Studies of science

Etudes sur la science

Henry Etzkowitz

Innovation in innovation: the Triple Helix of university–industry–government relations

Abstract. *Innovation is increasingly based upon a "Triple Helix" of university–industry–government interactions. The increased importance of knowledge and the role of the university in incubation of technology-based firms has given it a more prominent place in the institutional firmament. The entrepreneurial university takes a proactive stance in putting knowledge to use and in broadening the input into the creation of academic knowledge. Thus it operates according to an interactive rather than a linear model of innovation. As firms raise their technological level, they move closer to an academic model, engaging in higher levels of training and in sharing of knowledge. Government acts as a public entrepreneur and venture capitalist in addition to its traditional regulatory role in setting the rules of the game. Moving beyond product development, innovation then becomes an endogenous process of "taking the role of the other", encouraging hybridization among the institutional spheres.*

Key words. *Entrepreneurial university – Innovation – Interdisciplinarity – Triple Helix*

This article is the keynote address to the International Congress "Universities and Regional Development in the Knowledge Society", Universitat Politecnica de Catalunya, Barcelona, 12 November 2001. An earlier version was presented to the "Mode 2" Workshop at Le Musée de l'Homme, Paris. The analysis is based on studies of university-industry relations sponsored by the US National Science Foundation (NSF) and of university–industry–government relations sponsored by the National Institute of Standards and Technology (NIST). The National Research Agency (CNPQ) in Brazil, the state science agency in Rio de Janeiro (FABERJ) and the Center for Business and Policy Studies (SNS) in Sweden provided additional support. More than 200 in-depth interviews were conducted with academic researchers, incubator and science park managers, and founders of high-tech firms.

Social Science Information © 2003 SAGE Publications (London, Thousand Oaks, CA and New Delhi), 42(3), pp. 293–337.
0539-0184[200309]42:3;293–337;035103

Résumé. *L'innovation s'appuie de plus en plus sur un modèle de "triple hélice" d'interactions université–industrie–gouvernement. L'importance accrue du savoir et le rôle de l'université dans "l'incubation" d'entreprises hautement axées sur la technologie lui a donné une place de choix dans le firmament institutionnel. L'université-entrepreneur est un moteur important pour la production du savoir appliqué et l'élargissement des conditions de la production du savoir universitaire. Elle opère donc selon un modèle d'innovation interactif plutôt que linéaire. Tout en augmentant leur niveau de technologie, les entreprises tendent à se rapprocher d'un modèle universitaire en s'impliquant davantage dans l'éducation et dans le partage du savoir. Le gouvernement joue le rôle d'entrepreneur public et d'entreprise capitaliste parallèlement à son rôle traditionnel de régulation en établissant les règles du jeu. En allant au delà du développement de produits, le processus d'innovation devient alors un processus endogène qui consiste à "jouer le rôle de l'autre" en favorisant l'hybridation entre les différentes sphères institutionnelles.*

Mots-clés. *Innovation – Interdisciplinarité – Triple Hélice – Université-entrepreneur*

What is peripheral and what is central to innovation has been transformed in recent years. Knowledge-producing institutions have developed the organizational capacity not only to recombine old ideas and synthesize and conceive new ones, but also to translate them into use. As the production of scientific knowledge has been transformed into an economic enterprise, the economy has also been transformed to operate from an epistemological base (Machlup, 1962), and as the creation, dissemination, and utilization of knowledge have become more directly involved in industrial production and governance, the university has come to play a new role in society. The transformation of academia into a source of innovation is concomitant with the transformation of innovation from an internal process within individual firms to one that takes place among firms and between firms and knowledge-producing institutions.

The university has traditionally been viewed as a support structure for innovation, providing trained persons, research results, and knowledge to industry. Recently the university has increasingly become involved in the formation of firms, often based on new technologies originating in academic research. The first academic revolution, the transformation of the university from a teaching institution into one that combined teaching with research, is still ongoing, not only in the US but in many other countries. There is a tension, but the two functions co-exist because the combination has been found to be creative and productive. A similar result can be expected from the integration of economic and social development with teaching and research, the second academic revolution.

Intellectual capital is becoming as important as financial capital as the basis of future economic growth. One indicator is the inadequacy of traditional models of valuing firms primarily in terms of their tangible assets (Rivette and Kline, 1999). Another is the emergence of an entrepreneurial academic ethos that combines an interest in fundamental discovery with application. Rather than being subordinated to either industry or government, the university is emerging as an influential actor and equal partner in a "Triple Helix" of university–industry–government relations. The present article explicates the sources and development of the Triple Helix and the new academic format for an entrepreneurial university that is emerging as new and old academic missions come into conflict and confluence.

Emergence of the Triple Helix

Society is more complex than biology. A double helix was sufficient to model DNA. A triple helix is required to model university–industry–government interactions. The Triple Helix thesis postulates that the interaction in university–industry–government is the key to improving the conditions for innovation in a knowledge-based society. Industry operates in the Triple Helix as the locus of production; government as the source of contractual relations that guarantee stable interactions and exchange; the university as a source of new knowledge and technology, the generative principle of knowledge-based economies. A primary institution is one that fulfills a central purpose in society; other institutions depend on it to fulfill their missions. Industry and government have always been major institutions in modern society. The university is elevated to an equivalent status in a knowledge-based society, in contrast to previous institutional configurations in which it occupied a secondary status (e.g. Mills, 1958).

The Triple Helix denotes a transformation in the relationship among university, industry and government as well as within each of these spheres. As institutions increasingly "take the role of the other", the traditional match of institution to function is superseded. The Triple Helix model of simultaneously competing and cooperating institutional spheres differs from situations in which the state encompassed industry and the university, for example, the former Soviet Union, and some European and Latin American countries, in the era when state-owned industries were predominant. It is also different from separate institutional spheres, for example, the way the US is supposed to operate, at least in theory, according to laissez-faire principles. From either of these starting-points, there is a movement toward a new global model for analysis of the dynamics of innovation.

The Triple Helix thesis is expressed in 10 propositions:

1. Arrangements and networks among the Triple Helix institutional spheres provide the source of innovation rather than any single driver. New initiatives arising from these networks become the source of innovation policies at national, subnational, and supranational levels. Innovation is a broader phenomenon than anything that takes place in a single institutional sphere, such as the behavior of enterprises in planning and implementing changes to develop new products or learning from fellow firms in a cluster or from another sector. Academic research now increasingly intersects with industrial advance and government economic development policy. Government thus becomes a partner in the policy-making process as policies become an outcome of the interactions among the Triple Helix agencies.
2. Invention of organizational innovations, new social arrangements and new channels for interaction becomes as important as the creation of physical devices in speeding the pace of innovation. New organizational mechanisms such as incubators, science parks, and networks among them become a source of economic activity, community formation, and international exchange. New modes of interdisciplinary knowledge production, involving Triple Helix partners, inspire research collaboration and firm-formation projects.
3. The interaction between linear and reverse linear dynamics results in the emergence of an interactive model of innovation. The linear model of knowledge-transfer is transformed into an "assisted linear model" as technology generated in academia is transferred by licensing offices as intellectual property and through the formation of firms in incubator facilities. The reverse linear model, starting from industrial and social problems,

provides additional starting-points for new research programs and discipline formation. The interactive model, integrating research and practice, originated in the US with the founding of the University of Connecticut in 1816 as the progenitor of the ''land grant'' university, with a county agent as intermediary between farmers and researchers.

4. The ''capitalization of knowledge'' occurs in parallel with the ''cogitization of capital''. Financial capital is increasingly infused with knowledge through the invention of new risk-sharing and investment search mechanisms such as the venture capital firm, allowing capital to overcome some of its doubts and hesitations in making early-stage investments. Just as incubator facilities are created to assist the transformation of knowledge into capital, new organizational mechanisms are invented and old ones, such as the patent system, are extended from intellectual property protection into sources of new inventions, thereby transforming the capital- and knowledge-creation processes in tandem.
5. Capital formation occurs in new dimensions as different forms of capital are created and transmuted into one another: financial, social, cultural, and intellectual. The transformation of capital cannot be fully understood from the perspective of either the individual firm or the operation of markets. New forms of capital are created based upon social interaction, ''who you know'', and intellectual activities, ''what you know''. Forms of capital are interchangeable. Thus raising financial capital is based on accumulating intellectual as well as social capital. Human, social, and intellectual capitals are redefined as universities interact more intensively with industry and government.
6. Globalization becomes decentralized and takes place through regional networks among universities as well as through multinational corporations and international organizations. As organizational innovations for technology transfer diffuse from one part of the world to another, interaction across regions and nations reinforces globalization. As universities develop links, they can combine discrete pieces of intellectual property and jointly exploit them. These new configurations become the basis of a continuous process of firm formation, diversification, and collaborations among competitors.

7. Developing countries and regions have the possibility of making rapid progress by basing their development strategies on the construction of niche knowledge sources, supported by the local political economy. Political and social arrangements based on principles of equity and transparency lay the groundwork for rapid development in a stable environment. "Leap-frogging", to skip some stages of development, is thus possible as well as "catch-up" strategies of attracting foreign direct investment (FDI) and inward technology transfer. Universities and networked incubators can be used both to adapt advanced technologies to solve local problems and also to move abreast of the research frontier in special areas and to transfer local innovations abroad.
8. Reorganizations across institutional spheres, industrial sectors, and nation-states are induced by opportunities in new technologies that emerge from syntheses among previous interdisciplinary innovations in an ongoing flow. Technological innovation reshapes the landscape in terms of the development of niches and clusters, relations among firms of different sizes and types, and the creation of both public and private sources of venture capital. Enterprises are constructed out of elements from all the relevant institutional spheres, not merely from industry itself. Social developments take unexpected turns as new technologies reinforce the dynamics of firm formation and vice versa. Discipline formation takes place through intersection among previous interdisciplines as well as the splitting off of subdisciplines.
9. Universities increasingly become the source of regional economic development and academic institutions are re-oriented or founded for this purpose. The growth of industrial conurbations around universities, supported by government research funding, has become the hallmark of an entrepreneurial region, exemplified by Silicon Valley's electronics and semiconductor industry. The profile of knowledge-based economic development was further raised by the founding of Genentech and other biotechnology companies by academics and venture capitalists in the 1980s. Other regions in other countries, such as Karlskronna Ronneby in Sweden, shifting from shipbuilding to software, and the State University of Rio de Janeiro in Friburgo, inserting an IT-based graduate school to hybridize with older technologies, have adapted this strategy to revive

declining industrial regions. There have also been initiatives to develop other "greenfield" sites such as exurban Long Island, where the State University of New York at Stony Brook created a biotechnology industry from the research resources available in a new medical school.

