The Economics and Econometrics of Innovation

An Overview

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During the past few decades, the interest of economists in the sources of long run economic growth has led an increasing number to focus their attention on the role of innovation in creating that growth. Although some researchers have always been interested in this topic, in the last few years many others have recognized the central role played by innovation in almost all spheres of economic activity. Taking a somewhat U.S.-centric perspective, one can probably date the origins of the mainstream development of this research agenda from Solow's (1957) «discovery» of the importance of the «residual» in aggregate productivity growth and Nelson's (1959) and Arrow's (1962) influential papers on the economics of knowledge creation.

Of course, economic historians had for a long time been well aware of the importance of technical change in explaining economic development (see Rosenberg (1976), *inter alia*), and to some extent, modern research in this area has been more influenced by a historical and institutional approach than economic research in other areas. This is perhaps inevitable and necessary when dealing with a topic like innovation, so much of which seems to involve historical accidents and behavioral influences other than the purely economic. Nevertheless, the specific contribution that economists have made to the study of this topic has been and is to remind us of the importance of economic incentives in shaping and directing innovative activities, both by individuals and firms.

Following on Solow's early work, a few empirical pioneers began the task of measuring and understanding the micro-economic determinants and outcomes of innovative activity, at the same time that theorists began to use the new game theoretic tools to study the behavior and interactions of the firms undertaking innovative activity.[1] The same period saw a large increase both in government supported research and in organized industrial R&D in the United States and elsewhere, which has served to focus the interest of policy-makers on the topic; this last fact has had the welcome effect of increasing both the data sources available to researchers and the demand for their output.[2]

Thus the papers collected in the present volume reflect the enormous increase worldwide in the economics of innovation and technical change that has occurred. They are a selection of the over fifty papers that were first presented at the 10th international ADRES conference which

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1 For early empirical work, see Schmookler (1966), Mansfield (1961), and Griliches (1957). Among the first theoretical contributions were Arrow (1962), Kamien and Schwartz (1980), Loury (1979), and Dasgupta and Stiglitz (1980). See Reinganum (1989) for a survey of some of this literature.

2 For example, several papers in this volume make use of the French version of the new Innovation Surveys that have now been conducted for several European countries as well as for the United States (in a different form). See Duguet and Kabla (this volume) and Barlet, Duguet, Encaoua, and Pradel (this volume) for France and Cohen, Nelson, and Walsh (1996, 1997) for the United States.

was held at the European Parliament in Strasbourg, June 3-5.[3] This foreword briefly describes the contributions of the twenty-two articles making up this published volume, situating them within the major body of literature which has been built up around this topic during the past several decades.

We have gathered together the contributions to this issue under seven headings, structured by the types of questions addressed rather than by methodological differences such as the traditional distinctions between microeconomic and macroeconomic approaches and between theoretical and econometric approaches. In fact, one of the particular goals of this conference was to bring out the complementary nature of the various approaches to innovation, and to make possible in-depth dialogue both between microeconomists and macroeconomists, and between theoreticians and econometricians. As will be seen in the following pages, the dialogue was successful and produced an interesting and challenging juxtaposition of ideas and results. Above and beyond the wealth of information presented in the articles, readers of this volume will also appreciate the value of examining a single question from different angles and using different methods.

The seven general topics that are considered in this special issue are the following: 1) the economy-wide effects of innovation on growth and employment; 2) the organization and assessment of public sector scientific research; 3) the role of intellectual property rights and patents in protecting innovation; 4) the analysis of networks and standardization; 5) the determinants of Research and Development (R&D) investment and its relationship to firm productivity; 6) variation of individual firm innovative performance with respect to uncertainty and international competition; 7) the assessment of knowledge spillovers, in particular between countries, the consequences for competition and technology policy. In the following we discuss each of these topics in turn, highlighting the contributions made by each of the papers to the topics.

