Introduction: anti-cyclic triple helix

Riccardo Viale and Henry Etzkowitz

THE TRIPLE HELIX IN ECONOMIC CYCLES

The year 2009 may have represented a turning point for research and innovation policy in Western countries, with apparently contradictory effects. Many traditional sources of financing have dried up, although some new ones have emerged, for example as a result of the US stimulus package. Manufacturing companies are cutting their R&D budgets because of the drop in demand. Universities saw their endowments fall by 25 per cent or more because of the collapse in financial markets. Harvard interrupted the construction of its new science campus, while Newcastle University speeded up its building projects in response to the economic crisis. Risk capital is becoming increasingly prudent because of the increased risk of capital loss (according to the International Monetary Fund, the ratio between bank regulatory capital and risk-weighted assets increased on average between 0.1 and 0.4 for the main OECD countries during 2009) while sovereign funds, like Norway's, took advantage of the downturn to increase their investments. According to the National Venture Capital Association, American venture capital shrank from US$7.1 billion in the first quarter of last year to US$4.3 billion in the first quarter of 2009 (*New York Times*, 13 April 2009). Many of the pension funds, endowments and foundations that invested in venture capital firms have signalled that they are cutting back on the assets class. The slowdown is attributable in part to venture capitalists and their investors taking a wait-and-see approach until the economy improves.

The future outlook for R&D looks poor unless a 'white knight' comes to its rescue. This help may come from an actor whose role was downplayed in recent years, but that now, particularly in the USA, seems to be in the ascendant again. It is the national and regional government that will have to play the role of the white knight to save the R&D system in Western economies (Etzkowitz and Ranga, 2009). In the previous 20 years the proportion of public financing had gradually fallen in percentage terms, while the private sector had become largely dominant (the percentage of Gross Domestic Expenditure in R&D financed by industry now exceeds 64 per cent in OECD countries). In some technological sectors, such as biotechnology, the interaction between academy and industry has become increasingly autonomous from public intervention. University and corporate labs established their own agreements, created their own joint projects and laboratories, exchanged human resources and promoted the birth of spin-off and spin-in companies without relevant help from local and national bodies. Cambridge University biotech initiatives or University of California at San Diego relations with biotech companies are just some of many examples of double-helix models of innovation. In other countries and in other technological sectors the double-helix model didn't work and needed the support of the public helix. Some European countries, like France, Germany and Italy, saw a positive intervention of public institutions. In France, Sophia Antipolis was set up with national and regional public support. In Italy, support from Piedmont regional government to the Politecnico of Turin allowed the development of an incubator of spin-off companies that incubated more than 100 companies.

In sectors such as green technologies, aerospace, security and energy, public intervention to support the academy–industry relationship is unavoidable. Silicon Valley venture capitalists invested heavily in renewable energy technology in the upturn, and then looked to government to provide funding to their firms and rescue their investments once the downturn took hold. In emerging and Third World economies, the role of the public helix in supporting innovation is also unavoidable. In the least developed countries industry is weak, universities are primarily teaching institutions and government is heavily dependent upon international donors to carry out projects. In newly developed countries the universities are developing research and entrepreneurship activities and industry is taking steps to promote research, often in collaboration with the universities, while government plays a creative role in developing a venture capital industry and in offering incentives to industry to support research through tax breaks and grants.

The novelty of the current crisis is that the public helix becomes crucial even in countries and in sectors where the visible public role was minimal in the past. The Advanced Technology Program, the US answer to the European Framework Programmes, shrunk to virtual inactivity with zero appropriations under the Bush Administration but has found a second life under the Obama Administration and has been renamed the TIP (the Technology Investment Program).

The triple-helix model seems to play an anti-cyclic role in innovation.

It is a default model that guarantees optimal or quasi-optimal levels of academy–industry interaction through public intervention. It expresses its potential when the interaction is not autonomous, as is now the case in times of crisis, and the collaboration between universities and companies calls for financial support and organizational management. It works as a 'nudge tool' (Thaler and Sunstein, 2008), whose aim is to maintain a sufficient flow of innovation through the right incentives and institutional mechanisms for academy–industry collaboration.

In this book we will examine various models for the capitalization of knowledge and attempt to discern the features of the new relationship that is emerging between the state, universities and industry. Are they converging in a certain way across different sociopolitical cultures and political institutions?

Which of the key groups (scientists, politicians, civil servants, agency officials, industrialists, lobby groups, social movements and organized publics) are emerging as relevant players in the science and technology (S&T) policy arenas? What and how divergent are the strategies that they are pursuing and at what levels in the policy-making process do they take part?

What are the 'appropriate' policies that respond to these changes? Do they call for a radical paradigm-like shift from previously established research policy?

What degrees of freedom and autonomy can universities gain within the new triangular dynamics? Are the new patterns of interaction among those sectors designing a new mode of knowledge production? How are such changes altering the structure and operations of the knowledge-producing organizations inside these sectors?

POLYVALENT KNOWLEDGE: THREATS AND BENEFITS TO ACADEMIC LIFE

The triple helix is a model for capitalizing knowledge in order to pursue innovation (Etzkowitz, 2008). Academic communities are fearful that capitalization will diminish the university goal of knowledge production *per se*. This fear seems to be linked to a traditional image of the division of labour in universities. Curiosity-driven research is separated from technology-driven research. Therefore, if a university focuses on the latter, it handicaps and weakens the former. On the contrary, in our opinion, in many technological fields knowledge production simultaneously encompasses various aspects of research. The theory of polyvalent knowledge (Etzkowitz and Viale, 2009) implies that, contrary to the division of knowledge into divergent spheres – applied, fundamental, technological – or into mode 1 (disciplinary knowledge) and mode 2 (applied knowledge) (Stokes, 1997; Gibbons et al., 1994), a unified approach to knowledge is gradually becoming established. In frontier areas such as nanotechnologies and life sciences, in particular, practical knowledge is often generated in the context of theorizing and fundamental research. And, on the other hand, new scientific questions, ideas and insights often come from the industrial development of a patent and the interaction of basic researchers and industrial labs. The polyvalence of knowledge encourages the multiple roles of academics and their involvement in technology firms, and vice versa for industrial researchers in academic labs.