10. The ability to make the transition from one technological paradigm to another as the potential of an earlier regime becomes exhausted is the hallmark of a Triple Helix region. A broad-based research university or multiple interacting knowledge-producing institutions, with strategic investments in emerging research areas with economic potential, supported by government initiatives, provides the basis for this shift.[1] Conversely, too narrow a research base or inadequate support structure, sometimes based on the short-sighted belief that previous economic successes were due solely to business entrepreneurship, inhibits the potential for transition. Triple Helix interactions, institutionalized and renewed across generations of technologies, are the basis of seemingly self-organized networks of innovation.

Innovation in innovation

Innovation has taken on a broader meaning in recent years. More than the development of new products in firms, it is also the creation of new arrangements among the institutional spheres that foster the conditions for innovation.[2] Like the analysis of product development, innovation was a topic of interest to a small group of specialists in industry and academia. As economies and societies have been seen to be linked more to the process of transformation than to stable arrangements, a new interest in the broader conditions that foster innovation has arisen among policy-makers, academics, and business people. It has led to a transformation of the organizational arrangements within government designed to assist industrial innovation, to "co-opetitive" collaborations and consortia in and across industrial sectors, initially supporting pre-competitive R&D, and to the construction of hybrid academic research centers with industrial and governmental partners (Etzkowitz and Kemelgor, 1998). Instead of focusing only on the potential for product development from individual technologies, there is a broader concern with creating an infrastructure for innovation in innovation through an enhanced Triple Helix.

The organizing principle of the Triple Helix is the expectation that the university will play a greater role in society as an entrepreneur. The entrepreneurial university retains the traditional academic roles of social reproduction and extension of certified knowledge, but places them in a broader context as part of its new role in promoting innovation. And, of course, not all agree that it should play this new role. Many academics believe that the university best fulfills its mission by limiting itself to education and research, eschewing a broader role in economic and social development. According to this view, the university best fulfills the third mission by fulfilling the first two (Sorlin, 2002). Nevertheless there is new interest in pursuing the practical implications of research even among academics committed to basic research, who were most skeptical about the capitalization of knowledge.[3] Some of this increased interest in engineering and business is based on the realization of a positive contribution from application to pure research and vice versa.[4] Others simply wish to emulate colleagues who have gained great wealth from their inventions or enhanced academic status from forming a firm.[5]

A similar transformation is underway in industry. This can be seen in the movement from the hierarchical model of large firms to start-ups and in the phenomenon of spin-offs from universities that incorporate academic characteristics. Large firms that start incubator facilities to develop new business units, and biotechnology firms that advertise for post-doctoral fellows, exemplify these trends. Similar processes are at work in transforming government from different formats to a common role in innovation broadly conceived. In countries such as the US, which adhere to a laissez-faire ideology, government is playing a more interventionist role in innovation as an extension of the basic research-funding process. For example, the Small Business Innovation Research Program in the US makes grants to researchers and small firms to develop new technologies into businesses (Etzkowitz et al., 2001). Conversely, in countries where government was formerly a controlling force, increased autonomy is now allowed to the industrial and academic spheres. In both instances, there is a focus on encouraging interactions among the institutional spheres to initiate a self-sustaining innovation dynamic.[6]

Four stages can be identified in the emergence of such a Triple Helix:

1. Internal transformation in each of the helices. Universities and other knowledge-producing institutions play a new role in society, not only in training students and conducting research but also in making efforts to effectively put knowledge to use. Expressed through technology-transfer offices and the requirements of government grant programs for the support of research, the entrepreneurial university elides the traditional boundaries between academia and industry. Strategic alliances for R&D among companies and governments taking the role of venture capitalist are parallel, intersecting developments.
2. Influence of one helix upon another. The US federal government established a stable framework for academic technology transfer through the Bayh-Dole Act of 1980. This amendment to the Patent and Trademark Law instituted an indirect industrial policy through which government encouraged universities to assist industrial innovation. Secure rules of the game for the disposition of intellectual property arising from government-sponsored research encouraged the spread of technology transfer to a broader range of universities and expanded the academic technology-transfer profession. Since universities and their representatives were involved in lobbying for the law, the direction of influence went both ways.
3. Creation of a new overlay of trilateral networks and organizations from the interaction among the three helices. Such groups typically form to fill gaps in an innovation system by ''brainstorming'' new ideas. Joint Venture Silicon Valley, established during the economic downturn in the early 1990s, the Knowledge Circle of Amsterdam, organized during the past decade, and the New England Council, founded in the 1920s, included participants from small and large companies, local government, and academia. The New England Council played a key role in inventing the venture capital firm crucial to the growth of Route 128 and Silicon Valley.
4. A recursive effect of Triple Helix networks both on the spirals from which they emerged and on the larger society. One effect is on science itself. The capitalization of knowledge has displaced disinterestedness, the expectation that scientific knowledge would

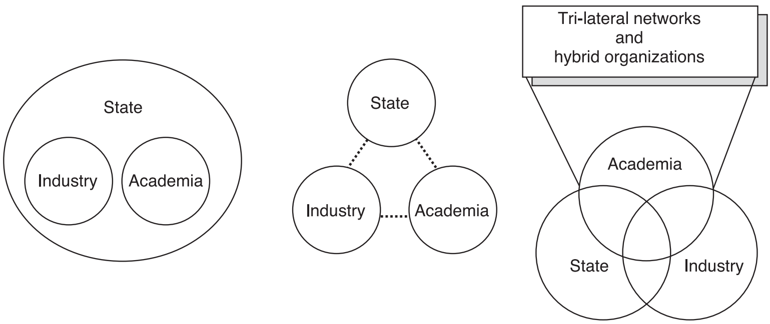

FIGURE 1
From etatistic and laissez-faire to Triple Helix

be freely distributed, with researchers taking their rewards solely in recognition from their peers (Merton, 1973). This new norm has arisen from the practices of industrial science, an internal entrepreneurial dynamic within academia, and from government policies. The capitalization of knowledge transforms both the way academic scientists view the results of their research and the role of the university in relation to industry and government. The knowledge base and its role in innovation can be explained in terms of changing relationships among university, industry, and government (see Figure 1).

Origins of the Triple Helix

Although the Triple Helix implies a common format of innovation, the path to the Triple Helix has different starting-points. The Triple Helix model of equivalent and overlapping institutional spheres begins from two opposing standpoints: (1) a statist model of government controlling academia and industry, and (2) a laissez-faire model, with industry, academia, and government separate and apart from each other, interacting only modestly across strong boundaries. From either of these starting-points, there is a movement toward a new global model for the management of knowledge and technology that enables analysis of the dynamics of innovation in terms of historical trends, new structural arrangements, and emerging moments of change. A third alternative, with each institutional sphere maintaining its special features and unique identity while also taking the role of the other, is a new development.

The Triple Helix model attempts to capture this transformation of roles and relationships in the emerging primary institutional triad of university–industry–government. University, industry, and government are conceptualized as intertwined spirals with different relations to each other in the classic innovation regimes. In a laissez-faire Triple Helix regime, industry is the driving force, with the other two spirals acting as ancillary supporting structures; in a statist regime government plays the lead role, driving academia and industry. Spirals are rarely equal; one usually serves as a motive force, the ''innovation organizer'', around which the others revolve. The institution that acts as the core spiral changes over time as one spiral replaces the other as the driving force in a Triple Helix configuration. Whether starting from the statist or the laissez-faire model, the shift to overlapping spheres takes place in a series of steps. Ideology paradoxically lags behind practice in the laissez-faire model, while change in ideas often precedes change in structure in the statist transition.

The statist Triple Helix

The Triple Helix model of simultaneously competing and cooperating institutional spheres differs from situations in which the state encompasses industry and the university, for example, the former Soviet Union, and some European and Latin American countries, in the era when state-owned industries were predominant. In these countries, government was the dominant institutional sphere. Industry and the university were basically part of the state. When relationships were organized among the institutional spheres, government played the coordinating role. One model of this relationship in Latin America was provided by the Argentinian physicist Jorge Sabato. He proposed a top-down model of development, with government coordinating industry and academia in their ''intra'' and ''extra'' relations with each other, moving beyond a more traditional model of government coordinating each sphere separately to promote technology development (Dos Santos and Fracasso, 2000).

In this model, government is expected to take the lead in coordinating and provide the resources for new initiatives. Industry and academia are seen to be relatively weak institutional spheres that require strong guidance, if not control. In Brazil examples can be seen in the S&T policies of the 1970s and early 1980s when government organized large-scale technology projects and raised the level of research at universities in order to support the creation of new technological industries such as computers and electronics, and concomitantly to affect regional development.

The idea of the statist version of the Triple Helix is that the country should keep its local technological industry separate from what is happening in the rest of the world. In Europe this model can be seen in terms of companies that are expected to be the dominant national leader in a particular field, with the government supporting those companies, such as the Bull computer company or Aérospatiale in France. In this configuration, the role of the university is seen primarily as one of providing trained persons to work in the other spheres. It may conduct research, but it is not expected to play a role in the creation of new enterprises. Even in France, the classic statist regime, many of these expectations have changed in recent years (Mustar and Laredo, 2002).

