THIRD ACADEMIC REVOLUTION:
POLYVALENT KNOWLEDGE; THE "DNA" OF THE TRIPLE HELIX

Riccardo Viale (Fondazione Rosselli, Torino)
Henry Etzkowitz (State University of New York, Purchase)

Abstract

This paper analyzes the changing relationship of tacit to codified knowledge over three industrial revolutions. Knowledge is increasingly "polyvalent" as theoretical, practical and interdisciplinary implications form a common center of gravity. The changing nature of knowledge drives the institutional spheres of university and industry together in advanced industrial societies and developing countries, alike. Government policy lags and leads a shift from mono helix to triple helix knowledge production under different societal conditions. An entrepreneurial scientific role and an entrepreneurial university embedded in a triple helix of university-industry-government relations is the epicenter of innovation in a Third Academic Revolution, the next "great transformation."

Key words: poly-valent knowledge, triple helix, industrial revolutions, entrepreneurial scientist and entrepreneurial university.

Introduction

New knowledge increasingly appears in "polyvalent" forms, with theoretical, practical and interdisciplinary implications forming a common center of gravity, the "dna" of the triple helix. In a classic instance of polyvalence, agricultural researchers at land grant universities in the 1930's discovered hybrid corn by extending their government funded research programs, designed to solve immediate crop problems, to address fundamental questions in genetics (Nevins, 1962; Griliches, 1957). Polyvalent knowledge supercedes both traditional disciplines and mode 2 knowledge created in the context of application (Gibbons et.al. 1994). Such univalent single sourced formats are less productive than the polyvalent research groups at the Catholic University of Louvain that, "…have developed a record of applied publications without affecting their basic research publications and, rather than differentiating between applied and basic research publications, it is the combination of basic *and* applied publications of a specific academic group that consolidate the groups R&D potential" (Ranga et.al., 2003).

There is a reciprocal relationship between organizational and cognitive innovation that enhances both processes. Basic research physicists like I.I. Rabi experienced this epiphany during their World War II service in radar research when they realized that ideas for basic research were arising from their engineering work at the MIT "Rad Lab," and other multi-disciplinary wartime emergency "triple helix" entities (Etzkowitz, 2002). Since the labs were directed by academics, government funding of academic research, rejected prior to the war for fear that control over research direction would be lost, became acceptable thereafter. The transition from univalent to polyvalent knowledge facilitates the collapse of barriers between university and industry expressed in the formula, "let the university be the university; let industry be industry." Society is transformed as public/private dichotomies in knowledge, institutions, organization and roles evolve from purebred to hybrid, specialization to integration and separation to synthesis. In a "third academic revolution," the entrepreneurial university becomes the centre of gravity for economic development, knowledge creation and diffusion in both advanced industrial and developing societies.

1) Useful knowledge for innovation

The growth of the western economy in the last three centuries was based on the stock of useful and tested knowledge (Kuznets 1965). The reason for this role of knowledge is that it is "controlled observation around us [whereas] economic production is manipulation of observable reality for the special purpose of providing commodities and services desired by human beings" (p. 84). Thus, production increasingly became an offshoot and extension of scientific research in the laboratory and of scientific methods of observation applied to production in the plant. Nevertheless, there was typically an extensive time gap between discovery and utilization.

The role of knowledge in the industrial revolutions has taken different forms in different periods. Thus, the concept of knowledge useful for industrial innovation needs to be defined more precisely. Useful knowledge can occur at the conjunction of science and technology. Science can be defined according to the linguistic conception of the analytical tradition as made up of statements followed by methodological principles and techniques to evaluate and generate new statements (Hempel, 1965; Nagel, 1961). The statements may be nomological (theories and laws of nature) or accidental; universal or probabilistic.

The second approach is the cognitive. It conceives science as based on the biunivocal relation between external linguistic statements and the internal mental models representing the physical phenomena (Giere, 1988;Viale, 1991). The mental models are based on images and propositions (Johnson Laird, 1983). They are mainly of three types (Cheng and Holyoak, 1985, 1989, Holland, et al 1986) empirical – that categorize the physical phenomena (corresponding to the laws of nature or accidental generalizations); inferential rules – that allows the generation of the empirical mental models (inductive and deductive reasoning) - and pragmatic schemes– that represent norms of conditional action (e.g. the methodological norms or know how rules).

Technological knowledge can be defined as the result of inference from empirical mental models of the conditions to reach practical aims (or in analytical terms the deduction of the initial conditions, for example of flying, from the scientific laws, for example of aerodynamics) or the generalizations from trial and error of pragmatic schemes of action (or in analytical terms the generation of deontic norms of action to solve technical problems).

The cognitive approach seems superior in explaining the difficult transfer and communication of knowledge between scientists. In fact, formal publications do not contain complete information about the scientific statements and methodological techniques that characterizes experiments, discoveries and inventions. Some part of it is tacit that is it is not contained in the paper but only in the mind as pragmatic schemes or images. Moreover any linguistic statement can be interpreted in a different way, by different scientists, according different conceptual premises.

Therefore, there is always a problem of non-translatability of knowledge among scientists. The more they are different regarding the epistemological and methodological aims and norms and the cognitive style, the greater is the problem of non translatability in the communication of knowledge. The difficult relation between a truth seeking scientist of a university lab and an applied scientist of a corporate lab is the paradigmatic case. The above frameworks operate under bilateral formats of university-industry relations, typically involving intermediaries to assist with the translation.

2) The industrial revolutions: from isolated inventors to the net of Entrepreneurial Scientists

Different types of knowledge were effective in different periods of the three industrial revolutions. As Mokyr (2003) writes, "It is agreed by historians of science and economic historians that the component of "science" properly speaking in the classical Industrial Revolution was quite modest, and that the tight interaction of scientific knowledge and engineering, applied chemistry, agriculture and so on postdate the middle of the nineteenth century" (p. 25). Much of the technological progress before 1850 – in the steam engines, textile, wrought iron - came from practical know how generated by engineers. There was little inference from empirical mental models in the form of laws of nature. Scientific contribution came mainly from empirical accidental generalisations. There was not much collaboration between scientists and engineers. The micro-inventions were generated by experiments and trial and errors made by engineers.

