the stimulus to collaborate provided by the program. The joint venture projects included, on average, six formal participants. Moreover, during the course of the contract, 35 out of 85 joint venture participants established subcontracts with five other companies, on average. All but one of the consortia were newly formed as a result of ATP.

It might be argued that many firms would develop external ties even in the absence of ATP, given the obvious leverage achieved through partnerships, but the survey results indicate otherwise. A participant in a large joint venture which brought together competitors as joint researchers observed:

> "Collaboration, cooperation, and learning to operate in a consortium with competitors were key outcomes of the ATP. We saw and experienced the value of working together with competitors. The ability to leverage knowledge has been so tremendous. It has broken invisible barriers."[49]

Another respondent noted, "We gain the leverage of working together with the companies. The money is not the actual benefit, but the leverage."[50] One of the most important indirect effects of ATP may be attitudinal change. A participant in a joint venture reported:

> "The ATP award has opened the eyes of management that technological projects like this one are valuable. Our company used to turn away from outside collaborations. We had a history of zero; we were an inward-looking company. We were skeptical at first of collaboration, but not now."[51]

ATP awardees responded overwhelmingly that the chief benefit of collaboration has been the stimulation of creative thinking by pooling expertise. The two other benefits rated most highly by participants relate to time savings. Firms value the ability to commercialize products more quickly and to save time in general.[52]

The chief difficulties reported concern the start-up period and the multi-party negotiations required to integrate different cultures for the purposes of the joint venture. Learning to collaborate equates to learning to trust, or establishing credibility among the parties. This process necessarily involves a series of interactions over time. However, in spite of these difficulties, 92% of the participants surveyed reported that the ATP experience heightened their interest in external collaboration. Moreover, 96% of the joint venture participants said that their ATP experience had motivated them to seek out future joint ventures.[53]

It is widely observed, although the evidence remains anecdotal at this time, that many firms not awarded funds also have found great value in the process of building consortia in order to apply for an ATP award. The existence of ATP creates a forum within which firms can identify potential partners and ventures. These spillover effects merit systematic evaluation to identify more fully the incentives and outcomes produced by programs that play a role in restructuring industry.

The favorable social, economic, and technological context for collaboration, plus the obvious benefits, suggest that even a relatively small incentive from government can foster the development of networks of firms and universities, and thus increase the rate and quality of technological innovation. For these reasons, several experts urge that ATP be focused primarily on networks of firms, and, in appropriate cases, networks in which universities, national laboratories, and perhaps subnational governments participate. The incentive that ATP could offer for formation of such networks or consortia might be the program's most valuable economic contribution.

Revitalizing manufacturing

The benefits of partnership and collaboration in networks are not confined to high-tech industries. The revitalization of manufacturing depends to a great extent on the capacity of manufacturers to develop external relationships. A limiting factor for many older manufacturing firms is the requirement of an attitudinal shift on the part of manufacturers to recognize the benefits, indeed the necessity, of working collaboratively in order to modernize and to remain abreast of technological developments that affect the business.

The key to state-of-the-art manufacturing is close integration throughout the supply chain. At the core of such integration of systems and operations are advanced manufacturing technologies such as electronic data interchange (EDI) and just-in-time (JIT) inventory control. Advanced technologies are necessary for the success of advanced manufacturing settings.

Studies demonstrate that effective manufacturing systems tend to implement state-of-the-art human resource practices in order to enable and support cross-functional teams and systematic, decentralized problem-solving at all levels of the operation.[54] Externally, those manufacturing firms that have successfully implemented product and process data exchange across firms have had to develop the ability to cooperate in order to evolve shared goals, resources, and incentives that provide a basis for smooth communication among firms.[55]

A key success of US technology policy during the 1990s has been the revitalization of manufacturing by means of policies that support both new technologies and the state-of-the-art business practices that allow new technologies to be implemented.[56] The Manufacturing Extension Partnership (MEP) comprises a broad network including the national and state governments, non-profit organizations, industry groups, and educational institutions. The MEP is itself a collaborative network. It links a host of management and technology assistance providers to small and medium-size manufacturing firms.[57]

Most of the services provided by MEP are focused on individual firm needs. However, MEP also helps firms to develop external relationships to promote integration and information processing capacity.[58] Given the importance of external relationships to innovation, the ability of MEP to promote linkages within more mature industries is a critical element in the revitalization of manufacturing.