One way of testing the reliability of this theory is to verify whether or not there is any complementarity between scientific and technological activities, measured by the number of publications and patents respectively. In the case of polyvalent knowledge, the same type of knowledge is able to generate both scientific output and technological output. Since the scientific knowledge contained in a publication generates technological applications represented by patents, and technological exploitation generates scientific questions and answers, we should expect to see some complementarity between publishing and patenting. Researchers who take out patents should show greater scientific output and a great capacity to affect the scientific community, measured by the impact factor or citation index.

In other words, increasing integration between basic science and technology implies that there is no rivalry between scientific and technological output. The rivalry hypothesis holds that there is a crowding-out effect between publication activities and patenting. The substitution phenomenon between publications and patents stems from the inclusion of market-related incentives into the reward structure of scientists (Dasgupta and David, 1985; Stephan and Levin, 1996). Scientists increasingly choose to allocate their time to consulting activities and research agreements with industrial partners. They spend time locating licensees for their patents or working with the licensee to transfer the technology. Time spent doing research may be compromised. These market goals substitute peer-review judgement and favour short-term research trajectories and lower-quality research (David, 1998). Moreover, the lure of economic rewards encourages scientists to seek IP (intellectual property) protection for their research results. They may postpone or neglect publication and therefore public disclosure. Industry funding, commercial goals and contract requirements may lead researchers to increase secrecy with regard to research methodology and results (Blumenthal et al., 1986; Campbell et al., 2002). Both these mechanisms may reduce the quantity and the quality of scientific production. This behaviour supports the thesis of a trade-off between scientific research and industrial applications.

On the contrary, a non-rivalry hypothesis between publishing and patenting is based on complementarity between the two activities. The decision of whether or not to patent is made at the end of research and not before the selection of scientific problems (Agrawal and Henderson, 2002). Moreover, relations with the licensee and the difficulties arising from the development of patent innovation can generate new ideas and suggestions that point to new research questions (Mansfield, 1995). In a study, 65 per cent of researchers reported that interaction with industry had positive effects on their research. A scientist said: 'There is no doubt that working with industry scientists has made me a better researcher. They help me to refine my experiments and sometimes have a different perspective on a problem that sparks my own ideas' (Siegel et al., 1999).

On the other hand, the opposition between basic and technological research seems to have been overcome in many fields. In particular, in the area of key technologies such as nanotechnology, biotechnology, ICT (information and communication technologies), new materials and cognitive technologies, there is continuous interaction between curiosity-driven activities and control of the technological consequences of the research results. This is also borne out by the epistemological debate. The Baconian ideal of a science that has its *raison d'être* in practical application is becoming popular once again after years of oblivion. And the technological application of a scientific hypothesis, for example regarding a causal link between two classes of phenomena, represents an empirical verification. An attempt at technological application can reveal anomalies and incongruities that make it possible to define initial conditions and supplementary hypotheses more clearly.

In short, the technological 'check' of a hypothesis acts as a 'positive heuristic' (Lakatos, 1970) to develop a 'positive research programme' and extend the empirical field of the hypothesis. These epistemological reasons are sustained by other social and economic reasons. In many universities, scientists wish to increase the visibility and weight of their scientific work by patenting. Collaboration with business and licensing revenues can bring additional funds for new researchers and new equipment, as well as meeting general research expenses. This in turn makes it possible to carry out new experiments and to produce new publications. In fact Jensen and Thursby (2003) suggest that a changing reward structure may not alter the research agenda of faculty specializing in basic research. Indeed, the theory of polyvalent knowledge suggests that dual goals may enhance the basic research agenda.

COMPLEMENTARITY BETWEEN PUBLISHING AND PATENTING

The presence of a complementary effect or the substitution of publishing and patenting has been studied empirically in recent years. Agrawal and Henderson (2002) have explored whether at the Departments of Mechanical and Electrical Engineering of MIT patenting acts as a substitute or a complement to the process of fundamental research. Their results suggest that while patent counts are not a good predictor of publication counts, they are a reasonable predictor of the 'importance' of a professor's publications as measured by citations. Professors who patent more write papers that are more highly cited, and thus patenting volume may be correlated with research impact. These results offer some evidence that, at least at the two departments of MIT, patenting is not substituting for more fundamental research, and it might even be an accelerating activity.

Stephan et al. (2007) used the Survey of Doctorate Recipients to examine the question of who is patenting in US universities. They found patents to be positively and significantly correlated to the number of publications. When they broke the analysis down into specific fields, they found that the patent–publishing results persisted in the life sciences and in the physical/engineering sciences. The complementarity between publishing and patenting in life sciences has been studied by Azoulay et al. (2005). They examined the individual, contextual and institutional determinants of academic patenting in a panel data set of 3884 academic life scientists. Patenting is often accompanied by a flurry of publication activity in the year preceding the patent application. A flurry of scientific output occurs when a scientist unearths a productive domain of research. If patenting is a by-product of a surge of productivity, it is reasonable to conclude that a patent is often an opportunistic response to the discovery of a promising area.

In the past, senior scientists and scientists with the most stellar academic credentials were usually also the most likely to be involved in commercial endeavours. But a feature of the Second Academic Revolution and the birth and diffusion of entrepreneurial universities is that the academic system is evolving in a way that accommodates deviations from traditional scientific norms of openness and communalism (Etzkowitz, 2000). In fact, Azoulay et al.'s (2005) data indicate that many patenting events now take place in the early years of scientists' careers and the slope of the patent experience curve has become steeper with more recent cohorts of scientists. Patents are becoming legitimate forms of research output in promotion decisions. Azoulay et al. (2005) show that patents and papers encode similar pieces of knowledge and correspond to two types of output