1. Macroeconomic Effects of Innovation

Our first topic concerns the analysis of the overall or aggregate **effects of innovation** on economic growth, employment and total factor productivity. These effects are of considerable importance, and much research is currently being devoted to their study. The theories of endogenous growth developed over the last few years have made it possible to bring new analytical methods to bear on the forms of technical progress and on its impact in terms of global performance.[4] Three aspects are analyzed in this issue:

- *the role of innovation in economic business cycles through the medium of collective learning;*
- *the influence of the system of property rights of innovation on the diffusion of knowledge and on the economic growth rate;*

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[3]The conference was organized in collaboration with the ninth Franco-American CREST-NBER Seminar (the Centre de Recherche en Économie et Statistique and the National Bureau of Economic Research) as part of the European Commission's TSER program on innovation and productivity. In addition to the financial contributions of the organizing institutions (ADRES, CREST, NBER and the European Commission), the conference received assistance from the Alsace-USA Association, the CEPR (Centre for Economic Policy Research, London), the CNRS (Centre National de la Recherche Scientifique, Paris), the Strasbourg City Council, the Bas-Rhin Regional Council, the Ministry of Foreign Affairs (Paris), the University of Paris-I Panthéon-Sorbonne and Strasbourg's Louis Pasteur University. We should like to thank these institutions for making the conference and this volume possible.

[4]There are a sufficiently large number of recent works presenting full accounts of the various growth theories for us to omit here a synthesis of work being carried out in that field. See particularly the works of Aghion and Howitt (1998), Barro and Sala-i-Martin (1995) and Grossman and Helpman (1991).

- *technical change and the impact of imperfections in labor market matching mechanisms on unemployment levels in endogenous growth models.*

The article by Philippe AGHION and Peter HOWITT (*On the Macroeconomic Effects of Major Technological Change*) concerns the question of why an instance of high technological discontinuity, such as the emergence of a major innovation, can initially have the effect of causing a decrease in economic activity before having a beneficial effect on long-term growth. Analysis of the link between innovation and economic activity cycles refers back to the Schumpeterian tradition of the technological origin of fluctuations and to the older literature devoted to Kondratieff's long cycles. An explanation for this link was recently given by Helpman and Trajtenberg (1995). It rests on the idea that the emergence of a major technological innovation - meaning an innovation with potential applications in many sectors of activity - requires a period of adjustment before having beneficial effects.[5] During this period, considerable capital and labor resources are taken away from traditional technologies and allocated to activities relating to the development of the new technology, in which the yield is uncertain and the results less readily appreciable than in traditional activities. In addition, the new technology requires the development of complementary tools, the perfection of which is a precondition for the success of the innovation. How is it possible to explain why the beneficial effects of the innovation only appear late in the second phase of the cycle under these conditions? The originality of Aghion and Howitt's model is to add to the foregoing pattern certain learning-related externalities based on the collective dimension of the process of evaluating the advantages arising from the new technology. The interaction between this process of collective learning, formalized as a circulation process, and that of the creation of additional tools, leads to an effect of sharp macroeconomic deceleration in activity, occurring a certain time after the appearance of the innovation. An obvious contemporary example is information technology, and from this point of view, Aghion and Howitt's analysis might be considered to provide an explanation of the «Solow paradox,» according to which computers may be observed everywhere except in productivity statistics.[6]

More fundamentally, Aghion and Howitt's model constitutes a theoretical basis for the Schumpeterian idea that long-run business cycles originate in technological discontinuity resulting from the emergence of major innovations. At present, there are few empirical tests proving the existence of these long cycles. However, it is likely that Aghion and Howitt's model will serve as a springboard for later empirical work. Furthermore, the model presented makes it possible to analyze the differential effect of three factors that influence the extent of recession and should be taken into account in empirical work: (i) the segmentation of the labor market according to skills; (ii) the existence of imperfections in the labor market, particularly that connected with difficulties in matching labor supply and demand; and (iii) the idea - once more Schumpeterian - that technological innovation is marked by a type of intrinsic obsolescence, given that a technological innovation may quickly be replaced by a second innovation inspired by the first.

The article by Philippe MICHEL and Jules NYSSEN (*On Knowledge Diffusion, Patents Lifetime and Innovation-Based Endogenous Growth*) analyses the impact on growth of the institutional constraints of the patent protection system, defined both as right of ownership and as a means of diffusing the knowledge contained within the innovation. During the protection period, a registered patent does not describe all the technological expertise involved, either because this expertise cannot be easily codified, or because the innovator wishes to retain some element of technological secrecy. The knowledge embodied in the innovation thus loses part of its status as public property as long as the patent is in force. For this reason patent policy should

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5 This type of innovation is sometimes designated by the term «General Purpose Technology.» See Bresnahan and Trajtenberg (1995), David (1990), and Rosenberg (1976) for development of these ideas.