In the second industrial revolution some great macro-inventions, such as the advances in organic chemistry were based on pivotal breakthroughs in the laws of nature, for example, the discovery of the structure of benzene molecule by the German chemist

August von Kekulè in 1865. Others, such as the steam engine or salicylic acid were generated by empirical generalisations and technical pragmatic schemes discovered by trail and error. In any case even a macro-invention like the telegraph that was based on the discovery by Hans Oersted of electro-magnetism required many other micro inventions to become a concrete innovation, for example the technology for the transmission of the electric impulses. In the case of telegraphy or organic chemistry the micro inventions stemmed from the close collaboration between science and technology. In other cases such as the steam engine and the salicylic acid, they were originated mainly by engineers and professional chemists detached from the university.

The first phase of the third industrial revolution is exemplified by such macro inventions as recombinant DNA and monoclonal antibodies, nuclear power, semiconductors and antibiotics based on important scientific discoveries. The collaboration between science and technology is intense. The centre of gravity of this collaboration is inside the university, with a supporting role of industry in its origin. Government typically plays a role in encouraging, structuring and funding these discoveries. Even the micro-inventions that brought about the development of biotechnologies and information and communication technologies were generated mainly by academy industry relations.

The reason why the centre of gravity is inside university is not only caused by the increased scientific density of the inventions but also stems from change in academic functions. The entrepreneurial university makes science but also technology and increasingly innovation. In the twentieth century there is a change of the process of innovation with the emergence of corporate, university, and government sponsored R & D, called by Mowery and Rosenberg (1998) the "institutionalization of innovation". Moreover there is the birth of a new type of scientist – "the entrepreneurial scientist" – who is able to interface basic knowledge with the innovation goal. Like the two faces of Janus, she is able to integrate two different and diverging perspectives the epistemological and the industrial one.

The future seems to foresee the reinforcement of the integration between different emerging generic technologies (second phase of the third industrial revolution). The acronym NBIC (Nano Bio Info Cognitive) of the new ”converging technologies to improve human performances” introduced by National Science Foundation in 2002 in its technological foresight exemplifies the phenomenon. Integration means more than collaboration between researchers in different fields and between academy and industry. It means reinforcement of the global role of the universities – from basic science to innovation and production – the development of less specialized universities with a wider disciplinary scope and the birth of a new scientist who integrates knowledge and innovation, as in the entrepreneurial model.

Moreover, such scientists also synthesize different kinds of disciplinary knowledge – e.g. life sciences and informatics or life sciences and nanotechnology or cognitive science and informatics or cognitive sciences and biotechnology - and, like Leroy Hood, formerly of the California Institute of Technology and the University of Washington, are involved in the creation of new disciplines from synthesis of elements of previous ones as in bio-informatics. The new scientist - “Kalì scientist” – of the future converging technologies looks in the same direction, that is the generation of knowledge for innovation, but, like the many arms of Kalì God, she uses different disciplinary approaches in problem solving.

3) From single helix to triple helix

A triple helix regime typically begins as university, industry and government enter into a reciprocal relationship in which each attempts to enhance the performance of the other. Most such initiatives take place at the regional level to address problems in industrial clusters, gaps in academic development and lack of governing authority. The first step usually involves collaboration among universities, firms and governments in a project to enhance a local cluster or create a technopole. Lack of fit between academic capabilities and firm needs is a typical issue in such arrangements.

To address such problems each triple helix partner “takes the role of the other” and learns to “take the view of the other” as well. Universities develop some business capacities even as firms increase their academic capabilities, including the ability to share knowledge with each 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 and perspectives of the other, each institution maintains its primary role and distinct identity. Each institutional sphere is thus more likely to become a creative source of innovation and to support the emergence of creativity that arises in other spirals.

> A reorganization of institutional relationships from opposed starting points in statist and laissez faire societies takes place with differentiation as the primary process in the former and integration, in the latter. Relative independent institutional spheres interacting on the basis of equality characterize the movement towards a triple helix society. Bounded entities persist but the boundaries are permeable; with networks and collaborations giving organizations an outward as well as an inward focus. Networking and taking advantage of complementarities supercedes “boundary work,” or defense of structures, as an organizational priority. A reciprocal relationship between the emergence of polyvalent knowledge and the differentiation and integration of the triple helix drive these changes.

> The development of the organizational models of innovation in the history of technology can be explained not only by the traditional socio-economic variables but also by the epistemological and cognitive constraints. In fact according the theory of bounded rationality (Simon, 1982) the cognitive limitations of the individual (Newell, 1990) are the major determinants of the organizational structure (March&Simon, 1993). It is evident in science that the cognitive features in the generation of different types of knowledge causes different social and organizational formats (Viale, 1991). For example the different organization of experimental physicists compared to the organic chemists or biologists is explained mainly by reasons based on the peculiar

generation and certification of knowledge (Shinn, 1982). The kind of knowledge implied in the industrial revolutions explains, ceteris paribus with the other factors, the organizational features of the relations between university, industry and government.

The Single Helix

In the first industrial revolution, for example, in the case of the development of the steam engine - the knowledge is little formalized, made of practical know how generated by individual experiments and trial and error. At the cognitive level the knowledge is based on simple empirical mental models that correspond to contingent accidental generalizations and mainly, by pragmatic schemes that are condition-action rules to drive the practical know-how. These mental models and schemes are idiosyncratic and embodied in the individual. It is difficult to transfer them to others. There is little knowledge that is explicit and represented in natural and formal language. Therefore, there is a lot of tacit knowledge that makes the collaboration and dialogue between inventors difficult. Consequently the organization is made, mainly, of isolated individual inventors. There is little collaboration inside university and almost no collaboration between university and industry. The model is the single helix.