Statist reform

In the statist format, where academia and industry are controlled by government, the first step toward change is the loosening of top-down control and the creation of a civil society where one is lacking. Once people can come together to create new ideas, the way is open to bottom-up innovation. Under the military regime in Brazil, academic associations provided a free space to exchange ideas about the future of the country. The incubator movement in Brazil originated from these discussions in the universities during the early 1980s, when the military regime was abandoning power. The movement took off when municipal governments became interested and funded buildings for some of the early incubators, allowing the projects to move from temporary buildings into new structures and gain official acceptance from the university. Additional support from industry associations and state governments extended the concept from high-technology firms to raising the level of technology in existing firms, for example through design incubators to help create new products and business units. Incubators have also been founded to assist the arts and cultural and non-governmental organizations.

The incubator concept has been creatively reinterpreted in Brazil and used to achieve a variety of economic and social objectives. Nevertheless there was considerable skepticism, expressed in charges of "privatization of the university", toward introducing the concept of a support structure to found new technology firms with the university. The critique of incubation abated as university technology-transfer organizations also established incubators, in collaboration with civic associations, to train low-income persons to organize cooperatives. Next federal programs encouraged a new wave of incubator development, especially in the software area, tied to plans for encouraging exportation. An association of incubators, ANPROTEC, brought the different incubator types and their supporters together in a common framework. An organizational innovation that had been imported from the US was reinvented and made more relevant to local circumstances (Etzkowitz et al., under review).

The laissez-faire Triple Helix

The polar alternative to the statist model is a laissez-faire Triple Helix of separate institutional spheres, in which people are expected to act competitively rather than cooperatively in their relations with each other. Strict separation leads to narrow definitions of institutional roles, strong boundaries, and high standards for justifying interaction among the institutional spheres. In reality the spheres are often closer together than the model of government, industry, and academia operating in their own areas without close connections. In this laissez-faire model, the university is a provider of basic research and trained persons. Its role in connection with industry is to supply knowledge, mainly in the form of publications and graduates, who bring tacit knowledge with them to their new jobs. It is up to industry to find useful knowledge from the universities without expectation of much assistance.

Only under the most severe circumstances, such as those occasioned by the international economic depression of the 1930s, are traditional laissez-faire economic prescriptions overridden. The role of government in industry is generally expected to be limited to regulation, as little as possible of course, and procurement, buying products for its own use. There is typically an exception for the military in laissez-faire countries, where much closer linkage between industry and government is accepted, with industry and universities playing a significant role within state coordination (Melman, 1970). In most circumstances, however, government is expected to play a role only when the market cannot provide an activity. For example, based on this argument of market failure, it is agreed that the government may provide funds to the university to support research. Since it would not take place otherwise, it is accepted that there is a limited role for government.

Not surprisingly, there is a very strong presumption of individualism in the laissez-faire approach. A new enterprise is expected to be initiated by an individual rather than by a group. Enterprises are expected to be run by individuals to whom great prominence and attention are given. Whether or not it is justified, the success of the organization is attributed almost entirely to the person at the top. This is reflected in very high salaries for heads of US corporations and much media attention to them. A recent example is the extensive publicity about Jack Welch, the long-term, recently retired CEO of General Electric. An even more skeptical view of corporations that has emerged in the wake of recent bankruptcies and the public response to them focuses on the CEO as the guarantor of organizational transparency. Government regulation is the last resort, and deregulation and proponents of institutional autonomy encourage decoupling of government and industry.

There is expected to be only limited interaction among university–industry–government in the laissez-faire Helix. When there is interaction and interrelationship among the spheres, it is expected to take place across strongly defended boundaries and preferably through an intermediary. For example, for many years before universities became directly involved in patenting research, there was an organization called the Research Corporation, an independent not-for-profit organization, which identified patentable research and licensed it to firms. Thus industry and university related not directly but through an intermediary. It was believed that it was not appropriate for them to be in direct contact with each other. Nevertheless, if they needed to interact, it should be through an intermediary. Thus, to the extent that there were relationships, they tended to occur at arm's length.

Laissez-faire reform

Modification of the policy of separation within and across institutional spheres took place in response to increased international competition, leading to a rethinking of appropriate relationships among companies in peacetime. At first in the laissez-faire model, when government begins to play more of a role, it does so indirectly. For example, in the US during the recession of the 1970s, government turned over the intellectual property rights emanating from research funded by the federal government, with the proviso that the universities make an effort to transfer those rights to industry in order to raise the technological level of industry. This is an indirect industrial policy, an action on the part of government to support industry, going through the universities to reach industry. That is a first step toward moving the institutional spheres closer by using one sphere to reach another, creating an immanent Triple Helix. A more direct initiative, the Advanced Technology Program, based upon ideas drawn from the US Defense Advanced Research Projects Agency (DARPA) and the European Union's Framework Programs, was put in place during the mid-1980s to support industrial R&D with spillover potential.

In normal circumstances, firms are linked to each other by the market relationships of buying and selling, with other social relations relatively excluded. It was expected that, if firms did communicate extensively with each other, the first thing they were likely to do would be to form a cartel and set prices. Thus companies were discouraged by anti-trust laws from interacting, except through meetings of professional associations, where people could get together according to their occupational specialization. Under economic pressure, the anti-trust rules were changed to allow companies to do pre-competitive research and then to allow joint product development. Industry was encouraged to restructure according to the framework of strategic alliances among different firms. A concept of "co-opetition" was invented to denote that companies should not only compete, but cooperate as well.

The Triple Helix model of innovation

Once the received models are open to change, a new set of interactions ensues that tends toward convergence of innovation regimes.

Innovation begins to take on a new meaning as the spirals of the Triple Helix intertwine, cooperating from a position of relative autonomy to enhance each other's performance of their traditional roles (see Etzkowitz and Leydesdorff, 1997; Leydesdorff and Etzkowitz, 2002). The increased interaction among university, industry, and government as relatively equal partners, and the new developments in innovation strategies and practices that arise from this cooperation, are the core of the Triple Helix model of economic and social development.

The Triple Helix also becomes a platform for "institution formation", the creation of new organizational formats to promote innovation, such as the incubator, science park, and the venture capital firm. These new organizations arise from interaction among university, industry and government to promote innovation and are themselves a synthesis of elements of the Triple Helix. Such "innovation in innovation" is a global phenomenon that involves "learning by borrowing", importing and adapting organizational models from abroad as well as independent invention (Etzkowitz, 2002a).

Development of a Triple Helix: enhancing existing roles

A Triple Helix regime typically begins as university, industry, and government enter into a reciprocal relationship with each other in which each attempts to enhance the performance of the other. Most such initiatives take place at the regional level, where specific issues of problems in industrial clusters, academic development, and lack of governing authority influence the development of the Triple Helix. In such instances, a university, an industry association, or both together may recognize gaps in the innovation environment and essay the "innovation organizer" role.

The first step toward a Triple Helix is usually collaboration, taking place through their traditional roles, among the institutional spheres most involved with innovation. For example, universities, firms, and governments in a region may participate in discussions to enhance a local economy, develop a regional growth agreement, or establish a technology council. As a result municipalities may agree to speed up building, permitting processes for new plant construction; universities may undertake to train more students in an area relevant to the local economy; firms may negotiate new supplier relationships with each other as an incipient cluster.

At this initial level of the Triple Helix, the three strands typically begin to interact in order to improve the local economy. As new knowledge infuses existing industry and as various combinations of new and old knowledge become the basis for firm formation, government and industry increasingly support academic development. The establishment of a research center speeding up academic research production is a typical strategy. The university gains additional resources from industry and government to enhance the performance of research, one of its traditional functions.

The Transformative Helix: taking the role of the other

The next step to development of the Triple Helix is that, in addition to performing its traditional tasks, each Triple Helix partner "takes the role of the other". The message of the Triple Helix model is not that universities become firms or governments become businesses. Rather, as each assumes some of the capabilities of the other, each institution maintains its primary role and distinct identity.[7] Indeed, "taking the role of the other" contributes to the traditional institutional mission, as when participation in the capitalization of knowledge leads to the development of new academic research and educational programs. Each institutional sphere is thus more likely to become a creative source of innovation in innovation and to support the emergence of creativity that arises in other spirals.

The fundamental role of the university as an institution for the preservation and transmission of knowledge remains its core mission. Thus universities continue their special mission of socialization of youth and knowledge dissemination even as they take on some business and governance functions. Similarly government is the ultimate guarantor of societal rules of the game, and industry is the primary source of productive activities. Thus industry continues to produce goods and services, and also does research, but in addition increasingly provides training at higher levels, reflected in the fact that many companies now have their own "universities", at least in their special area of expertise. Government is responsible for providing the rules of the game, but also makes available venture capital to help start new enterprises.

Emergence of a venture capital/start-up model

A start-up model based on new technology is an increasingly common alternative to creation of a new business unit within an existing firm (Roberts, 1991). Companies outside the pharmaceutical industry are only occasionally willing to commit to development of a research-originated product. Dupont's nylon is the exception to the rule. IBM's conservative role in RISC computing is more typical, with an innovation developed within the company taken up only after it had been brought to fruition elsewhere. The typical corporate decision-making process balances the investment required by the new product against profits that could be made from further investment in existing products, and usually takes the latter course. The potential for the new product cannibalizing the market for the old is another counterweight to internal innovation. Sometimes top management, like Xerox's, does not comprehend the potential of its lab's accomplishments or thinks them too far afield from the firm's business model. Failure to pursue product development may provoke employees to start a firm based on the new technology.

A firm based on a new business concept that uses available technology in new combinations is a parallel start-up model. Thus, FEDEX, originating as a course project in an MBA program, combined air transport with door-to-door ground delivery and communication systems, linking customers and delivery employees. Dell is based on the concept of building computers to order from a set of specified options, delivering directly to the purchaser, using voice and computer communications capabilities to interact with customers. The technological inputs to these businesses are based on available capabilities that are integrated into a common format and applied to a new purpose. Not surprisingly, firms change their orientations somewhat over time. Thus Dell now conducts close-to-market R&D in the US, India, and Brazil. Microsoft, which started out purchasing and repackaging software innovations, more recently conducts advanced research in software and related areas, such as Bayesian statistics, with long-range potential for product development.