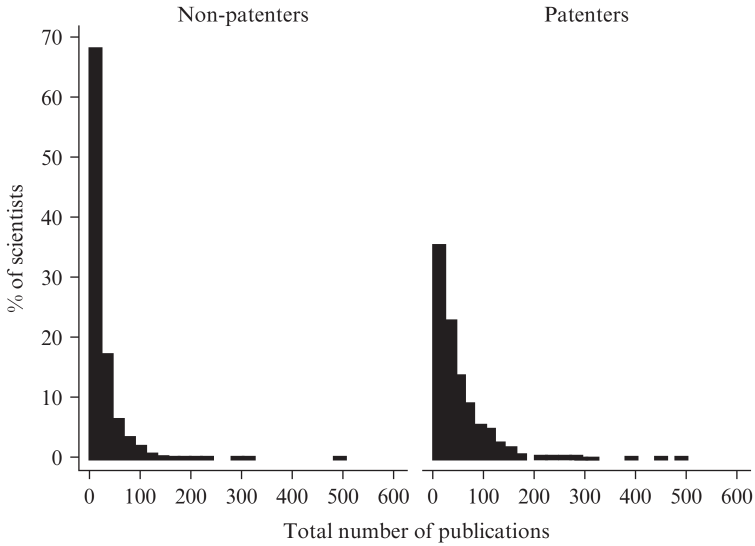

Figure I.1 Distribution of publication count for patenting and non-patenting scientists

that have more in common than previously believed. Figure I.1 shows the complementary of patenting and publishing in Azoulay et al. (2005). It plots the histogram for the distribution of publication counts for our 3884 scientists over the complete sample period, separately for patenting and non-patenting scientists.

The study that makes the most extensive analysis of the complementarity between patenting and publishing is by Fabrizio and DiMinin (2008). It uses a broad sample drawn from the population of university inventors across all fields and universities in the USA, with a data set covering 21 years. Table I.1 provides the annual and total summary statistics for the entire sample and by inventor status. A difference of mean test for the number of publications per year for inventors and non-inventors suggests that those researchers holding a patent applied for between 1975 and 1995 generate significantly more publications per year than non-inventors. The inventors in their sample are more prolific in terms of annual publications, on the order of 20–50 per cent more publications than their non-inventor colleagues. The results suggest also that there is not a significant positive relationship between patenting and citations and a faculty member's publications.

Nor was evidence of a negative trade-off between publishing and patenting found in Europe. Van Looy et al. (2004) compared the publishing

Table I.1 Patenting and publishing summary statistics for inventors and non-inventors

	Inventors		Non-inventors		All	
	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Annual pubs	3.99	5.18	2.24	2.96	3.12	4.32
Annual pats	0.56	1.55	0	0	0.28	1.14
Total pubs	79.93	84.78	43.71	47.72	62.00	71.30
Total pats	11.02	16.21	0	0	5.57	12.77

output of a sample of researchers in the contract research unit at the Catholic University of Leuven in Belgium with a control sample from the same university. The researchers involved in contract research published more than their colleagues in the control sample. 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 consolidates the groups R&D potential' (Ranga et al., 2003, pp. 301–20). This highly integrated format of knowledge production evolved from two divergent sources: industrial knowledge gained from production experience and scientific knowledge derived from theory and experimentation.

In Italy an empirical analysis of the consequences of academic patenting on scientific publishing has been made by Calderini and Franzoni (2004), in a panel of 1323 researchers working in the fields of engineering chemistry and nanotechnologies for new materials over 30 years. As shown in Table I.2, the impact of patents is positive in the quantity of publications. Development activities are likely to generate additional results that are suitable for subsequent publications, although there might be one or two years of lag. Moreover, quality of research measured by the impact factor is likely to increase with the number of patents filed in the period following the publication. Scientific performance increases in the proximity of a patent event. This phenomenon can be explained in two ways. Top-quality scientific output generates knowledge that can be exploited technologically. And technological exploitation is likely to generate questions and problems that produce further insights and, consequently, additional publications. The same kind of results are found by Breschi et al. (2007), in a study done on a sample of 592 Italian academic inventors (see Table I.3).

Table I.2 Results of T*-test and of test of proportions (two samples)*

T-test	Mean patent-holders	Mean non-patent-holders	Variance, patent-holders	Variance, non-patent-holders	Stat T Ho: 0 fidd in mean	*P*-value (two tails)
Observations	133	1190	133	1190		
Total publications	32.41	19.30	1026.59	897.86	4.50	0.00*
Impact factor	1.70	1.48	1.88	2.82	0.01	0.00*
Total cites received at 2003	8.21	5.17	39.97	33.30	5.30	0.00*
Test of proportions	**Mean patent-holders**	**Mean non-patent-holders**			**Stat Z Ho: 0 fidd in mean**	***P*-value (two tails)**
Observations	133	1190				
Academic personnel	0.98	0.96			0.89	0.37
Technician	0.02	0.38			1.35	0.187
Area	0.68	0.70			0.42	0.68

Note: * $\rho < 0.05$.

TRIPLE HELIX: LABORATORY OF INNOVATION

The incorporation of economic development into university missions and the further integration of the knowledge infrastructure into innovation systems take different forms in various countries and regions. Most regions, however, lack innovation systems; rather they are innovation environments in which some elements to encourage innovation are present and others missing. In such situations it is important for some group or organization to play the role of regional innovation organizer (RIO) and bring the various elements of the triple helix together to foster new projects. Momentum starts to grow around concepts such as Silicon Alley in New York and Oresund in Copenhagen/southern Sweden, uniting politicians, business persons and academics. Imagery is also important since there often are not strong market reasons to allocate resources to the development of a region.

Table I.3 Publications per year, inventors versus controls, 1975–2003; by field

	N	Mean	Std	Median
Inventors				
Chem. eng. & materials tech.**	63	2.0	1.75	1.5
Pharmacology*	83	2.2	1.21	2.0
Biology*	78	2.5	2.10	2.0
Electronic & telecom*	72	1.7	1.04	1.4
All fields	296	2.1	1.60	1.8
Controls				
Chem. eng. & materials tech.	63	1.3	1.10	1.1
Pharmacology	83	1.7	1.11	1.6
Biology	78	1.8	1.27	1.5
Electronics & Telecom	72	1.3	1.18	1.0
All fields	296	1.6	1.28	1.3

Note: * - ** *Inventor–control distribution difference significant at 0.90 - 0.95 (Kolmogorov–Smirnov test)*

Source: *Elaborations on EP–INV database and ISI Science Citation Index.*

Rather than importing innovation mechanisms that appear to have worked well elsewhere, it is important as an initial step to analyse a local situation in order to determine:

(1) the available resources that can be used to start the incubation process for knowledge-based development;
(2) what is missing and how and where those missing resources can be found, either locally or internationally.

To arrive at such a determination and follow-on collaboration means that there must be discussions among the potential actors rather than government saying by itself: this is what should be done.