6 For an interesting discussion of this point, see Oliner and Sichel (1992); also David (1990).

take into account not only the traditional balance between the encouragement to innovate and the market allocation inefficiency due to the innovator's monopoly power, but also a new dimension of dynamic balance between, on the one hand, the choice of a path to maximum economic growth obtained by encouraging the diffusion of knowledge through a reduction in the protection period, and on the other hand, the option of extending protection in order to encourage innovation to the detriment of the diffusion of knowledge.

The interest of the article lies in the fact that the authors study the impact of the institutional characteristics of the patent protection system within the framework of a general equilibrium model of endogenous growth, whereas most work related to determining the optimum combination of patent characteristics (legal duration of protection, scope of protected claims, authorized improvements, etc.) approaches the question in terms of partial equilibrium analysis.[7] One of the most striking results of the article is that the patent lifetime that maximizes the economic growth rate does not generally coincide with the lifetime that maximizes consumer welfare. One question the article does not tackle, but which is discussed below, is the fact that the effective lifetime of a patent is generally shorter than the legal lifetime.

The article by Frédérique CERISIER and Fabien POSTEL-VINAY (*Endogenous Growth and the Labor Market*) raises the important question of whether technical progress destroys more employment than it creates, or whether low-skill jobs destroyed in innovative industries are counterbalanced either by skilled jobs created in those same industries or more generally by low-skill jobs in other industries due to the increase in overall demand. This is probably one of the issues to which society is most sensitive. To answer this question using a conceptual analysis, Cerisier and Postel-Vinay develop a multi-sector model of qualitative endogenous growth, combining it with a process of imperfect matching of job supply and demand on the labor market. Growth is generated by the production of new varieties of goods and the improvement of the quality of the existing products. The process of *creative destruction* leads to established firms seeing their market shares decline, leading them gradually to lay off staff, while new firms creating new products take on workers. Recruitment implies frictions which the authors model as a process of matching as in Pissarides (1990): the number of matches per time period depends both on the number of unemployed and the number of vacant posts, and new firms are able to fill all their vacant posts only after a certain lapse of time. Furthermore, the cost of setting up these new firms is positive. In a steady state, there is a positive relation between growth and unemployment, in that the negative effect of the redistribution of labor due to frictions in the matching process prevails over the positive effect due to growth. Innovation thus creates unemployment through the creative destruction process.

Is this, however, a reliable conclusion? It is difficult to answer this question with a high degree of certainty, although it is clear that empirical studies can be highly useful here. For example, Davis and Haltiwanger (1992) show that there is a distinct long-term balance between growth and unemployment in the United States, and that periods of high unemployment are also those in which work mobility is greatest. However, further empirical studies are doubtless necessary, particularly on European data, in order to take into account the specific features of the labor market reallocation processes and the influence of technological bias on the characteristics of labor skill demand in Europe.[8]

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[7]See for example Nordhaus (1969), Klemperer (1990), Green and Scotchmer (1990), Gilbert and Shapiro (1990), and Chou and Shy (1991).

[8]For studies carried out on French data, see Duguet and Greenan (1997) and Goux and Maurin (1997), and for studies using data from a variety of OECD countries, see the special issue of the *Economics of Innovation and New Technology*, volume 6, issue 2/3/4, edited by Hall and Kramarz (1998). In general, a clearcut answer has not yet been obtained to this question.

2. Public Sector Scientific Research

Our second major topic concerns the upstream part of the innovative process, namely the resources devoted by many governments to basic or fundamental science. Against the present backdrop of budget deficit reduction and the partial privatization of certain major public services that had formerly taken an active part in national research and development efforts, the question of the organization of public sector research is a subject of current debate. This issue examines various aspects of this debate:

- *the problem of assessing academic research and the evaluation of the corresponding knowledge production function using scientific citation measures;*

- *the effects of reputation and competence on the funding and productivity of scientific research;*