Firm formation based on new technology became a systematic process with the invention of venture capital. Before, founders of firms were dependent on individual investors and family funds. Raising the level of knowledge invested in capital by creating a due-diligence process that incorporated financial and technical vetting integrated the ''cogitization of capital'' with the capitalization of knowledge. As venture capital expanded, it moved away from its original function of bridging knowledge to commercialization. It also lost many of its early ties to academia by moving downstream to the later stages of firm formation and industrial restructuring. Nevertheless, whether focused on early- or later-stage ventures, new technologies, or new business models, venture capital is the converse of the traditional banking approach, with its focus on identifying choices perceived as low-risk.

The essence of the venture capital model is a focus on firm formation in emerging technology areas. Reducing risk and compressing time frames in the transition of knowledge to utilization is the primary objective. A variety of initiatives are encouraged, with a relatively modest level of funding at the early stages, in order to determine which are worth selecting for larger-scale support. Since risk is spread over a variety of projects and approaches, a higher level of risk can be justified than if a single approach had to be chosen at the earliest stage. The larger return that can be expected from the success of a high-risk project is deemed more than sufficient to cover losses on unsuccessful ventures. Modestly successful ventures are also produced, but they are considered relative failures, ''living dead'', from the perspective of this high-growth/high-risk regime (Wilson, 1985).

The bright side is the potential for industrial and social innovation that new technologies, such as the electric light in the late 19th century and nano-technology at present, make possible. On the other hand, many new firms are minor variations of existing firms, with little or no technological advance. The ''dark side'' of the venture model came to the forefront during the late 1990s, when venture capitalists eschewed a relatively long-term strategy of five or more years to exit at 18 or even 12 months. This led to the creation of a spate of me-too firms, in which selling vitamins or pet medicine over the Internet was made the basis of companies that had no special technological advantage, only the hope of gaining market share through large expenditures on advertising. Venture capital needs to be re-invented to fulfill its original purpose of bringing advanced technology to market. A counter-cyclical model of venture capital is required, with a legitimate role for public venture capital to act as a balance-wheel to the private sector.

Backbone and flexibility in the Triple Helix

The Triple Helix is a historical model, in the tradition of Robert K. Merton's normative structure of science, designed to capture emerging trends and help us see where they might be going. For example, in Zambia recently, when there was a crisis in the national communications system, the university computer center stepped in and organized an Internet service provider (ISP) and established email communication. They had not thought they were acting as entrepreneurs, but they were, and this led to a new relationship between the university and society. Whereas before it had largely been a teaching institution, there is now a movement to renovate the university in an entrepreneurial direction.

The three spheres of university, industry, and government are those that in most cases are central to innovation. However, in some situations, such as in Africa, where organizational resources to promote innovation are limited, it has been suggested that the "innovation organizer" role may temporarily be played by international donors (Victor Konde, 2002, personal communication). The Triple Helix should not be viewed as a rigid framework. If one element is missing and another has appeared, then by all means insert that element in the framework to make your analysis or plan of action.

Nevertheless, to view the public as a fourth helix is to narrow the public to a private sphere, rather than seeing it as the underpinning of the entire enterprise of innovation. The existence of civil society, of the ability of individuals and groups to freely organize, debate, and take initiatives, without permission from the state, is the basis for a triple helix of bottom-up as well as top-down initiatives. When a society is organized on the basis of total government control, the possibility to have open discussions, except underground in small groups of persons already well-known to each other, is inhibited. Thus in Bucharest, even after the beginnings of regime change in the early 1990s, a group discussing innovation issues planned to pass around samizdat by hand.

This is an important difference between the Triple Helix and Sabato's triangle model of science-based innovation. In his model anything new that is to be done is expected to come from government direction rather than interaction among the different spheres. For example, Singapore is a society run through top-down coordination by government. Singapore now wants to shift from a manufacturing emphasis to knowledge-based economic development. It wants to develop a biotech industry, and some firms have been established. However, no association of biotech firms exists, and the reason given is that government has not decided to organize it. There was no space where people might come together to discuss such a possibility. Thus, unless the initiative came from government, no initiative was taken.

Indirect industrial policy

Since much government intervention in US industry takes place through indirect means and in a decentralized format, it does not rise to visibility as part of a general schema. Nevertheless a comprehensive US industrial policy can be discerned from more than 200 years of actions supporting invention, development, and diffusion of technology. Industrial policies operate at three levels in the US, moving ever closer to industrial intervention while still maintaining sufficient distance to claim ideological purity. "Industrial policy" occurs, first, as science or research funding policy, second, as an indirect policy in which government deputizes agents on its behalf, and, third, in the form of explicit public actions to encourage collaborations across institutional spheres and levels of government.

In response to ideological constraints, the US trajectory of immanent industrial policy formation creates networks of innovation across academia, industry, and government. An indirect and decentralized industrial policy, cutting across institutional spheres, may be more effective than traditional direct approaches since it is better able to take regional differences into account. There is a high threshold for obtaining government action to assist commercial innovation at the federal level. As a result of strenuous opposition, there is reluctance to recognize that a plethora of specific policies and programs accumulated over more than a century constitutes an industrial policy. Given the resistance to a role for government, when intervention is decided upon it is typically carried out collaboratively.

Federal initiatives complement similar programs at the state and local levels, filling gaps in the innovation system where opportunities for funding and collaboration traditionally have been weak. A common collaboration format brings representatives of different institutional spheres together in a bottom-up planning process. In addition, the programs fit nicely into a sequence. Together they constitute the world's most comprehensive industrial policy, supporting invention, development, and diffusion of technology at the national, regional, and local levels.

As the locus of significant research activity in the US, the university has become the focus of policies and programs to encourage technological innovation and reindustrialization. Government has invented new cooperative mechanisms, e.g. Industry–University Research Centers (IURCs) and Cooperative Research and Development Agreements (CRADAs), and provided "public venture capital" to translate academic research into economic activity, and industry problems into academic research (Etkowitz et al., 2001).

The European Union has initiated parallel processes and programs. Indeed, the EU and the US borrow innovation formats from each other through competitive reiteration and reinterpretation. Thus, the ESPRIT program to encourage software development was a response to the US "Star Wars" initiative, which focused heavily on this technological area. The US Advanced Technology Program was, in part, a response to the EU Framework Programs for encouraging national champions. All of these initiatives have in common the stimulation of networks among the institutional spheres, whether starting from the double helix of government–industry, commonplace in Europe, or government–university, more typical in the US. Eventually, as with the Advanced Technology Program (ATP), a US anomaly that was built upon an industry–government collaboration, the missing third institutional sphere is brought into the picture (Pavitt, 2000).

Over time, however, the ATP has conformed to the US model, which focuses on small firms as the legitimate receivers of government assistance and on the university as an appropriate recipient of federal R&D funds. Stung by criticism that its consortia programs, involving large corporations, were a form of "corporate welfare", the ATP has taken pains to demonstrate that most of its grants have historically gone to small firms. Moreover, even though universities were not allowed to take the lead in projects, as many as one-third of the attendees at ATP informational meetings to encourage proposal submission were from universities. Typically, entrepreneurial professors attended for two reasons: to find a firm to put forward a project on their behalf and to identify possible job opportunities in firms for their graduate students.

Most recently the ATP has transformed this unofficial process into an emerging requirement that all projects include a university partner. It is well accepted that the "market" cannot be expected to fund academic research. Thus it is accepted that it is legitimate for government to fund basic research, especially at universities. If a company has an academic partner, there is a presumption that its project has a fundamental orientation. This cultural lag persists despite the increasingly close links between research and product development in fields such as biotechnology. The role of government as an organizational entrepreneur in encouraging new waves of high-tech firms is disappearing from memory and is being replaced by the myth of individual entrepreneurship.

Relatively few Americans are willing to admit the considerable role government plays in the capitalization of knowledge, beyond funding basic research. Given the strong cultural emphasis on the individual entrepreneur and the private sector, the memory of university and government as a source of economic initiative tends to be suppressed (Kenney, 2000; see also Lee et al., 2000). This phenomenon can be seen most clearly in Silicon Valley, where DARPA supplied the funds to take a project from academic research idea to company, for example SUN Microsystems and Silicon Graphics. As entrepreneurs spin off from these firms, they lose the institutional memory that their progenitors emerged from the university, often with government support. Their world is one of interacting networks of technical people and firms (Saxenian, 1994). This highly publicized social reality lends validity to a laissez-faire model of entrepreneurship that downplays and even denigrates the role of government. Moreover, in response to this individualistic culture, government officials often self-deprecatingly disparage themselves and their own role in innovation.

The Triple Helix and the National System of Innovation

In the US, university–government relations were constructed from organizational mechanisms initially developed for relations with industry; in other societies, the movement has been in the opposite direction. The growth of university–government relations was intertwined with the formation of national identity in Germany in the early 19th century, through the Humboldtian academic model, integrating teaching and research in a civil service format. Apart from the land grant tradition, strong university–government relations in the US emerged from the Second World War military research projects. These were undertaken at the behest of academic scientists who saw the potential to develop advanced weaponry through the application of science to military problems (radar), on the one hand, and as an ultimate outcome of theoretical advance (the atomic bomb), on the other. University–government relations transcended the war-time emergency as academics realized that theoretical advance could arise from problem-oriented research as well as vice versa.

Classic institutional models tend to view institutions according to their traditional functions and typically find new activities to be a distraction. The Triple Helix focuses on new activities as a potentially productive innovation in innovation. When the primary meaning of innovation was new product development, a process which took place almost entirely in firms, a conceptual framework that focused primarily on industry was appropriate. A National System of Innovation (NSI) comprised the primary industrial sectors, and supporting structures, in which new product development took place in a given society. Since product development took place with government and university playing only supporting roles, industry was considered as the primary institutional sphere and focus of innovation analysis.

Following the NSI, each country has a particular industrial configuration, and Niosi (2002) has proposed the concept of "X effectiveness" for looking at institutional functioning in an NSI by benchmarking one country against another, not against ideal but against actual practices of industrial innovation. In effect an NSI is a special case of the Triple Helix model, where institutional spheres, each in its own area, play their traditional role in relation to each other. In the NSI model, industry could be viewed in terms of sectors that maintained long-term trajectories with secure knowledge bases that could largely be encapsulated within a firm. Much of this knowledge was tacit, directly tied to production processes rather than to research. Innovation or development of new products typically occurred through new combinations of knowledge and experience. Much innovation took place largely through "learning by doing" rather than formal R&D. R&D was largely firm-specific, but, as the focus has broadened, new organizational arrangements, such as industrial consortia, have been created to interrelate firms. Moreover, industrial R&D has become encompassed in a broader framework going beyond firms to incorporate elements from other institutional spheres.