A consensus space, a forum that brings together the different triple-helix actors in a region, is often the source of new ideas and plans for knowledge-based development. From the analysis of the resources in a region, an awareness can be generated of the potential of its knowledge space, the research units, formal and informal, in the science and arts that, in turn, can become the basis for the creation of an innovation space, a mechanism to translate ideas into reality. The invention of the venture capital firm in 1940s New England is one example. These 'triple-helix spaces' may be created in any order, with any one of them used as the basis for the development of others (Etzkowitz and Ranga, 2010).

Creating new technology-based economic niches has become a third strategy for regional and local development. As the number of niches for science-based technology increases, the opportunity for more players to get involved also increases. Universities not traditionally involved in research are becoming more research-oriented, often with funding from their state and local governments, which increasingly realize that research is important to local economic growth. A firm may start from a business concept looking for a technology to implant within it or a technology seeking a business concept to realize its commercial potential. The entrepreneur propelling the technology may be an amateur or an experienced professional. Whichever the case, the technology comes with a champion who is attempting to realize its commercial potential by forming a firm.

Universities, as well as firms, are developing strategic alliances and joint ventures. Karolinska University has recruited schools in the health and helping professions across Sweden into collaborations in order to increase its 'critical mass' in research. Groups of universities in Oresund, Uppsala and Stockholm have formed 'virtual universities', which are then translated into architectural plans for centres and science parks to link the schools physically.

As entrepreneurial academic activities intensify, they may ignite a self-generating process of firm-formation, no longer directly tied to a particular university. The growth of industrial conurbations around universities, supported by government research funding, has become the hallmark of a regional innovation system, exemplified by Silicon Valley; the profile of knowledge-based economic development was further raised by the founding of Genentech and other biotechnology companies based on academic research in the 1980s. Once take-off occurs in the USA, only the private sector is usually credited; the role of government, for example, the Defense Research Projects Agency (DARPA), in founding SUN, Silicon Graphics and Cisco is forgotten.

The triple helix denotes not only the relationship of university, industry and government, but also the internal transformation within each of these spheres. The transformation of the university from a teaching institution into one that combines teaching with research is still ongoing, not only in the USA, but in many other countries. There is a tension between the two activities, but nevertheless they coexist in a more or less compatible relationship. Although some academic systems still operate on the principle of separating teaching and research, it has generally been found to be both more productive and more cost-effective to combine the two functions, for example by linking research to the PhD training process. Will the same relationship hold for three functions, with the emerging third mission of economic and social development combined with teaching and research?

A recent experiment at Newcastle University points the way towards integration of the three academic functions. A project for the redevelopment of the region's economy as a Science City was largely predicated on building new laboratories for academic units and for firms in the expectation that the opportunity to 'rub shoulders' with academics in related fields would be a sufficient attractor. However, a previous smaller-scale project, the Centre for Life, based on the same premise, did not attract a significant number of firms and the allotted space was turned over to academic units. To jump-start Science City, the professor of practice model, based on bringing distinguished practitioners into the university as teachers, has been 'turned on its head' to attract researchers of a special kind: PhD scientific entrepreneurs who have started successful firms but may have been pushed aside as the firm grew and hired professional managers.

Newcastle University, in collaboration with the Regional Development Agency in Northeast UK, established four professors of practice (PoPs), one in each of the Science City themed areas – a scheme for knowledge-based economic development from advanced research. The PoPs link enterprise to university and are intentionally half-time in each venue so that they retain their industrial involvement at a high level and do not become traditional academics. The PoPs have initiated various projects, ranging from an interdisciplinary centre drawing together the university's drug discovery expertise, which aims to undertake larger projects and attract higher levels of funding, to a new PhD programme integrating business, engineering and medical disciplines to train future academic and industrial leaders in the medical devices field.

The next step in developing the PoP model is to extend it down the academic ladder by creating researchers of practice (RoPs), postdoctoral fellows and lecturers, who will work half-time in an academic unit and half-time in the business development side of the university, e.g. technology transfer office, incubator facility or science park. The RoPs would be expected to involve their students in analysing feasibility of technology transfer projects and in developing business plans with firms in the university's incubator facility. Each PoP could mentor three or four RoPs, extending the reach of the senior PoPs as they train their junior colleagues. Moreover, the PoP model is relevant to all academic fields with practitioner constituencies, including the arts, humanities and social sciences. Until this happens, entrepreneurial activities will typically be viewed as an adjunct to, rather than an equal partner with, the now traditional missions of teaching and research.

In the medium term, the PoP model may be expected to become a forward linear model, as professors spinning out firms reduce to a half-time academic workload, superseding the typical current UK practice of forced choice. As some professors reduce to half-time, additional RoPs may be hired to share their positions. When 25 per cent or one in four academics are PoPs or RoPs, the entrepreneurial academic model will be institutionalized. The RoPs are intended to link academic units with the new business development units of the university. Incubators and tech transfer offices are typically established as administrative arms rather than as extensions of academic units, their natural location once the 'third mission' for economic and social development is fully accepted. In the interim, there is a need to bridge internal 'silos' as well as external spheres.

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. As the university takes up a new role in promoting innovation, its educational and research missions are also transformed. As the university expands its role in the economy, from a provider of human resources to a generator of economic activity, its relationship to industry and government is enhanced. Paradoxically, as the university becomes more influential in society, it is also more subject to influence, with academic autonomy increased in some instances and reduced in others. When bottom-up initiatives that have proved successful, such as the incubator movement in Brazil, are reinforced by top-down policies and programmes, perhaps the most dynamic and fruitful result is achieved. It also means that universities and other knowledge-producing institutions can play a new role in society, not only in training students and conducting research but also in making efforts to see that knowledge is put to use.

There is also a convergence between top-down and bottom-up initiatives, which ideally reinforce one another. The flow of influence can go in both directions. If top-down, the local or regional level may adapt the policy or programme to local or regional needs. Bottom-up may also be the source of public pressure for action and the creation of models that can later be generalized top-down or through isomorphic mimesis. The US agricultural innovation system is a classic example of the 'hybridization' of top-down and bottom-up approaches, with government at various levels acting as a 'public entrepreneur' (Etzkowitz et al. 2001).