The second industrial revolution, for example in the case of advances in organic chemistry, is based on important scientific discoveries as that of benzene molecule by Kekulè. This knowledge is represented mentally by empirical mental models and expressed externally in natural and formal language. The technological knowledge stems from inference from empirical mental models (e.g. practical implication of the discovery of benzene), but also from the generation of pragmatic schemes by trial and error (e.g. the random experimentation of acetyl salicylic acid). There are also instances of experimental models derived from theory, such as Benjamin Franklin's lightening rod, which arose from the milieu of the scientific academy and its informal interaction with a community of practitioners: a transitional format between the first and second revolutions (Schiffer, 2003: 185). In the first case there is the need of formal collaboration between university and industry.

The Double Helix

Since the knowledge is also explicit the problem of tacit knowledge is less present than in the first revolution. Nevertheless the collaboration between academy and industry is difficult for the different methodological and epistemological rules and aims of the two worlds. But the industry has not the skills to solve many technical problems and it is obliged to interact with university. In these cases there are not yet the birth of hybrid organization and neither the phenomena of "industrialization" of academy and the "scientification" of industry. The development of chemical industry and organic chemistry in Germany is an example of a fruitful collaboration between academic and industrial worlds. In the second industrial revolution there is weak interaction with the government, except other than for military reasons. The model is the double helix.

The first phase of the third industrial revolution is characterized by a reinforcement of the centre of gravity on formal knowledge and science, mentally represented by mental models. The technology is generated mainly by inference from empirical rules (that is in analytical terms by deduction of initial conditions from scientific general assertions and explanandum). The mental models and the inferences are made explicit externally in formal language. They become public through academic publications and patents. Therefore the problem of tacit knowledge is minor even if it is present (Pozzali & Viale, forthcoming). Actually there are parts of the methodological techniques that cannot be explicit because they are represented mentally by pragmatic schemes of action. There is a convergence of methodological and epistemological aims and norms between academy (industrialization of science) and industry (scientification of industry).

The Triple Helix

The need of epistemological and cognitive integration between science and technology brought deep change in academic industry relations (Carayol, 2003). The process that began in the chemical revolution in Germany showed the difficulty of collaboration between two separate worlds. Neither can the solution be fully found in an intermediary agency that interfaces university and company. This solution lengthens the knowledge chain and increases the problems of cognitive and epistemological non-translatability and tacit knowledge. The solution was found in a gradual reinforcement of the "model of innovation centred on the university." It is evident in US particularly in biotechnology, information technology, nanotechnology, new materials, and other emerging technologies but similar developments occur in France and elsewhere (Mangematin et.al. 2003).

The initial relation between firm and university is centred in the PhD's that are trained in the university and go to work to the corporate labs. The second is the phenomenon of "entrepreneurial university" acting as a generator of spin-off firms (Etzkowitz, 2003). This university gives birth to the dual academic career. Beyond the traditional truth-seeking scientist there is another scientist the "entrepreneurial scientist" who is able to interface knowledge and innovation. The academic trained scientist working in the corporate lab, with an eye on basic research as well as company problems, and the entrepreneurial scientist in the university, with an eye for the practical implications of their findings, minimizes the problem of cognitive and epistemological non translatability, unavoidable gaps in tacit knowledge, and divergence in awareness of commercial potential. The non-linear relation between knowledge and innovation is realized in the same mind[1].

Nevertheless, the problem of translatability between knowledge and innovation never disappears, either on the industrial or academic side since there will be differences of opinion over which knowledge has innovation potential. [2]The differences in productivity in innovation systems in different countries can be seen in the extent to which they allow multiple possibilities for ideas to receive a chance to be realized. Governments and the public bodies that promote and finance the academic-industry collaboration operate best when they have diverse programs at the national and regional levels (Hayashi, 2003). Given an active civil society, initiatives will arise from non-governmental sources,

---

[1] This fact reduces but doesn't make the issue of non-translatability disappear, because of the modularity of mind (Fodor, 1983)

especially at the regional level. Through the leadership and cooperation of individuals from universities, industry and government, all three institutional spheres participate in the birth of hybrid institutions. The model is the triple helix.

The second foreseeable phase of the third industrial revolution (summarized by the acronym NBIC) will see the emergence of new form of integrated knowledge – nanobio, biocogninano, infocogni, and so on - stemming from different disciplines and domains (e.g the technological projects of ‘smart dust” arising from nano-technology and ICT or biochips from biotechnology and information technology). The traditional academic disciplinary borders will disappear. The Ph.D. training will be broader and inclusive of different, heretofore, distant domains. The university will try to be less specialized and more generalist as increasing numbers of faculty and students integrate elements of various specialities into their personal profile. The movement of physicists into biology and the invention of bio-physics and molecular biology were early augurs of this trend (Fischer and Lipson. 1988).

Future scientists should be able to manage different and distant conceptual frames and see both the theoretical and practical implications of their research. The potential cognitive overloading of this expertise will increase the need for collaboration, to fully realize both the theoretical and innovation potential of research. Will the Janus scientist, looking to different and diverging directions be replaced by a scientist with multiple expertise but with only “one face,” science or innovation oriented? Alternatively, single individuals may pursue science and innovation simultaneously, or at different stages of their academic career, and with multiple scientific and business collaborators.

As for Kalì she will be able to use, simultaneously, many “conceptual arms” to solve scientific and technological problems. This complexity and multiplicity of expertise will be very demanding. Only academic institutions will be able to cope with the human capital and the time scale necessary to realize the potential of discontinuous inventions. Moreover only inside the academic labs and centres it will be possible to interface science, technology and innovation without falling into the traps of non-translatability and tacit knowledge. The university becomes more salient when the innovation issue is development of a new technological paradigm rather than innovation as incremental product development.