- *the organization and localization of public sector research in Europe.*

The article by James ADAMS and Zvi GRILICHES *(Research Productivity in a System of Universities)* in one of the first empirical studies on the productivity of fundamental research in universities, a field which, according to their conclusions, is sure to be a rich research area for many years to come. Academic research accounts for some 50% of fundamental research in the United States and is a major component of national research. Beyond that, it is also an essential factor in innovation and economic development. The authors constructed an original database by matching the R&D expenditure of a wide sample of private and state-run universities with the number of articles published and the number of citations for these articles. Their work covered the 1980s and focused on eight major scientific fields: agriculture, biology, chemistry, computer science, engineering, mathematics and statistics, medicine and physics. A hundred institutions were studied for the first, more general, part of their analysis, and some thirty institutions for the second part, which goes into greater depth. The analysis of this new database, both descriptive and econometric, leads to interesting observations and questions.

Adams and Griliches highlight the significant discrepancy between the yields of research in terms of articles and citations estimated at the aggregate level of the major scientific fields and yields at the individual university level for each scientific field. The returns are constant at the aggregate level, whereas they are decreasing at the individual level (with an average coefficient value of 0.6 to 0.7). The authors suggest two interpretations of this discrepancy. One explanation may be the existence of positive research externalities created by the dissemination of knowledge among universities and among scientific fields (notably through the training of young researchers). Another equally, if not more, probable explanation may be the measurement errors resulting from individual comparison - necessarily difficult and imperfect at this level - between research (and expenditure) and the number of articles (and citations) arising from this research, and the partial, reductive nature of the measurement of scientific production in terms of numbers of articles (even when weighted by the citations). Adams and Griliches also document the absence of significant results of regressions in the «temporal dimension» of the data (the absence of correlation between growth in research expenditure and growth in the number of publications), which is yet another manifestation of a difficulty often encountered in the analysis of panel data when one wants to control for heterogeneity in the form of fixed effects or permanent unobserved differences across units.[9]

[9] For discussion of this question in the wider context of identification and estimation of production functions, see Griliches and Mairesse (1999).

The article by Ashish ARORA, Paul DAVID and Alfonso GAMBARDELLA *(Reputation and Competence in Publicly Funded Science: Estimating the Effects on Research Group Productivity)* focuses on the distribution of public funding for research among research teams according to reputation and competence, and on the productivity of these teams according to the allocation of funds they obtain. Like the foregoing article, this is one of the first empirical contributions to the new «economics of science.» The three authors also emphasize that this topic of study is in its infancy and needs to be developed further. They base their study on an original database which they constructed from the archives of the Italian National Research Center's five-year program (1989-1993) in the fields of molecular biology, genetic engineering and bio-instrumentation. They obtained a sample of almost 800 research teams proposing research projects, some 350 of which were selected and received, for five years, annual research budgets of varying amounts (and in varying proportions to the sums requested). For these teams, they compiled their budgets, their publications (numbers and journals) produced during and as a result of their research programs, and publications by the team leaders (that is, the principal investigators), taking into account work they published in the relevant field over the five years preceding the funding request. To analyze their data, Arora, David and Gambardella develop and estimate a model that conforms to the features of the system they are studying, although this model might also be applicable on a more general level.

Like Adams and Griliches, they find that research returns (measured by research budget) in terms of articles (weighted according to the international reputation of the journals in which they are published) estimated at the individual team level are decreasing (0.6 on average). However, they demonstrate that returns in relation to past performance are of the same order, mostly via the indirect effect of past performance that is both is due to the fact that the probability of a team having its project selected is higher if past performance is good, and to the fact that once chosen, the amount of funding allocated is correspondingly higher.[10]

In the first part of their article *(The Impact and Organization of Publicly Funded Research and Development in the European Community)*, Maryann FELDMAN and Frank LICHTENBERG study the important and often controversial question of the complementary nature of public and private research. In the second part, they test the hypothesis that the more decentralized research activities are (both administratively and geographically), the more the knowledge they produce is codified, and conversely, the more they are centralized, the more the knowledge produced is to a large extent tacit (barely codified, or difficult to codify). To perform these analyses, they take advantage of the rich database CORDIS (Community R&D Information Service) of the European Community, illustrating the usefulness of this resource. Feldman and Lichtenberg observe that private and public research in 16 European countries, from Norway to the United Kingdom, shows a strong tendency to be specialized in the same major scientific fields (26 in their study) in each country. They conclude that this fact gives a clear indication of the great extent to which the two forms of research are complementary, at least in Europe.[11] On the basis of two indicators of the degree of codification (the number of articles published in journals compared to the number of reports, and the proportion of tangible results of research such as prototypes or processes, as opposed to expertise, competence and methods), they also observe that the more these programs are spread over a large number of countries, and the more projects there are per program, the higher the degree of codification of the results.