The result is an interactive model, with intermediate mechanisms that integrate the two traditional starting points of science and technology policy. 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 our efforts, working from different starting points to achieve the common goal of knowledge-based economic and social development. Innovation thus becomes an endless transition, a self-organizing process of initiatives among the institutional spheres.

CAPITALIZING KNOWLEDGE AND THE TRIPLE HELIX

This book is structured into two parts. Part I deals with the ways, proprietary and not, to obtain an economic return from scientific and technological research. One of its focuses is how the epistemological and cognitive features of knowledge, its generation and utilization, can constrain and shape the way in which it is capitalized.

Economic and social factors are necessary to explain the capitalization of knowledge. However, they are not sufficient. Their flaw is to neglect the constraints on the capitalization process deriving from the epistemological structure and cognitive dimension of knowledge. According to Chapter 1 by Riccardo Viale, these are crucial factors in the organizational and institutional changes taking place in the capitalization of knowledge. For example let's consider the different ontologies and languages present in physics compared to material science or biology. The different use of quantitative measures versus qualitative and pictorial representations, the different types of laws and the role of experiments constrain the organizational ways knowledge can be capitalized. Any attempt to devise the right format for capitalization should consider these aspects. 'Nudging' (Thaler and Sunstein, 2008) the capitalization of knowledge means impressing institutions and organizations on the minds of the actors involved in the process of knowledge generation and application. Higher cognitive complexity, as in the case of converging technologies, cannot be coped with by isolated individual minds but calls for increasing division of computational labour. Greater epistemological generality, as in the case of the application of inclusive theories of physics and chemistry, allows better knowledge transfer but requires the involvement of many disciplines to widen the innovation field. Different background knowledge between university and companies hinders the reciprocal understanding that can be improved by better face-to-face interaction. Different cognitive styles in problem-solving, reasoning and decision-making hamper collaboration in research projects, but that can be remedied by the emergence of hybrid roles and organizations. Two 'nudge' suggestions made in the chapter are greater proximity between universities and companies and the emergence of a two-faced Janus scientist, a hybrid figure that combines the cognitive styles and values of both academic and industrial scientist.

While Viale's chapter sees the collaboration between businesses and universities as being difficult owing to differences in values and cognitive styles, the thesis proposed by Paul David and Stanley Metcalfe in Chapter 2 proposes an alternative, but not incompatible, account. After the Bayh–Dole law, US universities are under increasing pressure to capitalize their knowledge and strengthen IPR (intellectual property rights). Collaboration with companies is not intermediated by faculty researchers but by employees of university 'service units' (e.g. technology transfer office, university research services, sponsored research office, external relations office). The main task of these offices is to sell licences and patents derived from the knowledge produced in university labs. Their main expertise is property right protection and avoidance of legal liability. When they have the chance to collaborate with companies on a joint research project, their risk adversity towards legal liability and concerns over IPR often hinders the agreement. Firms are always complaining about the proprietary approach taken by universities. Interaction has become difficult. As Stuart Feldman, IBM's vice-president for computer science, explained to the *New York Times*: 'Universities have made life increasingly difficult to do research with them because of all the contractual issues around intellectual property . . . We would like the universities to open up again'. Thus, in order to be more useful for companies, universities should become less entrepreneurial in managing IPR, according to IBM.

The paradox is obvious and the thesis is counterintuitive. Most innovation policies in the USA and Europe were informed by the opposite equation: more knowledge transfer equals a more entrepreneurial university. Without reorienting the incentive structure of universities towards commercial aims, it seemed difficult to increase the knowledge transfer towards businesses. In short, if it is true that joint collaboration implies more similarity in background knowledge and cognitive styles between academic and industrial researchers, and if it is true that universities should abandon their overly aggressive IPR policy and that there is a growing need for open innovation and science commons in universities, the conclusion is that companies will bear the burden of cultural change. Their researchers should acquire more academic values and styles in order to pursue fruitful joint collaborations with universities. New ways of connecting universities with companies, like academic public spaces and new academic and industrial research roles, like the Janus scientists or professors of practice, must be introduced to support a rewarding collaboration.

Older technology companies are especially fearful of universities creating competitors to themselves. They are concerned that by licensing IP to start-ups, including those founded by faculty and students, new firms may be created that will displace their prominence on the commercial landscape. Thus, we have the irony of formerly closed firms espousing 'open innovation' and imploring universities to donate their IP rights. Not surprisingly, most universities take the innovation side of the IP debate and increasingly assist new firm formation. Universities are making a long-term bet that equity and employment created in a growth firm will redound to the benefit of the region where they are located and to the university's endowment. As universities invest in the formation of firms from the IP they generate, they become closely tied to the venture capital phenomenon that, in an earlier era, they helped create.

A clear example of 'knowledge-driven capitalization of knowledge' is the emergence of venture capitalism. Until the beginning of the twentieth century, technological knowledge was mainly idiosyncratic and tacit. These epistemological features limited the possibility of its tradability but also limited the need for the legal protection of intellectual property. With the widening of the scientific base of innovation, knowledge became more general and explicit. As tacitness decreased, so the tradability of knowledge and the need for IPR grew. Recognition of this epistemological change is essential to understanding the institutional phenomena that brought about the emergence of venture capitalism, the current major institution in the capitalization of knowledge. Cristiano Antonelli and Morris Teubal in Chapter 3 outline the evolutionary dynamics of the financial markets for innovation.

Whoever finances innovation must assess two combined sets of risk: that the innovative project could fail and that the result cannot be appropriated by the inventor. The second risk is better faced by equity finance, e.g. corporate bodies, because the investors have the right to claim a share of the profits of successful companies whereas the lenders, e.g. banks, can claim only their credits. The first risk is better faced by banks because their polyarchic decision-making (i.e. great variety of expertise and number of experts less tied to vested interests) results in a higher chance of including outstanding projects, whereas the hierarchical (i.e. less variety of expertise and experts more closely tied to vested interests) decision-making of corporate bodies tends to favour only minor incremental innovation. Venture capitalism seems to be able to combine the advantages of both, that is the screening procedure performed by competent polyarchies, a distinctive feature of banks, and the equity-based provision of finance to new undertakings, a distinctive feature of corporations.