In contrast to the NSI model, in which each institution operates along a single axis, in the Triple Helix model institutions operate on two axes, an x axis, in which they play their traditional roles, and a y axis, in which they play new roles. The Triple Helix model incorporates both the old and new roles and relationships among the institutional spheres of university, industry, and government. In most institutional models, each institution performs a single defining task. Indeed it is almost a defining characteristic of institutions that they perform a single function; traditionally conceived, institutions are functionally specific. Thus the second essential characteristic of the Triple Helix model, in addition to the enhanced significance of the university, is the recognition that institutions may perform multiple functions. A specific corollary is that the secondary functions performed are the primary functions of the other spirals in the Triple Helix. Differentiation rather than one-to-one correspondence of functions and structures occurs as innovation takes place in unexpected places.

The basic thesis is that it is possible for an institutional sphere to play multiple roles without the original role being degraded or harmed. The Triple Helix is a thesis of "the more the more", rather than one of organizational and institutional depletion. Research on faculty members in the biomedical sciences in the US demonstrates that those who publish more are also more involved in industrial interactions (Blumenthal et al., 1986b). We can look at how well these institutions play their new role and benchmark these activities by effectiveness, for example universities playing an industrial role as an engine of firm formation.

The second academic revolution

There has been a long-term academic development from teaching college to research university (the first academic revolution) and then from research university to entrepreneurial university (the second academic revolution). The first phase in the emergence of entrepreneurial science is the internal development of academic research groups as "quasi-firms" based upon a system of competitive research funding. The second phase refers to academic participation in the transfer of technology to enterprises, through intermediary mechanisms established for that purpose. Finally academics become more directly involved in entrepreneurial activities and firm formation. Research groups and firms then exist on a continuum as the boundaries between the university and other institutional spheres overlap.

During the first academic revolution, the theoretical and specialized outlook of the graduate schools was conveyed throughout the academic institutional order (see Geiger, 1998; Jencks and Reisman, 1966; Storr, 1953). Following upon the introduction of research as an academic mission in the late 19th and early 20th centuries, a "second academic revolution" (see Figure 2) got underway as universities took up the task of economic development, in the course of which the valorization of research is integrated with scientific discovery, returning science to its original 17th-century format prior to the appearance of an ideology of basic research in the mid-19th century (Kevles, 1978). Academia–industry connections have, of course, long been present. They can be traced back to 17th-century pharmaceutical science and the early development of a pharmaceutical industry in Germany. Nevertheless, until quite recently this modality only existed *in nucleo*. For example, although Marx perceptively cited Perkin's research as the basis for the dyestuffs industry, he was at a loss to offer additional instances in the mid-19th century.

A broader entrepreneurial ethos pervaded US research universities, extending well beyond those few universities that took explicit

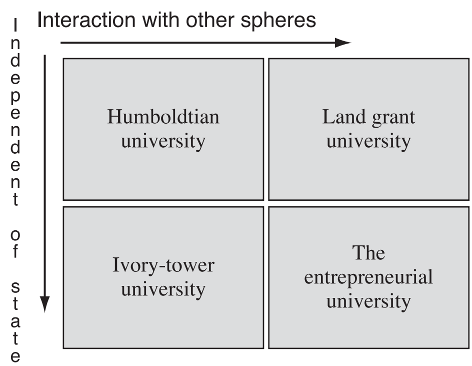

FIGURE 2
The second academic revolution

steps to develop close relations to industry. The US research university had an entrepreneurial ethos even before technology transfer and regional economic development came on to the academic agenda. Fund-raising for research was early on an individual faculty responsibility rather than tied to the position. Junior and senior faculty alike had responsibility for setting their own research and obtaining support to realize their academic goals (Kohler, 1991). This was originally a unique US academic element but is being universalized as other countries adopt the project grant model as a means of funding academic research. On the other hand, the US has more recently been moving toward the block grant model in order to gain a critical mass of research in certain areas by funding centers and groups of researchers rather than individual investigators.

University research groups have many firm-like characteristics, such as an entrepreneurial impetus, ongoing fund-raising responsibilities, personnel management problems, and public relations tasks in publicizing the group's achievements. Thus the cultural distance between academia and industry is often less than commonly perceived. During the 1980s, academic biotechnology firm founders noted that their tasks in founding a firm were not so different from running their research group. A parallel academic system tied to agricultural innovation, the land grant universities, was also created that fed into industrial innovation as agricultural research led to new products as well as to improved farming practices. These academic trends made it possible to rapidly expand the entrepreneurial academic scene as the potential arose in additional research fields and the need grew in industry for an infusion of new technologies.

The entrepreneurial university

To be an entrepreneur, a university has to have a considerable degree of independence from the state and industry, but also a high degree of interaction with these institutional spheres. If a university system operates as it formerly did in Sweden, where the ministry of higher education decided how many students would be admitted each year to each discipline, there is hardly a possibility of sufficient autonomy on which to base an entrepreneurial university. The first requisite is that the university have some control over its strategic direction.

The second requisite is that it be in close interaction with the other spheres, that it not be an ivory-tower university isolated from society. It means that the university takes a strategic view of its own development and its relationship to potential partners, but it is much more than that (Clark, 1999). On the one hand, the relationship of the university to society changes, while on the other hand there is a renovation of the internal structure of the university. The classical teaching college still exists in the US and Ireland, but we shall treat it as a peripheral first phase in our model of the entrepreneurial university. However, it is the originally stem phase of academia, the base from which universities have been built until quite recently, when a new line of academic development, a fourth phase, has emerged from science parks and firms, from a base rooted in economic activities, rather than from a teaching and educational base rooted in the preservation and transmission of knowledge.

The transitional entrepreneurial university

The first variant of the entrepreneurial university is a transitional phase from the research university. Thus, the transitional entrepreneurial university continues to operate with problem formulation and research goals as an internal process that takes place within scientific disciplines and academic research groups. What is different is that the economically and socially useful results from the so-called "meandering stream of basic research" are taken into account, and specific steps are taken to see that they are used. A series of organizational mechanisms (e.g. liaison and patent offices) are created to arrange their transfer across the still existing strong boundaries between the university and the larger society. The innovation model is an assisted linear model, with transfer mechanisms, in contrast to the classic research university, based on a pure linear model in which knowledge flows, through alumni, publications, and conferences, are the primary output.

At MIT during the early 20th century, involvement with industry occurred through a series of organizational innovations that legitimized the interaction between the two spheres. This included the invention of the one-fifth rule regulating consultation and the utilization of contracts to formalize hitherto informal university–industry ties and the patent system to protect intellectual property

(Etzkowitz, 2002b), the traditional academic committee process to review inventions, and an external organization, the research corporation, to market the patents to industry. The next step was the creation of an organization within the university, the technology transfer office, to carry out this task on a more intensive basis. In either format, as a branch of the university or as a free-standing entity, a search mechanism was introduced to identify commercializable knowledge within the university and to market it to potential users.

The full-fledged entrepreneurial university

The most important characteristic of the full-fledged entrepreneurial university is that research problem definition comes from outside sources as well as from within the university and scientific disciplines. In its fullest form, the definition of research problems arises from an interaction between university researchers and external sources as a joint project. Indeed, what would have previously been considered as external in the previous model is less so when boundaries are lessened. Just as there is a two-way flow between teaching and research in the classic research university model, similarly there is now a two-way flow between research and economic and social activities. Although quantitative data are limited, a significant but continually expanding group of academic scientists and engineers, disciplines, and subdisciplines engage in industrial interactions that transcend the traditional dissemination of knowledge.[8]

The entrepreneurial university takes the initiative to put knowledge to use. There are various organizational mechanisms for this purpose that work differently in different countries. Ownership rights to intellectual property can be shared among inventors and the university, as they are in the US; in Sweden they are entirely owned by the professor. However, university holding companies have been established to buy those rights and commercialize them. Thus it is not necessary to wait for the professor to become an entrepreneur in conditions where this is unlikely. A similar situation exists in Japan. One strategy is to introduce intermediary mechanisms to encourage transfer.

As the university becomes involved in technology transfer and firm formation, it attains a new entrepreneurial identity. This is part of a long-term trend in which business expertise, formerly localized within the university in extra-academic functions, is extended to traditional academic fields. A growing number of US universities are willing to use a small portion of their endowment funds to capitalize new firms, typically in association with other investors. This can be seen as the latest stage in a long-term movement of endowment managers to a more risk-intensive investment strategy, having previously shifted from a concentration on preferred stocks in the pre-war period to common stocks in the post-war period.

The center is the characteristic organizational form of the entrepreneurial university. Originally an internal university mechanism to draw together faculty members from diverse disciplines into ongoing interdisciplinary research projects, the boundary-spanning character of centers has been extended beyond the formal boundaries of the university to draw members of other institutional spheres into academic activities and academics into theirs. Such a center typically comprises university and non-university members, who participate together in the formulation and conduct of research. Thus, as in the NSF-sponsored IURCs, faculty members and firm representatives jointly decide on and supervise research projects. The Stanford University Center for Integrative Systems (CIS) is another instance where company researchers from various firms participate in formulating and carrying out joint research activities with academic researchers. Although the companies are ongoing permanent members of CIS, the firm researchers participate directly on a rotating basis, while the faculty participates on a continuing basis.