From Creative Destruction to Creative Reconstruction

What are the implications for the triple helix from the third academic revolution, a continuous process of creative reconstruction that supersedes the 50 year Kondratieff cycle of creative destruction? As the ability is developed to move across technological trajectories, from one technological paradigm to another, a "triple helix region" is attained. For example, Massachusetts developed the capacities, in government technology agencies, academic research centres and high-tech associations, to assist the transition from a minicomputer to a biotechnology industry. There were fewer painful gaps than the previous transition from traditional manufacturing industries to the computer era. Thus, creative reconstruction takes place through a continuous series of organizational innovation that infuses society with new activities to replace those lost through creative destruction.

An evolving knowledge and innovation infrastructure is constructed from elements of the triple helix. For example, university research centers adopt industrial models of research management to provide a support framework for several academic research groups. Similarly, start-up firms are a hybrid creature, embodying academic, industrial and government elements rather than a pure business model even though legally constituted as firms. Indeed, the social space taken up by the overlaps may become greater than that occupied by single and double helix organizations in the future.

As the knowledge base of societies increase, hybrid organizations such as "Public science laboratories are located within the overlaps of these institutional spheres" (Simpson, 2004). New hybrid organizational formats are invented from elements at the intersections of the triple helix. Thus, knowledge utilized to 'design Dolly" emanated from a government supported research institute, allied with a university and a firm (Fransman, 2001). Indeed, the U.K. firm was a cross-national entity, the result of a merger with a US start-up, a hybrid of a hybrid.

The Co-evolution of Knowledge, Institutions, Organizations and Roles

Polyvalent science was institutionalized in the U.S. during the post-war, along with funding agencies that offered diverse opportunities. Universities became involved in a closer relationship with government, whether the funds were provided by basic or applied funding agencies, by peer review or program officer initiative. When international competitiveness became an issue in the 1970's, government-funded science was expected to contribute to industrial renewal. Closer ties were forged between university and industry in order to overcome impediments to innovation..

As the triple helix evolves, institutions, organizations and roles are transformed. New tasks are often defined as conflicts of interest and obligation when viewed in relation to old. For example, when research was introduced as an academic task in the late 19th century, some said it diverted teacher's attention from students. A process of normative change takes place as controversies are resolved and new and old tasks are reinterpreted as complementary.

Academic patenting is currently undergoing this transformation as professionalization of technology transfer creates an organizational search, marketing and business development capability. As individual academics become involved, they perceive their findings in a new way, seeking out the practical as well as the theoretical implications of their work. The process is uneven and persistence of pre-modern social structures may explain resistance to change in academia just as feudal relations impeded the transfer of modern technology to southern Europe in the 19th century (Mazotti, 2004). Indeed, similarities in the social relations of feudal agricultural and academic systems may explain similar resistance to creation of formal mechanisms for inventions that could not be transferred through informal university-industry ties. (Rashdall, 1896).

1) *Institutional Evolution: From Physical to Intellectual Property*

The co-evolution of knowledge, organizational forms and institutions is exemplified by the transformation of the patent. A "patent" was originally a grant of an exclusive right to extract a mineral or pursue an area of industrial activity that government wished to encourage locally, such as glass-making in 16th century Venice, on the condition that the activity be vigorously pursued (Long, 1991; MacLoud, 1988). Invention was not a requirement to obtain such a patent. The connection between new knowledge and business development began to become apparent during the First Industrial Revolution and government, first in the US and then in France, expanded the focus of the patent to incentivize inventors.

During the 2nd industrial revolution, corporations in technology-based industries subsumed the individual rights of employees to knowledge developed in the firm by assigning intellectual property rights to the firm as part of the employment contract. Railroad workers, who had previously retained patent rights and then sold them to their employees, were superceded by intellectual property-less employees (Lazonick, 1991). Corporate inventor's still spin-off firms, with or without permission; in the latter case a litigated solution is the typical outcome.

In US the passage from physical to intellectual property can be placed in the judgment of the Supreme Court in 1908 for Continental Paper Bag Company vs. Eastern Paper Bag Company. The Court set the attribution of IPR not only to the product but also to the patent idea before it generates the new product. This change of rights from the object to the idea was originated by the change of the knowledge intensity of the inventions. That caused a change of the ownership of IPR. In the first and part of the second industrial revolution the knowledge was mainly practical, tacit, informal and idiosyncratic. Consequently it was impossible to protect it at early stages of invention. Only when the new invented physical object was built might it have property rights. Therefore the IPR was focused on inventors and companies but not on academic institutions. In part of the second and in the third industrial revolution the knowledge is mainly codified, theoretical, formal, and conveyable. Consequently it is possible to protect it at early stages of invention. Thus, the IPR is increasingly focused on academic institutions and researchers.

Where is the appropriate locus of intellectual property rights in academic research? In a univalent era, the fit was likely to be obvious and rights left with the individual researcher would typically be informally transferred to a firm through a former student working for the company. It is not always obvious where to locate a new discovery with diverse implications. A more formal search mechanism such as a technology transfer office is required to seek out these opportunities. Thus, locating ownership rights at the individual, or a higher organizational level, such as the university, is at issue in the era of polyvalent knowledge.

If the scientist or the universities do not have protection of rights they are not incentivized to make technologies, patents and transfer them. Government recently assigned intellectual property rights to the university in Germany and Denmark as intellectual property rights became more salient to economic development. When the US government owned intellectual property emanating from research it funded in the early post-war, only a relatively few universities, those with a strong entrepreneurial culture, made an effort to obtain these rights from government and patent and transfer technology. The Bayh-Dole Act of 1980 transferred these rights to the university, giving it the responsibility and incentive to patent, thus expanding technology transfer to all U.S. research universities (Rogers, Yin and Hoffman, 2000).

A parallel transition of institution and organization is a key to success. If the university is given the legal authority, but fails to develop an organizational capacity, a university owner may be a barrier to transfer. Under such conditions, rights are best left to the individual, as in Italy, where at least a few entrepreneurial academics will utilize them. In an intermediate situation, as in Japan until recently, and at most Swedish universities, technology transfer organizations have little problem arranging faculty agreement to represent them.