Since the early days venture capital firms have specialized in the provision of 'equity finance' to new science-based start-up companies, together with business services and management advice. Limited partnerships, which were the leading form of organization for start-ups during the 1960s and 1970s, converged progressively into private stock companies based upon knowledge-intensive property rights shares in the new science-based start-up companies. Private investors and financial companies elaborated exit strategies for collecting the value of these new firms after their creation and successful growth. Exit took place mainly through the sale of knowledge-intensive property rights. Initially these were private transactions over the counter. Later a public market emerged, characterized by automatic quoting mechanisms to report the prices and quantities of private transactions. This mechanism, better known as NASDAQ, evolved into a marketplace for selling knowledge-intensive property rights to the public at large. The demand for new knowledge-intensive property rights by investment funds, pension funds and retail investors accelerated the diffusion of NASDAQ with a snowball effect. The growing size of the market enabled it to become an efficient mechanism for identifying the correct value of knowledge-intensive property rights, a key function for the appreciation of the large share of intangible assets in the value of the new science-based companies.

Intellectual property rights (IPR) have become the currency of technology deals, the 'bargaining chips' in the exchange of technology among different firms. What kind of justification is there for this strong emphasis on IPR? Are IPR the best way to strengthen the capitalization of knowledge? Is the current explosion of patents the right explanation for the innovation rate? Are there other factors, detached from proprietary incentives, capable of driving innovation pathways? For example, in the case of converging technologies, the high interdisciplinarity of their epistemological problem-solving dynamics tends to overcome any attempt to create proprietary monopolies of knowledge. The rate of change of knowledge is very fast; the knowledge useful for innovation is tacit in the minds of scientists; innovative problem-solving stems from the conceptual recombination and theoretical integration of different sources of knowledge; only open discussion, without IPR constraints, among academic and industrial researchers can generate the proper 'gestalt shift' that will afford the proper solution. Moreover, each particular body of knowledge drives the dynamics of knowledge change and capitalization of knowledge.

The many components (ontic, deontic, epistemological and cognitive) of knowledge shape the directions of technological development towards given innovative products. They address the technological trajectories of technological paradigms described by Giovanni Dosi, Luigi Marengo and Corrado Pasquali in Chapter 4. The authors discuss the classic dilemma of the relation between IPR and innovation: on the one hand, the intellectual property monopolies afforded by patents or copyright raise product prices, while on the other, IPR provide a significant economic incentive for producing new knowledge. The answer to this question is not straightforward.

It is important to emphasize that, as far as product innovations are concerned, the most effective mechanisms are secrecy and lead time, while patents are the least effective, with the partial exception of drugs and medical equipment (Levin et al., 1987; Cohen et al., 2000). Moreover, the effects of IPR seem to be deleterious for innovation in the case of strongly cumulative technologies in which each innovation builds on previous ones. To the extent that a given technology is critical for further research, the attribution of broad property rights might hamper further developments. For example, in the case of the Leder and Stewart patent on the genetically engineered mouse that develops cancer, if the patent (the 'onco-mouse') protects all the class of products that could be produced ('all transgenic non-human mammals') or all the possible uses of a patented invention (a gene sequence), it represents a serious obstacle to research and innovation. On the other hand, Stanford University's Office of Technology Licensing demonstrated that, by proactively licensing the Cohen–Boyer patent for recombinant DNA at reasonable rates, it helped create a new industry. How to navigate between the Scylla of creating fears due to appearance of 'free riders' in the absence of Clear IPR and the Charybdis of over protection stifling innovation is a persisting question.

Symmetrically a 'tragedy of anti-commons' is likely to arise also when IP regimes give too many subjects the right to exclude others from using fragmented and overlapping pieces of knowledge with no one having the effective privilege of use. In the software industry, extensive portfolios of legal rights are considered means for entry deterrence and for infringement and counter-infringement suits against rivals. When knowledge is so finely subdivided into separate property claims on complementary chunks of knowledge, a large number of costly negotiations might be needed in order to secure critical licences. Finally, the history of innovation highlights many cases in which industry developed strongly with weak IPR regimes. For example, the core technologies of ICT – including transistors, semiconductors, software and telecommunication technologies like the mobile phone – were developed under weak IPR regimes.

The organizational effect of the epistemological structure of knowledge is evident in some science-based innovations, such as biotechnology, in particular biopharmaceuticals. The high level of interdisciplinarity between biotechnology and biochemistry, informatics, mathematics, nanotechnology, biophysics, immunology and so on makes the knowledge very unstable. The potential problem-solving resulting from the intersection, hybridization and conceptual recombination of different and connected models and theories is very high. Thus there are many inventive solutions that continuously transform the field. As pointed out by Philip Cooke in Chapter 5, skills are in short supply and requirements change rapidly. The potential inventions are in the scientists' minds. Therefore the level of useful and crucial tacit knowledge is very high. Knowledge in the scientist's mind is often taken as a tacit quasi proof-of-concept of an invention waiting to be disclosed. This is why we need proximity and direct interaction between academics and business. Interaction and face-to-face discussion can improve focusing on the right technological solution, making knowledge transfer easier. Thus, at the early stage of knowledge exploration, the cluster of dedicated biotechnological firms (DBFs) and research institutes is geographically localized. Only when the cluster enters the stage of knowledge exploitation does it tend to globalize.

Knowledge-driven capitalization of knowledge is evident also in another way. Why did Germany experience so many difficulties and false starts in biotechnology? Because the predominant knowledge and methodology was that of organic chemistry and pharmaceutics in which Germany was the world leader. Germany tried to implant the embryo of a biotechnological industry in an epistemological environment characterized by the knowledge structure of industrial chemistry, the methodological techniques of pharmaceutics and the reasoning and decision-making processes of organic chemists. On the contrary, the UK epistemological environment was much more fertile because it was the birthplace of molecular biology, of which biotechnology is an applied consequence. Nevertheless, there was a significant gap between the discovery of the double helix and the rise of a UK biotech industry. In the interim, the US took world leadership through a plethora of 'companies of their own' founded by entrepreneurial scientists at universities that had made an early bet on molecular biology. Consequently, different epistemological path dependencies lead to different ways of capitalizing knowledge. Lastly, the birth of biopharma clusters is a clear example of a triple-helix model of innovation. The holy trinity of research institutes, DBFs and big pharmaceutical companies within the cluster is often triggered by local governments or national agencies. For example, the driver of cluster-building in Washington and Maryland's Capitol region was, mainly, the National Institutes of Health. From this point of view, biopharma clusters neither conform to the Schumpeterian model nor to Porterian clusters. They tend to be more milieu than market. They need public financial support in order to implement research programmes.