[10] It should be pointed out that these results, like the main results of Adams and Griliches, are based on the analysis of cross-sectional data (as opposed to panel data where it is possible to control for unobserved individual effects and to take account of the dynamics of the relationship).

[11] More precisely, the greater the number of private research organizations (consultancies, industrial and service organizations) specialized in a given field in a given country, the greater the number of public research organizations (state laboratories, technology transfer centers, universities) specialized in the same field in the same country.

3. Intellectual Property Rights and Patents

Our third topic concerns problems related to systems that protect the ownership of innovations through intellectual property rights and patents. The patent, which is a right of ownership designed to ensure that the patent holder enjoys legal protection against possible imitation during the patent protection period in return for publication of the protocol defining the innovation, offers both problems and solutions to those studying technical change.

For example, patents are extremely useful to empirical researchers as the only easily and widely available measure of innovation output that carries with it some information about technological field. However, not all innovations are necessarily patented, even among those that do meet the legal requirements of patentability, indicating either that the protection conferred by the patent is not considered as valuable as it might initially appear, or that the legal costs incurred in filing for a patent or by bringing an action for patent infringement are deemed to be too high. Clearly these factors have been changing over time, which limits the ability to use patents as a measure of the fecundability of R&D in the temporal dimension.

In addition, in many economic models, patents are often treated more as a technical instrument than as a strategic instrument, although firms appear to use them strategically in some cases. That is, whether or not a firm applies for a patent or renews a patent may depend on some cases on the behavior of competitors or other factors outside the immediate profit stream expected from the innovation associated with that particular patent. This could be either for signaling reasons (see the article in this volume by Crampes and Langinier) or because firms wish to have a strong bargaining position in the case of patent litigation threats (see Hall and Ham 1999).

The results of analyzing the functioning of patent and intellectual property systems can also be of considerable policy interest. For example, the documentary purpose of a patent is that it provides information necessary for the improvement of existing innovations. Therefore, if technological development is part of a cumulative process, and more new possibilities for development are offered when accumulated knowledge is greater and more codified, it is clear that the recent drop in the number of patents in Europe, as revealed by statistics, is cause for concern. The production of patented innovations in the countries which now make up the European Union fell from 110 000 a year in 1950 to some 85 000 in 1995, whereas in the other two major trading blocs, the United States and Japan, the annual figures for patents have risen from 55 000 to 140 000 and from 18 000 to 320 000 respectively. Understanding the reasons for the drop and whether it can be expected to slow down the knowledge accumulation process in Europe are thus important for policy makers.

Several patent-related topics are discussed in this issue:

- *the problems raised by the imperfect protection conferred on the patent holder, particularly the potential necessity of litigation to enforce the property right;*

- *the choice of various modes of intellectual property protection;*

- *the strategic dimension of patents;*

- *the relationship between patenting and R&D inputs.*

The article by Jean LANJOUW and Josh LERNER *(The Enforcement of Intellectual Property Rights: A Survey of the Empirical Literature)* is a contribution to the emerging literature on the economic analysis of law.[12] The authors provide an analytical model of litigation concerning intellectual property rights and an overview of the empirical literature studying this litigation. They attempt to answer a number of questions: What is the cost of detecting and taking legal action for patent infringement? What influence does the cost of enforcing patents have on the private value of patent rights? What is the impact of the threat of litigation on the innovation process? Lanjouw and Lerner report figures relating to the United States which show that the cost of patent litigation is substantial, and that the start of a trial leads to a considerable fall in the stock market value of the defending company. Furthermore, these costs occasionally lead small companies to renounce their property rights and seek a compromise rather then go to court.