A viable academic technology transfer regime is embedded in an entrepreneurial culture, with a fair division of proceeds to stakeholders, and a knowledge management strategy that combines patenting with publication as complementary forms of dissemination (Amesse and Cohendet. 2001). A general trend toward division of rewards among the various interested parties, researchers, their academic units and the university as a whole can be discerned, whether formal ownership is left to the individual or shifted to the university.

Has the use of the patent mechanism to spur innovation merely scratched the surface since most university technology transfer offices patent only when they can identify a market in advance? This suggests that technologies well in advance of current industrial uses may not be receiving patent protection. Although it has been argued that too much academic patenting has become a barrier to knowledge diffusion, patenting is a form of publication. The alternative is secrecy and getting to the market first, a traditional industrial strategy. Nevertheless, companies are also increasing their patenting and licensing activities, following the lead of universities.

Rear-guard discourses respond to this paradigm shift in intellectual property regimes by recuperating a mythical era of pure research, the dominant ideology from the late 19th to mid-twentieth century. From the formation of modern science in the 17^{th} century until the emergence of the ”ivory tower” university in late 19^{th} century, researchers and practitioners, such as the 18^{th} century “electricians” often shared common communities of discourse and action (Schiffer, 2003). Polyvalent knowledge supercedes the inherited dichotomy between public and private knowledge but the issue is a continuing one (Hellstrom, 2003).

2) Polyvalent Knowledge and Organizational Evolution

The transition from univalent to polyvalent knowledge also brings forth new issues and opportunities to be puzzled out (Beesley, 2003). The entrepreneurial university and the entrepreneurial scientist combine multiple purposes and sources of funding to support their research enterprises, helping create the conditions for the emergence of polyvalent knowledge (Van Looy et.al. 2004). A portfolio of overlapping basic research agency, industry supported, strategic research foundation, applied research agency and start-up firm supported projects is the underpinning of the contemporary academic research group. At the macro-level, a diversity of potential sources of support is a pre-condition for the combination of resources at the micro-level. The insertion of a series of quasi-public research agencies in between the classic research councils and industry in Sweden, during the 1990's, exemplifies this transition.

New organizational arrangements for collaborative research, formerly conducted at a distance, stem from the passage to polyvalent knowledge. The establishment of a research center, focused on an emergent field, integrating several research groups along with industry and government scientists is the next step to encompass the multiple tasks presented by polyvalent knowledge. Polyvalent knowledge is often produced in triple helix contexts such as the "incubator of centers" at the State University of New York at Albany, bringing together academic, industry and government researchers (Etzkowitz, 2002a). Research units at the overlaps of the triple helix tend to develop broad-based theoretical knowledge with multiple utilities. A dual transition of knowledge and organization is the model here.

3) The Emergence of Polyvalent Roles

New constellations of roles are created as people operate at the intersections of the triple helix, leading "double" and even "triple lives" in university, industry and government, simultaneously and successively. Their expertise in more than one field is often reflected in an educational profile that may include a Ph.D. in molecular biology and an MBA in Business Administration or a medical degree combined with a computer science or law degree. Such people are often employed in hybrid organizations, such as venture capital firms and technology transfer offices, which work at the overlaps of the triple helix.

Dual roles have been institutionalized separately and in combination. The introduction of the 2^{nd} mission of research by law in Sweden in 1919 brought with it the creation of a new post of Lecturer to carry out teaching, leaving research to the professor. On the other hand, in the U.S. the two tasks have been combined in the professorial role. As spin-off firms arise from research groups, some of the people in both entities are one and the same! Leave procedures, consulting rules and the norms of science are adapted to regulate entrepreneurial science. Resolution of conflicts through compromise between opponents and the invention of new rules, such as MIT's one/ fifth regulation of consultation, is the basis for realizing seemingly opposed values (Etzkowitz, 2002).

The academic career encompasses multiple roles, in tandem and ad seriatim, on the premise that each enhances the other. Government and industry increasingly support academic development in new directions based on these results (Andretsch, Link and Scott. 2002). Ethical and organizational research questions raised include: What are the appropriate roles of persons located in more than one institutional sphere? Are conflicts of interest and obligation inevitable or are complementary arrangements possible? The emergence of the "entrepreneurial university," a new type of academic format holds within it some of the answers to these questions of dual academic career vs. triple academic career (basic scientist, innovation researcher, entrepreneur).

Varieties of Entrepreneurial Universities

The entrepreneurial university arises as an extension of educational mission, as well as from academic research capacities. The entrepreneurial university extends the traditional teaching mission of the university by educating organizations in its incubators as well as students in its classrooms. The university by its very nature has a constant flow through of persons, generating new ideas, in contrast to relatively static research institutes and R&D laboratories of large firms. This is why successful faculty firm founders do not leave the university; they want to stay close to the students who are the source of new ideas.

The university is the core institution of knowledge-based society because the university has the students. The triple helix thesis is that the university goes into the future as the predominant organizational format of a knowledge-based society. As an institution of medieval origin, the university has successively reinvented itself over the centuries into the central institution of knowledge-based society. The entrepreneurial university encompasses traditional academic responsibilities for human capital formation, research and the critical function, even as it takes on the tasks of institution formation (Owen-Smith, 2003).

A unique feature of universities is the availability of significant free time, space and facilities to initiate new activities. In a knowledge-based society, the university plays a key role in creating growth as well as intellectual advance; indeed the two go hand in hand. Thus, "If high impact publications provide an entry ticket to information rich networks in the life sciences, and if access contributes to increasing commercial accomplishment, then scientific reputation might start universities on a path of increasing returns."(Owen-Smith and Powell, 2003: 1708).