The phenomenon of knowledge-driven capitalization of knowledge is evident in the different architectures of capitalization depending on the different conceptual domains and disciplines. In a few cases the proprietary approach may be useful at the first stages of research, while in many other cases it is better only for downstream research. Sometimes for the same kind of knowledge a change happens in the way it is capitalized.

The change is linked to cultural and economic factors. In some instances the proprietary domain is perceived to be socially bad (because of hyperfocusing and exaggerated risk-perception of the consequences of the 'tragedy of anti-commons') and there are emergent successful cases of open innovation having good economic returns. Therefore scientific communities tend to shift from a proprietary approach to an open one and back again as their interest shifts from working with existing firms to starting new ones. Indeed, the same individual may pursue both courses of action simultaneously with different research lines or even with pieces of the same one.

Software research is a case of a knowledge capitalization that has shifted in recent years from the first to the second category in upstream research, maintaining the proprietary domain only for the downstream stages. This is because if the proprietary domain is applied to the upstream basic software knowledge, there is a risk of lack of development and improvement that is achieved mainly through an open source approach. If the public domain is applied to the downstream commercial developments, there is a risk of lack of economic private resources because companies don't see any real economic incentive to invest. Alfonso Gambardella and Bronwyn H. Hall in Chapter 6 analyse and explain in economic terms the evolution of the proprietary versus public domain in the capitalization of knowledge. The proprietary regime assigns clear property rights and provides powerful incentives at the cost of creating temporary monopolies that will tend to restrict output and raise prices. The public regime does not provide powerful incentives but the dissemination of knowledge is easy and is achieved at low cost.

There is an alternative third system, that of 'collective invention'. This system allows 'the free exchange and spillover of knowledge via personnel contact and movement, as well as reverse engineering, without resort to intellectual property protection'. Collective invention in the steel and iron industry, in the semiconductor industry, and in the silk industry are some of the historical examples of this third alternative. The production of knowledge is supported by commercial firms that finance it through the sale of end products. The sharing of information is motivated since rewards come from product sales rather than information about incremental innovations. This system works when an industry is advancing and growing rapidly and the innovation areas are geographically localized, but it doesn't work when an industry is mature or the innovation areas are not geographically localized. In these cases, how can an open science approach to upstream research be supported? Without coordination, scientists don't perceive the advantages of a public rather than a proprietary approach, namely the utility of a larger stock of public knowledge and the visibility of their research and achievements. Therefore, without coordination they tend to behave egoistically and collective action is hard to sustain (as in Mancur Olson's famous theory of collective action).

A policy device, particularly useful in software research, and that could sustain the right amount of coordination, is the Generalized Public License (GPL), also dubbed the copyleft system: 'the producer of an open source program requires that all modifications and improvements of the program are subject to the same rules of openness, most notably the source code of all the modifications ought to be made publicly available like the original program'(Gambardella and Hall, this volume) In order to make the GPL function there is need of legal enforcement because the norms and social values of the scientific community, and the reputation effect of their infringement, seem to be insufficient.

Part II deals with the growing importance of the triple-helix model in the knowledge economy. The generation of knowledge, in particular knowledge that can be capitalized, seems to be linked to emerging knowledge networks characterized by academy–industry–government interaction.

As an institution, the university has changed its mission many times in the last hundred years. From the ivory tower of the German university model in the nineteenth century, focused mainly on basic research and education, the shift has been towards a growing involvement in solving social and economic problems at the beginning of the twentieth century. The growing involvement of universities in social and economic matters reached its acme with the birth and prevalence of the MIT–Stanford model. According to Henry Etzkowitz in Chapter 7 academy–industry relations are radically changing the actors of the knowledge economy. Universities are becoming the core of a new knowledge and creative economy. Paradoxically, it is by holding to the values of basic research that radical innovations with the highest market value are created. Capitalization of knowledge is becoming a central target of research policy in most American and many European universities. Technology transfer officers (TTOs) are acquiring a strong and proactive policy for IPR, the sale of licences and the creation of spin-off enterprises. Dual career is an ever more popular option. Academic scientists in some fields such as life sciences feel increasingly at ease in collaborating with companies.

The market culture is not a novelty in the American university. Already during and especially after the 1980s the fall in public funding for research obliged academics to seek resources in a competitive way from companies, foundations and public agencies. The concept of the 'quasi firm' was born at that time. Researchers joined to form a group of colleagues with common research and also economic objectives. They competed with other groups for a slice of the funding cake. Universities that organized their funding successfully through 'quasi firms', were the most suitable to become entrepreneurial and to capitalize knowledge.

The capitalization of knowledge through IPR is losing ground according to the analysis made by Caroline Lanciano-Morandat and Eric Verdier in Chapter 8. National R&D policies can be divided into four categories based on numerous important factors:

1. the Republic of Science is summarized by the Mertonian ethos and has as its main aim the development of codified knowledge. Its incentive structure is based on peer evaluation that implies disclosure and priority norms;
2. the state as an entrepreneur is based on the convention of a mission-oriented public policy aimed at pursuing national priorities in technology and innovation. It uses top-down planning exemplified by the traditional French technology policy successful in big military projects or in aerospace and energy. The incentives shaping individual behaviour are mainly public power over the actors of the scientific and industrial worlds;
3. the state as a regulator promotes the transfer of scientific knowledge to the business world. The objectives of academic research should be shaped by the market expectations. The incentives are focused on the definition of property rights in order to promote the creation of high-tech academic startups and the development of contractual relations between universities and firms;
4. the state as facilitator of technological projects is represented by the triple helix of the joint co-production of knowledge by universities, companies and public agencies.

The emergence of hybrid organizations, strategic alliances and spin-offs relies on local institutional dynamics. The information generated by invention is ephemeral and rapidly depreciates due to the speed of technological change. This tends to reduce the protective role of contracts and IPR for the capitalization of knowledge. Therefore incentives in science and technology districts are fewer royalties and more capitalization through shares, revenues and stock options arising from participation in new industrial initiatives. Individual competences include the ability to cooperate, to work in networks and to combine different types of knowledge. 'Janus scientists' capable of interfacing knowledge and markets and of integrating different conceptual tools pertaining to different disciplines will become increasingly sought after in the labour market. This R&D policy is gaining ground in most Western countries.