The entrepreneurial university as an extension of the science park

A further development is a new kind of entrepreneurial university organized on the base of a science park, research institute, or group of firms. Such academic institutions have begun as an extension of a firm or research institute. Examples include the PhD program in the policy sciences sponsored by the RAND Corporation, in the US, and the development of the Blekinge Institute of Technology on the base of the Soft Center science park in Karlskronna Ronneby. In this model, the knowledge-based economic activity precedes the development of academic work, which is then built on and closely tied to its originating source. The university, at least

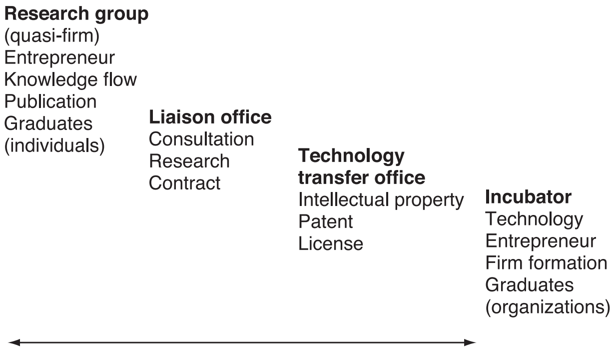

FIGURE 3
Co-evolution and multi-linearity of university–industry relations

in its initial phases, is an extension of the science park, research institute, or group of firms. Eventually the academic activities may grow into a full-fledged entrepreneurial university (see Figure 3).

The entrepreneurial university incorporates and continues the traditions of the research university just as the research university incorporated and continued the traditions of the foundations, going back to Bologna and Paris, of student- and teacher-run learning collectives. Even though more administrative functions were introduced, those older traditions still sustain the academy to this day. There will inevitably be tensions between these different missions. Indeed, there is a continuing tension between teaching and research. Where should the balance fall? State legislators always ask why academics are teaching only six or nine hours, what they are doing the rest of the time, they should be back in the classroom. On the other hand, there is the pressure to do more research, bring in more grant funds, and now there is a ''third mission'', to see that the knowledge is put to use and to relate more closely to the rest of society.

Nevertheless, just as it was more productive to combine these two missions, so it is more productive to join three missions together. Certainly conflicts of interest occur in the commercialization of research, just as there were conflicts of interest between teaching and research. However, there are also confluences of interest between teaching and research because it is more productive to have students and teachers developing new ideas together. That is why the university survives and does not disappear into consulting firms or research institutes.

The comparative advantage of the university

The comparative advantage of the university is its flow-through of students in comparison to the research institute or corporate laboratory, where the staff is relatively stable except under conditions of rapid expansion. New students bring new ideas to the research process, not only by themselves but through interaction with older generations of students and professors. It is not just the regular entry and departure of persons that is important, but the re-ordering of social relations in the laboratory that takes place on a regular basis due to the rhythm of academic life.

Moreover, as they are involved in research, students typically make advances by not knowing what cannot be done. The university is unique in its integration of teaching and research, even as it takes on some business functions. The core competency of the university has expanded from the production and distribution of human capital and knowledge to the packaging and diffusion of intellectual property, increasingly by recombining and enhancing internal and external innovations. Indeed, corporations such as Dupont have donated intellectual property, unrelated to their core interests, to universities, expecting that students and professors will be more effective than companies in taking it the next steps through development. Government has incentivized these interactions in various ways in the US, both directly and indirectly, for example through provision of research funds that must be used jointly by academia and industry, and by mandating the sharing of intellectual property rights among researchers, research units, and academic researchers.

Nor is the consulting firm likely to displace the university as the prime node of the knowledge society. Such firms typically work to order according to a set template, which they recycle to successive clients. Economic pressures rarely allow time for reflection on the accumulated data. Although there are notable exceptions, these typically occur in collaboration with academic partners. Indeed, such firms may be extensions or spin-offs of academic research groups and operate in a symbiotic relationship with them, drawing upon students as a labor pool and providing faculty with opportunities to capitalize academic knowledge and draw real-world experience into academia for theoretical analysis. Vannevar Bush commented on the fruitful infusion of research ideas into his academic research laboratory from his consulting practice with industry as early as the 1920s. More recently, the academic founders of biotechnology firms in the 1980s thought it best practice to maintain a dual base in academic and firm laboratories.

The university as natural incubator

The university is a natural incubator. It has flexible resources, people a good deal of whose time is potentially flexible, with access to inexpensive human resources, students, who can be organized to undertake new projects. Although this potential is often underutilized, with students being trained passively in large lecture classes, more active modes of training by organizing students into project groups such as those undertaken at The Blekinge Institute of Technology in Sweden are increasingly common.

The university is a flexible and capacious organization. Like the Church, its medieval counterpart, it is capable of reconciling apparent contradictions while pursuing multiple goals in tandem. MIT has long combined the practical and the theoretical, and one has not "crowded out" the other. The theoretical is important to the practical and vice versa, as demonstrated in the mid-19th-century career of German chemist Justus Liebig, who was at the forefront of organic chemistry while also adumbrating the practice of firm formation from academic research (Etzkowitz, 1983). Even at a distance, the close relationship between the theoretical and the practical became clear just prior to the Second World War in the dialectic between Lise Meitner's inference about the potential for a nuclear reaction releasing immense energy and the subsequent Manhattan Project. The success of that project provided enormous resources for devices to pursue theoretical work in the post-war period, in a Faustian bargain that lasted until the demise of the superconducting supercollider project.

Moreover, during the Second World War, physicists like I.I. Rabi, who were committed to basic research, found to their surprise that their work on war-time engineering projects related to radar led to new theoretical insights that they pursued after the war. Similarly, advances in instrumentation led to the development of radio-telescopy and new insights into cosmology. More recently the borders between the theoretical and the practical have been elided, and it has become difficult to tell where molecular biology leaves off and biotechnology begins, and even harder to distinguish between nano-science and technology. Increasingly one and the same persons and groups pursue both goals simultaneously in start-up firms, the laboratories of large firms, and academic research groups and centers, and in collaborations criss-crossing all of these. Both goals mutually contribute to and reinforce each other.

Discipline formation through synthesis

Modern science has always been organized to pursue practical as well as theoretical interests. Robert K. Merton reported that somewhere between 40 and 60 percent of discoveries in the 17th century could be identified as having their impetus in trying to solve practical problems in navigation, mining, etc. (Merton, 1970). Trying to solve practical problems through scientific means is neither new nor a modest part of science. It has been an important impetus to science from its inception. Nor is the Triple Helix interaction new. In many ways it can be seen as the renewal of relationships that were present at the initiation of modern science when, for example, the British government, seeking to improve international trade and commerce, offered prizes to encourage invention of new aids to navigation. Astronomers with a theoretical orientation and clockmakers with a practical bent both competed for these awards. The dynamic was an interactive one among the institutional spheres. Rather than the pursuit of knowledge as an end in itself, the needs of business were taken into account, with government, active as a public entrepreneur, playing the organizing role.

An individualistic and theoretical ideology of scientific accomplishment, created in the late 19th century, obscured the collaborative and practical nature of science that was apparent from the founding of modern science in the 17th century. Before the existence of autonomous disciplines, research having both theoretical and practical implications was the original format of science from its institutionalization in the 17th century. Moreover the original substrate of the medieval university was based on the unity of knowledge and the inherent interdependence of all disciplines (Feingold, 2002). The interesting question is why mode 1 of disciplinary research, isolated from the context of application, arose after mode 2, the original institutional basis of science, consisting of collaborations, networks, invisible colleges, and a concatenation of theoretical and practical concerns (Gibbons et al., 1994). Mersenne, before denoting an Internet site, was a person who by visits and letters knitted the early European scientific community together. The academies of science played a similar role in local and national contexts from the 16th century.

In recent years, new scientific disciplines and technologies, such as bio-informatics and nano-technology, have regularly emerged from Triple Helix interactions. Discipline formation through synthesis is the next step beyond the phenomenon of interdisciplinarity. There has been a shift in knowledge organization from creating a discipline by splitting it off and differentiating it from an old discipline in the way psychology developed out of philosophy in the 19th century (Ben David, 1991). New disciplines are more recently created through synthesis, for example integrating elements of psychology, applied mathematics, electrical engineering, philosophy, and a machine into computer science. Moreover, university–industry–government interactions took place among DARPA, IBM and various universities.

Max Weber held that scholars would lose control of their means of production as the scale of scientific instrumentation increased (Weber, 1946). Indeed, the separation of investigators from their research tools has occurred in many laboratories as academic scientists can more often be found in their offices than at the laboratory bench. Although these researchers have given up direct control of their instrumentation to students and technicians, they have retained control over the direction of its use. The dependence of scientists on large-scale research tools they do not own themselves has grown greater than in Weber's time, but the outcome is reversed: researchers' ability to capitalize knowledge has superseded the proletarianization of scientists.

A reciprocal relationship between practical and theoretical interests constituted the organizational substructure of the intellectual development of discipline formation in academic computer science departments in the US. Similar processes were at work in creating material science and the other techno-sciences that are on everyone's critical technology list. As interdisciplinary collaboration has expanded, a further series of new disciplines has been created at the intersections between earlier syntheses. For example, bio-informatics arose out of the intersection of molecular biology and computer science. A new department at the University of Washington was constituted through a collaboration among academic disciplines, supported by the Microsoft Corporation, as a window on an emerging area of knowledge with business potential. However, the academic leader of the department, Professor Leroy Hood, had also been a participant in successful instances of firm formation during his earlier career at the California Institute of Technology.[9] It was a long way from the ivory tower to the entrepreneurial university – or was it?

The origins of the endless frontier

Mode 2 represents the material base of science, how it actually operates. Mode 1 is an ideological construct upon that base in order to justify autonomy for science, especially in an era when it was still a very fragile institution. This ideology appeared in the US in association with the founding of universities by holders of large industrial fortunes and served to protect them from interference. There were grave concerns that the industrialists making these gifts would try to directly influence the direction of research at the universities, including the hiring and firing of professors as well as what topics were acceptable for study (Storr, 1968).

An ivory tower model, emphasizing isolation and de-emphasizing practical concerns, served to protect academic freedom when universities were a weak institutional sphere. In the late 19th century, the President of the American Association for the Advancement of Science, Henry Rowland, held that if anyone with external interests tried to intervene, the conduct of science would be harmed. Even as the ideology of basic research carved out a protected space for science, the land grant universities developed in parallel, and MIT was founded as a part of that tradition. Robert K. Merton's positing of the normative structure of science during the Second World War strengthened the ideology of basic research (see Hollinger, 1995; Wang, 1999). This initiative arose from the need to defend science from external attack by Nazi proponents of racist ideas of science, as well as from Lysenko in the Soviet Union. Again, the objective was to protect the free space of science.