The entrepreneurial university subsumes the classic Ivory Tower, Humboldtian, Land Grant and Polytechnic configurations in a new framework. In addition to all the traditional university functions, the entrepreneurial university creates triple helix organizations such as spin-off firms and NGO's. It also disseminates knowledge through traditional formats such as publication and patents. These innovations in knowledge, institutions, organizations and roles are integrated in a new academic format.

The entrepreneurial university has the ability to set its own, strategic direction and thus is relatively independent of government and industry even as it takes some of the role of industry and government. It also has the internal organizational capability to conduct technology transfer and initiate regional cooperation. Rather than relying on bureaucratic forms of authority, the university engenders a culture of entrepreneurship among its students, faculty and staff in seeking resources and opportunities. The entrepreneurial university grows from different academic starting points and thus exhibits a variety of hybrid characteristics.

Entrepreneurial universities have emerged under different academic and social conditions in the U.S., Europe, Latin America and Africa. U.S. academic entrepreneurship is a natural extension of an entrepreneurial dynamic that has been built into the American research university from its inception. Each professor, from the most junior to senior, is responsible for obtaining their own research funds. Government R&D funding in the post-war, given out by agencies utilizing a mix of peer review and program director initiatives, expanded an entrepreneurial academic research system that had evolved since the mid-19th century. Research groups grew up as “quasi-firms” with many characteristics of the business firm, except for the profit motive. It was a relatively short step to firm formation when opportunities appeared.

Academic entrepreneurship takes a distinct course in Europe, especially given a strong tradition of state control. The European entrepreneurial university emerges top down as a mission set by government. Since the professorial role has traditionally been defined as a civil servant, the professor is rarely an entrepreneur. Recognizing this professorial distance from entrepreneurship, Linkoping and Chalmers universities, in Sweden, have focused on training students to develop start-up firms, with the professor as advisor to the new firm. The entrepreneurial role in spin-offs is typically taken by students in information technology and by persons from large firms in the biomedical field. Thus, the European entrepreneurial academic model focuses on changing academic culture by empowering students.

The Brazilian model diffuses entrepreneurship throughout the university. For example, a course to write and test a business plan is part of general education for all students at the Pontifical Catholic University of Rio de Janeiro. During the past 30 years universities adapted the incubator to a broad series of organizational training tasks. Incubators form high tech firms, fill gaps in traditional clusters and establish consulting firms that perform a modernizing function, transferring high tech knowledge to low tech firms. Incubation serves a variety of other organizational needs in Brazilian society, including forming cooperatives to create employment and address the issues of poverty, community development projects, NGO's and arts groups. Industry associations and government, at all levels, have spread an incubator movement that has gown well beyond its academic origins, developing its own networks and organizational structure (Etzkowitz and Mello, 2004).

The entrepreneurial university has appeared in Africa in response to innovation crises. When the telecommunication system in Zambia broke down the university computer center stepped in and set up an Internet Service Provider (ISP) that was later spun off as a firm (Konde, 2002). This individual event is currently being generalized into a broader academic and national development model. The objective is to set a virtuous circle in motion in which academia is transformed from a cultural entity that consumes the surplus of a society into a productive force that generates new resources.

The Triple Helix and Entrepreneurial University as Normative Concepts

Triple helices emerge as a trajectory that include developing as well as advanced industrial societies in innovation. In developing countries, the triple helix and the entrepreneurial university are often viewed as normative as well as analytical concepts; a goal to be sought rather than a reality to be investigated. From this perspective, the triple helix is often seen as a working model of innovation in advanced industrial countries. Finding ways to enhance nascent triple helixes in societies where an institutional sphere, such as industry, may be largely lacking is a challenge. There may be a low level of research intensity, or other innovation gaps. Nevertheless, developing countries have various elements of a working triple helix, including innovations in organizational formats, such as occurred with incubation in Brazil, that could usefully be transferred to developed countries. The capacity for technological and organizational innovation is global, given the universality of universities.

The triple helix model suggests that universities in transitional and developing countries take a leading role in catalyzing regional growth spaces. As new universities are founded, greatly expanding higher education in all societies, it is especially important that universities in developing countries, such as Ethiopia, envision a broader role for themselves than sanctioned by the ivory tower model.[3] However, the same prescription basically holds for developed countries where governments and industry are often bound to inherited sectors and outdated regional development models.

There is a nascent division of labor in the triple helix with the university taking the lead in future technology areas, with government and industry playing a support role, and vice-versa in existing sectors (Lofsten and Lindelof. 2002). Existing clusters could be strengthened if legal and administrative restrictions engendered by national boundaries were removed (Lindstrom, 2004). This would allow firms who are adjacent to a strong cluster, but just across a national boundary, to work with compatriot firms. On the one hand, there is concern that firms might be lost to the national innovation system; on the other, there is the expectation that cluster development could be strengthened. These competing fears and hopes make the steps taken likely to be relatively tentative and incremental, at least at the outset.

Even as the Nordic Industrial Ministries work to remove barriers to collaboration among firms across national borders, a university has led in developing a new industrial sector. The Karolinska University in Sweden has worked its way through a variety of technology transfer initiatives during the past decade, with its biosciences faculty and with universities in other Nordic countries. Karolinska established a venture investment instrument for seed capital by spreading risk among a broad portfolio of previously founded firms that had attained some growth. Government regulatory reforms have removed barriers such as the requirement that shares in start-ups be taxed before they achieve value.

[3] Etzkowitz, Henry 2004 Interview with Mohammed Duri, Ethiopian Ambassador to the UN March

The Karolinska initiative reprises the effort of MIT and its partners in the 1930's and 40's in inventing the venture capital firm as part of a regional development strategy create new industrial sectors. To promote start-ups, the inventors of venture capital recombined the scientist, inventor, capitalist, entrepreneurial and managerial roles into new hybrid formats, of entrepreneurial scientists and venture capitalists. However, as the industry grew, the venture firm outgrew its original purpose by focusing on existing firms. Venture capital replicated traditional financial institutions, whose deficiencies were among the reasons for the industry's foundation. Venture capital needs to be reinvented as a counter-cyclical model, active in the downturns, when it is less expensive to start-up firms, as well as the upturns of the business cycle and at all stages of the firm formation process.