To analyze these facts, they propose a model of a two-stage game with two players, in which the plaintiff is the patent holder and the defendant is the company allegedly having infringed patent rights. In the first stage of the game, the defendant decides whether or not to move into the market for the product in question. If this happens, the plaintiff may either file a suit or suggest a compromise with the defendant. All things being equal, an increase in legal costs or a decrease in the probability of winning the case (or even a drop in the expected returns) can encourage the parties to seek a compromise. Empirically speaking, the studies that they survey confirm these predictions of their mode, demonstrating that small and medium-sized companies often avoid innovating in fields in which large companies are already present, and that in jurisdictions where legislation provides that the legal costs of a trial shall be borne by the losing party innovation is reduced.

Michael WATERSON and Norman IRELAND *(An Auction Model of Intellectual Property Rights: Patents versus Copyright)* seek to determine which of the two methods of protection - patent and copyright - is the more effective, and more precisely, in what types of activity one would be more appropriate than the other. The question is all the more relevant since patents do not cover all inventions: for example, historically computer software could only be protected by copyright.[13] Using the criterion of total private profit for evaluation, Waterson and Ireland demonstrate that different protection systems should be used for different industries, depending on the volume of R&D expenditure, the number of competitors and the number of potential applications for a given discovery. For example, in the pharmaceutical industry - in which considerable sums are invested in R&D, the number of agents pursuing the same research track are few, and technological spillovers linked to the applications of a discovery are low - the patent seems to be the most appropriate protection. On the other hand, in the computer software industry - in which investment is relatively lower, the number of agents is fairly large, and a vast number of potential applications are linked to the development of a program - copyright is preferable. The analysis presented in the article thus yields a useful method for studying the properties of various instruments for the protection of intellectual property and their effects on innovative activity, according to the characteristics of the innovation, the environment in which it is made and the methods by which it is disseminated.

In their article *(Information Disclosure in the Renewal of Patents)* Claude CRAMPES and Corinne LANGINIER examine the strategic dimension of patents, more precisely that dimension due to asymmetry between the market information held by the innovator and that held by potential competitors. Consider the case in which a patent is taken out by an innovator,

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[12] Among available references on the law and economics of intellectual property, the editors recommend Lerner (1994, 1995), and Hugues and Snyder (1995). The legal aspects of intellectual property rights in the EC are covered in Korah (1994, chapters 9 and 10).

[13] This is an evolving area of the law in some countries. For example, in the United States it is now possible to protect certain types of software code and algorithms by patent rather than copyright. Also, code that is embedded in physical microprocessors can by protected using mask work protection (although patenting is preferred where it is feasible).

and he must decide whether or not to renew it during the legal lifetime of the patent. Under perfect information, the fee will be paid if later profits compensate for the renewal cost.[14] When information is imperfect, another element comes into play. The decision to renew means that the innovator sends out a positive signal concerning the profitability of the market for the innovation, which may encourage a potential competitor to enter this same market. Thus the decision not to renew clearly has a strategic dimension, since it lowers the potential entrant's belief in the profitability of the market.

The model is presented as a signaling game yielding multiple equilibria. In one of these equilibria, if the potential entrant expects *a priori* a low probability of the market being profitable, the innovator will not pay the renewal fee in order to send a negative signal to the competitor. Crampes and Langinier's model thus provides a plausible explanation for the observation that the effective lifetime of a patent is generally much shorter than its legal lifetime, although of course it does not rule out other explanations. A model similar to theirs was presented in Choi (1985), which studied the decision not to announce an intermediate discovery so as to discourage competitors who were also working towards the final innovation. The analysis of strategic behavior when information is imperfect thus makes it possible to explain a number of phenomena in the field of innovation.

In their article *(Appropriation Strategy and the Motivation to Use the Patent System)* Emmanuel DUGUET and Isabelle KABLA examine the determinants at play in the decision to patent an innovation. It is widely known that the patent is not the only appropriation mechanism available. Secrecy, particularly in the case of processes, and, more simply, the technological lead one company has over others may be sufficient to protect its innovations effectively. In the second case, the patent may even harm the innovator if the patented technology can be improved upon. By using the information disclosed by the patent, competitors may improve on any innovation which is sufficiently innovative to be patented, close the technological gap and even leapfrog the initial innovator. However, the patent may still be necessary in order to transfer the technology to another party.