The third element in establishing an ideology of science as an isolated enterprise was, of course, the 1945 report, *Science: The Endless Frontier* (Bush, 1945). The huge success of science in supplying practical results during the Second World War in one sense supplied its own legitimization. But with the end of the war, a rationale was needed that would accommodate scientists' wishes to control the disbursement of funds with the need to promise practical results in the civilian arena, equivalent to what had been achieved for the military in war-time in order to secure those funds. The report contained an implicit concept of science as a self-regulating mechanism, operating according to a linear progression: put in the money at one end and the results will flow out at the other in 50 years' time.

An interactive model

As academia, industry, and government interact more intensively, the social location of research and the way research is put to use are also affected (Etzkowitz, 2003). Hybrid organizations, such as cooperative research centers, strategic alliances, and incubator facilities, have been created at the interface of academia, industry, and government to stimulate innovation. Thus some university-originated firms located in incubators appear as much, if not more, committed to research goals as to making money, despite the best efforts of incubator administrators to focus their attention on the latter. Conversely, some academics are so attentive to the commercial implications of findings produced in their research groups that they tune their research programs to produce results that will be amenable to commercialization, even as they maintain their pursuit of fundamental research (interview with L. Gold of the Molecular, Cellular and Developmental Biology Department, University of Colorado at Boulder, 1992).

Academic research groups and science-based start-ups increasingly have a common focus on rewards of recognition and finance. Indeed companies developed on the basis of discoveries made at universities tend to continue to publish new findings based on their elaboration of the original discovery. Licensing, joint ventures, marketing, and sales of products provide additional ways of disseminating knowledge to broader areas of society, above and beyond the traditional means of academic dissemination. These commercial channels bring with them informal social relations that also provide pathways of dissemination (Saxenian, 1994).

A reverse linear model that shares some of the characteristics of the linear model is based on using knowledge to solve problems in industry and the larger society. This model is typically more conservative and, not surprisingly, closer to the market than the traditional linear model. The industrial research laboratory made a partial transition, first from applying scientific methodology to improve existing products, then to the creation of new products and processes requested by the firm, and finally to research-generated products from the laboratory. In the mid-19th century, technical innovation, for example in the railway industry, came from operational employees who produced inventions in the course of their work. By the late 19th century, a firm had established the first formal research laboratory, when GE hired Professor Willis Whitney from MIT. By the 1890s there were four industrial research laboratories, and by 1930 1000 (Servos, 1990). At the highest level, industrial labs made the transition from supporting existing production processes to creating new products using the methodologies of basic science. It is increasingly difficult to separate a series of cognitive and entrepreneurial activities that increasingly occur along a continuum rather than across strong boundaries.

The endless transition

We are moving from the era of the endless frontier, based on an assumption that research automatically translates into use, to an era of mediated innovation, the endless transition. Three fields of transition in science and technology policy can be identified in innovation, technology, and institutions. The first transition is in the relationship among basic research, applied research, and product development. These three heretofore relatively distinct phases are moving together. There will no longer be such strict boundaries among different types of research. Instead, they will blend into each other and move back and forth, without strict separation among them.

A penumbra of firms generated from the university and/or attracted to the university increasingly surrounds campuses. Research universities are especially important as a source of investments in advanced technology. A venture capitalist noted that "two of the deals we are currently in originated out of research first conducted at Harvard. Nanophase [a start-up] came out of laboratories at the University of Chicago" (Goncharoff, 2002). Governments, especially at the regional and local levels, are playing a new role in industrial development to encourage the growth of science and technology research as a basis for firm formation in regions that formerly lacked these capabilities. Industry is acting a little more like a university in sharing knowledge not only with the universities but with fellow firms, in collaborating with each other through strategic alliances in a quasi-academic mode.

The second endless transition is between different technological areas. They had been thought of as being connected to different disciplines and different industries, but they are now cross-fertilizing each other. Previously there were strong boundaries between individual disciplines. Moreover, as we have seen, new interdisciplinary synthetic disciplines with industrial significance have been created, such as bio-informatics, whose components came out of the previous syntheses that created computer science and molecular biology. Now these two have themselves been brought together to form a new field in a continuing process of combination and re-combination that has created other new fields, such as behavioral economics and nano-technology. Nevertheless the traditional legitimization of science as an important cultural institution still holds, even as military and health interests persist as stimuli to research funding. However, the future legitimization for scientific research that will keep funding at a high level is the fact that science is increasingly the basis of future economic development.[10]

The third transition has to do with the relationship between basic research and the uses of research. The linear model produces practical results, but not by itself. The US has established a series of programs and a regulatory environment to facilitate technology transfer in order to reap the benefits of munificent research funding. Other countries, such as Sweden, with high rates of R&D spending and relatively low rates of economic return, are currently undertaking parallel steps. Although the endless frontier provided a justification for the establishment of the National Science Foundation, much greater amounts of funds were devoted to academic science through the military in fields such as artificial intelligence and to molecular biology through the National Institutes of Health. At present technology transfer from academia makes a significant contribution to the US economy.[11]

Conclusion: the Triple Helix of innovation

The enhanced importance of science and technology to economic development is recognized north/south and east/west. It is increasingly the case that industrial firms need the application of knowledge to improve their production processes or to develop new firms on the basis of knowledge. It cannot be expected that entrepreneurs can always do this by themselves. Government programs have an important role to play, not only from the national level – top-down – but also from the local level – bottom-up, often in collaboration with other organizations in civil society. When bottom-up initiatives are reinforced by top-down policies and programs, the most fruitful result is achieved.

Of course, top-down coordination of university and industry can accomplish significant results, not only in totalitarian regimes but in democratic societies under emergency conditions. A Manhattan Project or an Apollo Project, with resources available to reach a goal through hierarchical coordination, can work. However, when this approach is applied to normal civilian conditions, a gap typically opens up between R&D providers and users. For example, Brazilian research institutes in the electrical industry prepared a technical solution that did not meet user needs because firms had not been included in an open discussion. The top-down process breaks down under these conditions.

The prerequisite for a viable Triple Helix model is a free and open democratic society. As we have seen in Brazil, it was the re-establishment of civil society and the ability to act in a free and open way that made the Triple Helix possible in terms of relatively independent partners. Indeed, Agnes Heller argues that there is a universal movement in this direction (Heller, 1999). Nevertheless, civil society is also an ideal that has to be fought for; without it, bottom-up innovation is smothered.

The Triple Helix incorporates historical, analytical, and normative dimensions. The study of history helps not only to understand the past, and empirical analysis helps not only to understand the present, but also to identify organizational innovations that may be imported, re-interpreted, and adapted to local circumstances and then exported. Another purpose of the Triple Helix discourse is to turn science studies from a constructivism narrowly focused on micro-processes to also address the reconfiguration of the relation among institutional spheres and the interaction between these two levels of analysis. Thus, innovation studies may be turned from a narrow focus on path-dependent national and regional systems to a more open-ended approach.

Finally, the entrepreneurial university is not the ''commercialized university'' but a university that encompasses the conservation and passing on of knowledge, integrating teaching, and research, as well as supporting innovation. The establishment of an entrepreneurial university or the re-organization of an existing university is an increasingly popular regional development strategy (Braczyk et al., 1998). As universities spin off for-profit entities from their research and educational activities, and fund some of their own research, they shift their institutional focus from eleemosynary activities to self-generation. The ability to achieve a balance among multiple sources of support, including industry, state and local government, and self-funding can be expected to increase the independence of the university. This transition to decreased dependence on federal government is partially hidden by increases of research funding in selected areas such as health (NSF, 1999).

There is also a movement away from an assumption that there is a single starting-point of research and an end-point of the economy. As entrepreneurial academic activities intensify, they may ignite a self-generating process of firm formation no longer directly tied to a particular university. A guided evolution of knowledge-based economic development can typically be discerned behind laissez-faire facades. The transition from textiles and machine tools to mini-computers and then to biotechnology in Boston, from the mid-19th to the early 21st centuries, exemplifies this process, as does the emergence of computer networks as a focus for the renewal of Silicon Valley in the early 1990s.

Is there a uniquely American way of bridging knowledge to commercialization? Certainly any method found in the US can also be identified in other advanced industrial countries and vice versa. Nevertheless, just as the American System of Manufactures was identified in the 19th century, so a Triple Helix of university, industry, and government is the current dynamic. It is based on a public/private partnership that connects the patent system to the intellectual output of the university research group, on the one hand, and integrates the research group into an organizational network of transfer offices, incubator facilities, and venture capital firms, on the other, supported by government R&D funds and production contracts.

An entrepreneurial academic ethos that combines an interest in fundamental discovery with application is re-emerging, as new and old academic missions persist in tension. Thus universities have retained their prerequisites, such as the right to publish, limiting firms' requests for delays in the time it takes an article to go through the publication process. Similarly universities have forbidden secret on-campus military research during peacetime. In contrast to biological evolution, which arises from mutations and natural selection, social evolution occurs through "institution formation" and conscious intervention. The Triple Helix provides a flexible framework to guide knowledge-based economic and social development. Innovation thus becomes an endless transition, an endogenous series of initiatives among the institutional spheres.

Henry Etzkowitz received a BA in history from the University of Chicago and a PhD in sociology from the New School University in New York City, where he studied with Peter Berger and Thomas Luckmann. He did post-doctoral work with Robert K. Merton and Harriet Zuckerman. He has published several books, including *Athena Unbound: The Advancement of Women in Science and Technology* (Cambridge: Cambridge University Press). Etzkowitz will serve as Visiting Professor, Research Policy Institute, Lund University, in Summer 2003. *Author's address:* Science Policy Institute, State University of New York at Purchase, 735 Anderson Hill Road, Purchase, New York 10577, USA.
[*email:* Henryetzkowitz@earthlink.net]

Notes

1. The critical mass provided by artificial intelligence "shops" at MIT, Harvard, and Bolt Beranek and Newman in Cambridge, MA exemplifies this dynamic (interview with Marvin Minsky, 1986).