The university as the site of advanced knowledge is often the institution with the greatest potential to realize discontinuous technological advance. What is crucial is that the university develop the organizational capacities to fund the formation of new businesses (Di Gregorio and Shane. 2003). Government will tend to work with existing clusters and industry will tend to focus on incremental advances within existing technological paradigms (Goldfarb and Henrekson 2003). The university is best suited to take a long term view and develop advanced research areas with technological and commercial potential, supported by government and industry (Leydesdorff, L and M. Mayer 2004).

As the university generates income from licensing technology and holding equity in spin-offs it is able to start new projects with their own funds although this is a future prospect for most schools. (Thursby and Kemp 2002). Nevertheless, a small but steadily increasing number of universities, with a financial base from technology licensing and from the sale of equity in previously successful firms, are initiating "blue sky" projects, without dependence upon on other institutional spheres that are more tied to existing reality.

The Endless Transition

The triple helix of university-industry-government relations is emerging as a common format that transcends national boundaries. As this takes place there is a shift from bi-lateral to trilateral interactions from single and double helixes to university-industry-government joint projects like the land grant universities in the US, the research schools program in Sweden and the incubator movement in Brazil. Whether starting from statist or laissez faire regimes, the movement is to a midpoint of relative autonomy of institutional spheres, on the one hand, and stronger interrelations and creation of new hybrid formats embodying elements of two or more institutional spheres, on the other. Nevertheless, practical knowledge continues to arise from the context of discovery in the "meandering stream of basic research" just as theoretical knowledge appears in the context of application.

In countries where the government has previously dominated the other institutional spheres, there is a need for differentiation of institutions and the establishment of clear boundaries among the institutional spheres so that they can begin to interact from a position of independence and relative equality. The emergence of university-industry-government relations---a tri-institutional model of society—is the great transformation of late 20th and early 21st centuries. This transformation includes a shift from: manufacturing to service occupations; the individual firm to strategic alliances; tacit to codified knowledge; technical to organizational innovation.

The triple helix transition followed from the emergence of government-industry relations, -–a bi-institutional model of society— that constituted the great transformation of the 19th century (Polanyi, 1957). The Speenhamland law in England placed limits on exchange relationships in wage labor, guaranteeing workers a living wage. On the one hand, the market became the organizing principle of social relations while, on the other, government moderated exchange relationships to insure a living wage. Government-industry relations thus created a compromise that insured social stability in the wake of an industrial revolution that opened up new social chasms and conflicts. It also encouraged a shift in social relations from status to contract, gemeinschaft to gesellschaft, mechanical to organic solidarity and the invention of the social sciences to elucidate these transitions (Durkheim, 1997).

All societies are in transition in the 21st century, with no fixed endpoint to change in sight. The functional differentiation of institutions in the early modern era is being displaced by integration and hybridization of functions in the post-modern era. Although this process begins from different starting point of relationships among institutional spheres, a secular trend toward a common triple helix can be identified. An open civil society paves the way for triple helix actors to organize and overcome blockages to the transformation of knowledge into innovation. A meta-innovation system is created of bottom up, top down and lateral initiatives in which science, technology and innovation policy are the outcome of the interaction among university, industry and government, rather than a unique state function.

The next great transformation, the third academic revolution, is based upon the creation of entrepreneurial universities embedded in triple helix relations. The academy will become ever more central to the innovation process and it will supersede many functions of the industrial enterprise. The first and second academic revolutions integrated research and then economic and social development as academic missions, changing the nature of the university. The third academic revolution integrates forward and reverse linear models in a programmatic and regulatory framework, synthesizing knowledge, organization and institutions: the endogenous, exogenous and mesogenous drivers of innovation. The university thus becomes an increasingly important platform for societal transformation.

BIBLIOGRAPHY

Amesse, F and P. Cohendet. 2001. Technology transfer revisited from the perspective of the knowledge-based economy. *Research Policy* v. 30 no. 9 1459-1478

Andretsch, D. A. Link and J Scott. 2002. Public/private technology partnerships: evaluating SBIR-supported research *Research Policy* v. 31 no. 1 145-158

Beesley, L. 2003 Science policy in changing times: are governments poised to take full advantage of an institution in transition *Research Policy* v. 32 no. 8 1519-1532

Carayol. N 2003. Objectives, agreements and matching in science-industry collaborations: reassembling the pieces of the puzzle *Research Policy* v. 32 no. 6 887-908

Cheng, P. W. and Holjoak, K. J..(1985). "Pragmatic Reasoning Schemas. *Cognitive Psychology.* 17, 391-416;

Cheng, P. W. and Holjoak, K. J..(1989). "On the Natural Selection of Reasoning Theories". *Cognition.* 33, 285-313;

Di Gregorio, D and S. Shane. 2003. Why do some universities generate more start-ups than others? *Research Policy* v. 32 no. 2. 209-228

Durkheim, E.[ ] 1997 *The Division of Labor in Society. New York: Free Press*

Etzkowitz, H. 2003. "Innovation in Innovation: The Triple Helix of University-Industry-Government Relations". *Social Science Information* 42 (3), 293-338 Oct.

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

Etzkowitz, H. 2002a "Incubation of Incubators: Innovation as a Triple Helix of University-Industry-Government Networks" *Science and Public Policy*, April,

Etzkowitz, H., and J. Mello 2004 "Rise of the Brazilian Triple Helix" *International Journal of Technology Management and Sustainable Development* V. 2. no.3.