The delivery mechanism used by MEP also builds social capital. Awards stimulate public and private organizations to collaborate in order to work with local manufacturers in a systematic, integrated fashion. Typically, MEP centers form an integral part of local networks of service providers. A national network of more than 300 local MEP offices has links to more than 750 service delivery organizations. This vast and growing network includes a wide variety of players: "non-profit technology or business assistance centers, economic development groups, universities and community colleges, private consultants, utilities, federal laboratories, and industry associations."[59]

In many aging manufacturing settings and in some urban settings, the key obstacle to development of strategic alliances, networks of innovation, and consortia lies in outmoded ways of interacting. Information is closely held. There are few institutionalized opportunities for discussion and dialogue across functions and firms. Joint problem-solving skills have not been developed as they have been in larger, more profitable firms that experimented with quality programs, team-based problem-solving, and the formation of consortia during the 1980s and 1990s. These basic skills are necessary for collaborative efforts to work.

Training and development programs, as well as exposure to the criticality of network linkages in order to gain access to innovations, could foster development of these skills. The Manufacturing Extension Partnership provides a model to manufacturers for networked approaches to innovation.

Recommendations and conclusions

This paper closes with a set of recommendations for government action. These have been developed for the United States at the request of the Clinton administration. However, they generalize to a number of other industrial countries given similarities in technological change, increased competitiveness, the obvious benefits of pooling a variety of resources, and the increases to innovative capacity that stem from linking diverse actors and organizations with similar objectives.

In general, policymakers should consider use of an expanded set of policy tools that would foster linkages and a level of trust that would support an accelerated rate of innovation and productivity growth. First, in settings that have been characterized by relatively autonomous actors, government should aggressively provide incentives and information to promote the use of networks and consortia in order to connect firms to universities, national research laboratories, and government partnership programs. Second, governments should examine closely the potential use of the Internet to diffuse the power of regional agglomerations to distance-independent ones.

Third, governments should develop their capacity to use consensus building as an indirect tool to advance the objectives of technology policy. National-level governments can seek explicitly to build social capital among key stakeholders in science and technology by providing a forum for dialogue and discussion to search for and establish consensus as a basis for collaboration.

Fourth, the urgent need for collaboration and integration signals the importance of a less adversarial relationship between government and business in those countries whose policies may be considered adversarial. Government constitutes an indispensable element of the national network of innovation, through both its incentive programs and its regulatory constraints. Therefore, the need for trust within the national network is essential. This recommendation does not suggest that government should weaken control mechanisms. By contrast, it should make full use of a modernized and actually more powerful view of control, made possible by advanced information and communication technologies.

Fifth, greater decentralization within science and technology policy programs would allow for greater responsiveness without loss of control. For national-level government actions to fit the needs of industry and of regions, government must understand better the needs of different industries and states. The tendency to adopt 'one size fits all' politics and overly standardized programs has been an impediment to innovation.

Finally, research is needed to illuminate the process of social capital formation. Mapping of industry clusters as well as regions that remain relatively insular is critical to adequate policy design. The actual potential of the Internet to foster linkages that transcend geographic boundaries has yet to be explored. The dynamics of the start-up period for consortia demand study. If initial negotiations among parties can be made more efficient and effective, resources could move toward innovation more quickly and at lower cost.

The current political, economic, and technological environment in most industrial countries forces government to invest less money more wisely in higher-leverage policy instruments. Rather than simply 'doing more with less,' policymakers must identify and use more advanced and powerful policy tools to yield the best return on investment of tax dollars. Policy design that reflects the importance of institutional arrangements to technological innovation has the potential to yield substantial return on government investment.

In sum, national policies must be adapted to the extraordinary structural changes taking place in industries as firms develop and maintain competencies by forming alliances and overlapping collaborative relationships. The key enabler to strengthening innovation, and its dissemination and absorption, may lie as much in increasing the social capital of our productive sectors as in direct investments in science and technology.

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