The triple helix is characterized by the birth of ever new and changing hybrid organizations. One specific example of a hybrid organization is that of boundary organizations that group the representatives of the three helixes and aim to bridge the gap between science and politics. In Chapter 9 Sally Davenport and Shirley Leitch present a case study on the Life Sciences Network (LSN) in New Zealand that acted as the boundary between the position of the scientific community and industry and that of the political parties in the discussion about the moratorium on GMO. LSN increased the chances of pro-GMO arguments being accepted by public opinion because of its supposed neutrality and authoritative status compared to those of member organizations. In this way it increased the chances of achieving the common aims of the representatives of the three helixes.

The economic role of the triple helix in the knowledge economy is more than just a way to capitalize knowledge. Knowledge is not economically important only because it can be capitalized. The concept of the knowledge economy is justified by a wider interpretation of the economic impact of knowledge. The economic utility of knowledge is present not only when it becomes an innovation. All economic activities involved in knowledge production and distribution are relevant. The problem is: how can we define what knowledge is and how can we measure its economic value? Chapter 10 by Benoît Godin introduces the pioneering work of Fritz Machlup. He tries to define knowledge with the help of epistemology, cybernetics and information theory.

Knowledge is not only an explicit set of theories, hypotheses and empirical statements about the world. It is also the, often implicit and tacit, set of procedures, skills and abilities that allows individuals to interact in the real world. Or in the words of Ryle, and of Polanyi, knowledge is not only represented by 'know-that' statements but also by 'know-how' abilities (or to put it differently, by ontic and deontic knowledge). If knowledge does not need to be merely explicit, and a true linguistic representation of certified events and tested theories, and if it can also be subjective, conjectural, implicit and tacit, then it can include many expressions of social and economic life: practical, intellectual, entertaining, spiritual, as well as accidentally acquired. From an operational point of view, knowledge should be analysed in two phases: generation and transmission. Therefore R&D, education, media and information services and machines are the four operational elements of knowledge.

Knowledge is not only a static concept, that is to say what we know, but a dynamic one, that is what we are learning to know. The first is knowledge as state, or result, while the second means knowledge as process, or activity. How can we measure knowledge? Not by using the Solow approach as a production function. By using this approach Solow formalized early works on growth accounting (breaking down GDP into capital and labour) and equated the residual in his equation with technical change. According to Machlup, the production function is only an abstract construction that correlates input and output, without any causal meaning. The only reliable way to measure knowledge is by national accounting, that is the estimate of costs and sales of knowledge products and services (according to his broad definition). Where the data were not available, as in the case of internal production and the use of knowledge inside a firm, he looked at complementary data, such as occupational classes of the census, differentiating white-collar workers from workers who were not knowledge producers, like blue-collar workers. His policy prescriptions were in favour of basic research and sceptical about the positive influence of the patent system on inventive activity.

Basic research is an investment, not a cost. It leads to an increase in economic output and productivity. Too much emphasis on applied research is a danger because it drives out pure research, which is its source of knowledge. Finally, his policy focus on information technologies was very supportive. Information technologies are a source of productivity growth because of improved records, improved decision-making and improved process controls, and are responsible for structural changes in the labour market, encouraging continuing movement from manual to mental and from less to more highly skilled labour.

The knowledge economy is difficult to represent. The representation must not focus only on economic growth and knowledge institutions. It should focus also on the knowledge base and on the dynamic distribution of knowledge. To reach this goal, knowledge should not be represented only as a public good but as a mechanism for coordinating society. Machlup was the first to describe knowledge as a coordination mechanism when he qualified it in terms of the labour force. In Chapter 11, Loet Leydesdorff, Wilfred Dolfsma and Gerben Van der Panne try to define a model for measuring the knowledge base of an economy. In their opinion it can be measured as an overlay of communications among differently codified communications. The relevant variables are the territorial economy, its organization and technology. The methodological tools are scientometrics, which measures knowledge flow, and economic geography. Territorial economies are created by the proximity – in terms of relational dimensions – of organizations and technologies. New niches of knowledge production emerge as densities of relations and as a consequence of the self-organization of these interactions. The triple helix is an exemplification of this dynamics. It is the emergence of an overlay from the academy–industry–government interaction. In some cases feedback from the reflective overlay can reshape the network relations from which it emerged.

Academy–industry relations aim to establish knowledge networks that function as complex problem-solvers devoted to the generation and diffusion of knowledge. They are Complex Adaptive Systems (CADs), whose emergent dynamics are difficult to predict but whose micromotives driving the individual behaviours can be represented (Viale and Pozzali, 2010). According to Chapter 12 by Matilde Luna and José Luis Velasco, there are four mechanisms for integrating triple-helix actors with different and diverging norms, interests, resources, theories and abilities: trust, translation, negotiation and deliberation. As is highlighted in other chapters of the book, communication and collaboration between the members of the three helixes offset the difficulties posed by a different set of values, interests and skills. It is difficult for industrial scientists to coordinate with academic researchers if their perception of time and money is different: if for one the aim is commercial and for the other it is epistemological, or if one has expertise of the more practical problem-solving kind while the other tends towards more theoretical solutions. If there are too many differences, no trust can be generated and therefore collaboration is difficult. Moreover, often there is linguistic distance, and cognitive styles of reasoning and decision-making are different. This calls for translation between two worlds. This can be provided by players who fulfil a bridging role between academy and industry (e.g. technology transfer officers) or by translation provided by the scientists themselves (e.g. Janus scientists).

Without translation it is impossible to find a rational ground for deliberation about the goals, methods, techniques and timescale of the research project. There can be only tiring and long negotiations, often with irrational and unbalanced results. Academy–industry relations can be assessed on two different functional and operative levels. If a knowledge network is capable of generating outputs that satisfy normative, epistemological and pragmatic desiderata, and if these outputs are achieved with the lowest costs (time, technical resources, money, physical effort etc.), they show a positive functional performance. If they become stable and 'robust' in their organizational structure and activities, they show a positive operative feature. Under these conditions *The Capitalization of Knowledge* both advances knowledge and presages a new mode of production beyond industrial society in which the university is co-equal with industry and government.

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