Fodor, J. (1983). *Modularity of Mind*. Cambridge, Mass.: MIT Press;

Fransman, M. 2001 Designing Dolly: interactions between economics, technology and science and the evolution of hybrid institutions *Research Policy* v. 30 no. 2 263-274

Gibbons, M. et. al. 1994 *The New Production of Knowledge* Beverly Hills: Sage

Giere, R. N.. (1988). *Explaining Science.* Chicago: Chicago University Press.

Goldfarb, VB and M. Henrekson 2003. Bottom-up versus top down policies towards the commercialization of university intellectual property *Research Policy* v. 32 no. 4/ 639-658

Griliches, Z. 1988 [1957]). "Hybrid Corn: An Exploration of the Economics of Technological Change." In *Technology, Education and Productivity: Early Papers with Notes to Subsequent Literature*. Pp. 27-52. New York, Basil Blackwell

Hellstrom, T. 2003. Governing the virtual academic commons *Research Policy* v. 32 no. 3. 391-402

Hayashi, T. 2003. Effect of R&D programmes on the formation of university-industry-government networks: comparative analysis of Japanese R&D programmes *Research Policy* v. 32 no. 8 1421-1442

Hempel, Carl G.. (1965). *Aspects of Scientific Explanation.* London: The Free Press;

Holland, J., Holyoak, KJ., Nisbett, R.E. and Thagard, P. (1986). *Induction.* Cambridge, Mass.: Brandford Books/MIT Press;

Johnson Laird, P. N..(1983). *Mental Models.* Cambridge : Cambridge University Press

Konde, V 2002 The Entrepreneurial University in Zambia Belfer Center, Harvard University

Fischer, E and C. Lipson. 1988. *Thinking about Science: Max Delbruck and the Origins of Molecular Biology*. New York: Norton

Lofsten, H and P. Lindelof. 2002. Science Parks and the growth of new technology-based firms- academic-industry links, innovations and markets *Research Policy* v. 31 859-876

Kuznets, S. 1965.*Economic Growth and Structure.* New York: W.W. Norton;

Lazonick, W. 1991. *Business Organization and the Myth of the Market*. Economy Cambridge: Cambridge University Press

Leydesdorff, L and M. Meyer 2004. The Triple Helix of University-Industry-Government Relations *Scientometrics* 2004

Lindstrom, Bjorn. 2004. "Nordic Strength, National Advantage and Global Excellence" Stockholm School of Entrepreneurship, 15 April

Long, P. 1991, "Invention, Authorship 'Intellectual Property,' and the Origin of Patents: Notes Toward a Conceptual History," *Technology and Culture*, vol. 32: 4 pp.846-884

Macleod, C. 1988 *Inventing the Industrial Revolution*, Cambridge University Press,

Mangematin, V et.al. 2003. Development of SME's and heterogeneity of trajectories: the case of biotechnology in France *Research Policy* v. 32 no. 4 639-658

March, J.G. and Simon, H.A. (1993). *Organisations.* London: Blackwell.

Mazotti, Massimo. 2004. "Enlightened Mills: Mechanizing Olive Oil Production in Mediterranean Europe" Technology and Culture (45)2 277-304

Mokyr, J. (2002), "Innovation in an Historical Perspective: Tales of Technology and Evolution" in B.Steil, D. G.Victor, and R.R. Nelson, eds. *Technological Innovation and Economic Performance..*, Princeton: Princeton University Press;

Mowery, D. and Rosenberg, N. (1998). *Paths of Innovation: Technological Change in 20th Century America.* New York: Cambridge University Press;

Nagel, E. (1961). *The Structure of Science.* New York: Harcourt, Brace & World, Inc.;

National Science Foundation. (2002). *Converging technologies to Improve Human Performance.* Washington DC

Nevins, Allen. 1962 *The State Universities and Colleges*

Newell, A. (1990). *Unified Theories of Cognition.* Cambridge Mass.: Harvard University Press.

Owen-Smith, J. 2003 From separate systems to a hybrid order: accumulative advantage across public and private science at Research One universities *Research Policy*

Owen-Smith, J and W. Powell 2003 The expanding role of university patenting in the life sciences: assessing the importance of experience and connectivity *Research Policy* v. 32 no. 9 1695-1711

Polanyi, K. (1957). *The Great Transformation.* Boston: Beacon Press;

Pozzali, A. and Viale, R. (forthcoming). "Tacit Knowledge in a Case of Biotechnological Transfer" ;

Ranga, L K. Debackere, N von Tunzelman "Entrepreneurial universities and the dynamics of academic knowledge production: A case of basic vs. applied research in Belgium *Scientometrics* V. 58 No.2 301-320

Rashdall, H. 1896. *The Universities of Europe in the Middle Ages*. Oxford: Oxford University Press

Rogers, E., J. Yin. J. Hoffmann 2000. "Assessing the Effectiveness of Technology Transfer Offices at U.S. Research Universities" The Journal of the Association of University Technology Managers. Volume XII

Schiffer, M. 2003 *Draw the Lightening Down: Benjamin Franklin and Electrical Technology in the Age of Enlightenment*. Berkeley: University of California Press

Shinn, T. (1982). "Scientific disciplines and organizational specificity: the social and cognitive configuration of laboratory activities". *Sociology of Science*, IV, 239-64;

Simon, H. (1983). *Models of Bounded Rationality.* Vol. 2. Cambridge Mass.: MIT Press;

Thursby, J and S. Kemp (2002) Growth and productive efficiency of university intellectual property licensing *Research Policy* v. 31 No. 1 109-124

Van Looy, B., M. Ranga, J. Callaert. K. Debackere and E. Zimmerman. 2004. *Research Policy* V. 33 No. 3. April 443-454

Viale, R. (1991). *Metodo e Società nella Scienza.* Milano: Franco Angeli;

Viale, R. and Campodall'Orto, S. (2001). "An evolutionary Triple Helix to strengthen academy_industry relations: suggestion from European regions". *Science and Public Policy,* vol. 29, 3, 154-168;

Weber, M. [ ] 1997. *Theory of Economic and Social Organization*. New York: Free Press;