2. See Nauwelaers and Wintjes (2002): "innovation refers to a behaviour of enterprises, planning and implementing changes in their practices, in order to come up with new products, services or organization."

3. See Kornberg (1996). Dr Kornberg, a Nobel Prize winner and self-described pure academic, discusses how he became enthralled by the firm formation process.

4. In the face of skepticism from the military sponsors of artificial intelligence research in the mid-1970s, the head of the computing office in the Advanced Research Program in the US Defense Department concluded that it would be to the mutual advantage of all for the academic researchers to take an interest in their sponsors' practical problems: "the shift will give the university research groups an engineering arm, a marketplace, customers, users. [That] integration will strengthen the basic work because there will be more feedback from real tests of the big new ideas" (Waldrop, 2001: 405).

5. Interview with Alan Pau, Director of Technology Transfer, University of California at San Diego, June 2002.

6. This transition can be seen in the evolution of Swedish research policy to an innovation policy during the past three decades (see Benner, 2001).

7. See Mingers (2002) for a discussion of radical change and development in a social system without loss of identity. "This is rather common in the social world where we see many groupings – families, companies, religions, cultures, and societies – that exhibit long-term stability and persistence despite enormous changes in their environment, and their own internal membership and structure" (2002: 281).

8. For a report on survey research on this phenomenon in one academic discipline, molecular biology, see Blumenthal et al., 1986**a.**

9. Interview with Leroy Hood, 1986.

10. Thus, John Ziman's prescient thesis of "steady state" science, characterized by stable or even reduced funding, is seen as a transitional phase between the "endless frontier" and "endless transition" eras. See Ziman (1986).

11. E.g. see "US Universities and Research Institutions Ranked by Adjusted Income per 100 Faculty", 2000. For a discussion of the methodological bases of how these calculations translate into economic growth, see Etzkowitz and Stevens (1995).

References

Ben David, J. (1991) *Scientific Growth: Essays on the Social Organization of Science and the Ethos of Science*. Berkeley: University of California Press.

Benner, M. (2001) *Kontrovers ochs consensus: Veteskap och politik I svenskt 1990–Tal* [Controversy and Consensus: Science and Politics in Sweden: 1900 to the Present], SISTER Report [Institute for Studies on Research and Education]. Stockholm and Nora: SISTER and Nya Doxa.

Blumenthal, D. et al. (1986a) "Industrial Support of University Research in Biotechnology", *Science* 231: 242–6.

Blumenthal, D., Gluck, M., Louis, K. and Wise, D. (1986b) "University–Industry Research Relationships in Biotechnology, Implications for the University", *Science* 232: 1361–6.

Braczyk, H. J., Cooke, P. and Heidenreich, M., eds (1998) *Regional Innovation Systems*. London: UCL Press.

Bush, V. (1945) *Science: The Endless Frontier*. Washington, DC: US Government Printing Office.

Clark, B. (1999) *Creating Entrepreneurial Universities: Organizational Pathways of Transformation*. New York: Pergamon.

Dos Santos, M. R. and Fracasso, E. M. (2000) "Sabato's Triangle and Triple Helix: Expressions of the Same Concept?", in J. Mello and H. Etzkowitz (eds) *The Endless Transition: Book of Abstracts; Third Triple Helix International Conference*. Rio de Janeiro: COPPE [Graduate School and Research in Engineering, Federal University of Rio de Janeiro].

Etzkowitz, H. (1983) "Entrepreneurial Scientists and Entrepreneurial Universities in American Academic Science", *Minerva* 21: 198–233.

Etzkowitz, H. (2002a) "Incubation of Incubators: Innovation as a Triple Helix of University–Industry–Government Networks", *Science and Public Policy* April 28(2): 115–28.

Etzkowitz, H. (2002b) *MIT and the Rise of Entrepreneurial Science*. London: Routledge.

Etzkowitz, H. (2003) *Triple Helix: A Manifesto for Innovation, Incubation and Growth*. Stockholm: SNS Press.

Etzkowitz, H. and Kemelgor, C. (1998) "The Role of Centres in the Collectivisation of Academic Science", *Minerva* 36(3): 231–68.

Etzkowitz, H. and Leydesdorff, L., eds (1997) *The University in the Global Knowledge Economy*. London: Pinter.

Etzkowitz, H. and Stevens, A. (1995) "Inching Toward Industrial Policy: The University's Role in Government Initiatives to Assist Small Innovative Companies in the US", *Science Studies* 8(2): 13–31.

Etzkowitz, H., Carvalho de Mello, J. M. and Almeida, M. C. (under review) "Evolution of the Incubator: The Emergence of Civil Society and Transformation of Science and Technology Policy in Brazil", *Research Policy*.

Etzkowitz, H., Gulbrandsen, M. and Levitt, J. (2001) *Public Venture Capital: Sources of Government Funding for Technology Entrepreneurs*, 2nd edn. New York: Aspen/Kluwer.

Feingold, M. (2002) "Science as a Calling: The Early Modern Dilemma", *Science in Context* 15(1): 79–120.

Geiger, R. (1998) "The Ten Generations of American Higher Education", in P. Altbach, R. Berdahl and P. Gumport (eds) *American Higher Education in the Twenty-first Century*, pp. 38–69. Baltimore, MD: Johns Hopkins University Press.

Gibbons, M., Nowotny, H., Limonges, C., Trow, M., Schwartzman, S. and Scott, P. (1994) *The New Production of Knowledge*. Beverly Hills, CA: Sage.

Goncharoff, K. (2002) "Tiny Technologies, Big Risk", *The Daily Deal* Thursday 15 August: 9.

Heller, A. (1999) *A Theory of Modernity*. London: Blackwell.

Hollinger, D. (1995) "Science as a Weapon in the United States during and after World War II", *ISIS* 86: 440–54.

Jencks, C. and Reisman, D. (1966) *The Academic Revolution*. New York: Doubleday.

Kenney, M., ed. (2000) *Understanding Silicon Valley: The Anatomy of an Entrepreneurial Region*. Stanford, CA: Stanford University Press.

Kevles, D. (1978) *The Physicists: The History of a Scientific Community in Modern America*. New York: Knopf.

Kohler, R. (1991) *Partners in Science: Foundations and Natural Scientists 1900–1945*. Chicago, IL: University of Chicago Press.

Kornberg, A. (1996) *The Golden Helix: Inside Biotech Ventures*. Sausalito, CA: University Science Books.

Lee, Chong-Moo et al., eds (2000) *The Silicon Valley Edge: A Habitat for Innovation and Entrepreneurship*. Stanford, CA: Stanford University Press.

Leydesdorff, L. and Etzkowitz, H. (2002) "The Transformation of University–Industry–Government Networks", *Electronic Journal of Sociology* April. (Available at: www.sociology.org/content/vol1005.004/th.html)

Machlup, F. (1962) *The Production and Distribution of Knowledge in the United States*. Princeton, NJ: Princeton University Press.

Melman, S. (1970) *Pentagon Capitalism*. New York: McGraw-Hill.

Merton, R. K. (1970) *Science, Technology and Society in Seventeenth-Century England*. New York: Harper and Row. (Orig. published 1938.)
Merton, R. K. (1973) ''The Normative Structure of Science'', in N. Storer (ed.) *The Sociology of Science*. Chicago, IL: University of Chicago Press. (Orig. published 1942.)
Mills, C. W. (1958) *The Power Elite*. New York: Oxford University Press.
Mingers, J. (2002) ''Can Social Systems be Autopoietic?'', *The Sociological Review* 50(2): 278–99.
Mustar, P. and Laredo, P. (2002) ''Innovation and Research Policy in France (1980–2000) or the Disappearance of the Colbertist State'', *Research Policy* 31(1): 55–72.
National Science Foundation (NSF) (1999) Science Indicators. (Available at: www.nsf.gov)
Nauwelaers, C. and Wintjes, R. (2002) ''Innovating SMEs and Regions: The Need for Policy Intelligence and Interactive Policies'', *Technology Analysis and Strategic Management* 14(2): 201–15.
Niosi, J. (2002) ''National Systems of Innovation are 'X-efficient' (and X Effective). Why Some are Slow Learners'', *Research Policy* 31(2): 291–302.
Pavitt, K. (2000) ''Why European Union Funding of Academic Research Should Be Increased: A Radical Proposal'', *Science and Public Policy* 27(6): 445–60.
Rivette, K. and Kline, E. (1999) *Rembrandts in the Attic: Unlocking the Hidden Value of Patents*. Boston, MA: Harvard Business School Press.
Roberts, E. (1991) *Entrepreneurs in High Technology*. New York: Oxford University Press.
Saxenian, A. (1994) *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.
Servos, J. (1990) *Physical Chemistry from Ostwald to Pauling: The Making of a Science in America*. Princeton, NJ: Princeton University Press.
Sorlin, S. (2002) ''Cultivating the Place of Knowledge'', SISTER Working Paper no. 9. (Available at: www.sister.nu)
Storr, R. J. (1953) *The Beginnings of Graduate Education in America*. Chicago, IL: University of Chicago Press.
Storr, R. J. (1968) *Harper's University*. Chicago, IL: University of Chicago Press.
''US Universities and Research Institutions Ranked by Adjusted Income per 100 Faculty'' (2000) *Technology Access Report* 13(2): 11.
Waldrop, M. M. (2001) *The Dream Machine: J.C.R. Licklider and the Revolution that Made Computing Personal*. New York: Viking.
Wang, J. (1999) ''Merton's Shadow: Perspectives on Science and Democracy'', *Historical Studies in the Physical Sciences* 30: 280–306.
Weber, M. (1946) ''Science As a Vocation'', in H. Gerth and C.W. Mills (eds) *From Max Weber*. New York: Oxford University Press. (Orig. published 1921.)
Wilson, J. (1985) *The New Venturers: Inside the High-Stakes World of Venture Capital*. Reading, MA: Addison-Wesley.
Ziman, J. (1986) *Science in a ''Steady State''*. London: Science Policy Support Group.