Until recently, the determinants of the decision to apply for a patent have not been the subject of empirical economic studies due to the lack of appropriate data, although many studies of the patent yield in relation to R&D expenditure have been conducted.[15] The availability of new data from the French Appropriation Survey, carried out in 1992 by the SESSI industrial statistics service, made it possible for Duguet and Kabla to carry out such a study. From this survey, they obtain the percentage of innovations which companies decide to patent and also their views on the main qualities and defects of the patent as a means of appropriating the profit from the innovation. They observe that companies register patents for only one-third of their innovations on average. They also verify that the major factor differentiating companies in terms of the percentage of patented innovations is the extent to which they fear that the information disclosed by the patent will be used by competitors. They find that this factor affects not only the percentage of patented innovations but also their actual numbers, independently of the influence of R&D expenditure levels. Another interesting observation is that the use of patents in technological negotiations is a significant motivation for companies to patent their innovations, whereas patent application and renewal fees are of little significance.

The article by Georg LICHT and Konrad ZOZ *(Patents and R&D: An Econometric Investigation Using Applications for German, European and US Patents by German Companies)* uses data from a European Community survey on innovation in Germany to

[14] Unlike that of Pakes (1982), this analysis is performed under certainty. When the future profit stream is uncertain, the patent may be renewed because it has option value even though expected profits might not justify renewal.

[15] For a review of the U.S. literature in this area see Griliches, Pakes, and Hall (1987), and for work using French and German data, Crepon and Duguet (1997a,b) and Licht and Zoz (this issue), respectively.

explore the relation between R&D expenditure and the filing of patents in the German, European and United States patent offices.[16] A descriptive study of the data first demonstrates that the probability that a company invests in R&D or applies for a patent increases with company size. Large companies are also more likely to apply for patents in more than one country, whereas the national patent office is clearly more important to small and medium-sized companies. Econometric count data models are then used to study the relation between R&D spending and the patents filed at the various patent offices. In each case the chosen econometric specification is one which separates the decision to file for patents from the number filed.[17]

The main results of this research are the following: R&D expenditure in companies has a considerable influence on the number of patents obtained, with an elasticity varying between 0.8 and 1.1, depending on the level of R&D expenditure and the location of the patent office. This coefficient was much higher for the United States and lower for Germany. The spillover effect, estimated by including total industrial R&D expenditure in the model, appeared to be of little significance. However, the size of the company has a significant effect on the tendency to file for patents. A number of explanations may be submitted to explain the behavior of small companies. There may be a lack of information about the patent system, there may be other mechanisms for protecting innovation, it may be due to the more incremental nature of innovations brought about by smaller companies, or it may simply be that there are fixed costs in obtaining patents so that smaller firms find each patent relatively more expensive to obtain.

4. Networks and Standardization

The fourth heading concerns the analysis of decisions for network standardization. There are many links between the economics of innovation and the economics of networks. First, decisions about the compatibility of goods that are complements to a particular innovation (such as peripherals for a personal computer) may themselves be considered product innovations, since they make available new combinations and thus new varieties. Second, the choice of technological standards in a large number of industries is crucial for their survival, and gives rise to stiff competition. Whether it be GSM standards for mobile phones, VHS standards for video-cassettes, standards for high-definition television,[18] the arrangement of typewriters and computer keyboards,[19] or computer operating systems, the choices made for standards often depend more on the historical background and strategies used by the companies in which the innovations originated than the intrinsic technological superiority of the standard adopted. In addition, network externalities leading to the adoption of a standard must themselves be related to the general innovation-generated externalities linked to growth that were described under our first heading.

Two topics that concern standardization are examined using theoretical tools in this volume:

- *the determinants of the decision by competitors to conform to a common standard;*

- *the effects of standardization on output.*

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[16] This was the first survey carried out on the MIP (Mannheim Innovation Panel).

[17] This two stage econometric model corresponds to a Type II negative binomial specification combined with a hurdle model (see Cameron and Trivedi 1998 for the econometric details on this kind of model). The negative binomial model itself is an extension of the basic Poisson specification where the patenting propensity parameter is assumed to follow a gamma law chosen so that the ratio of the variance to the expectation is an affine function of the expectation.

[18] See Farrell and Shapiro (1992).

[19] See David (1985).

In their article *(Equilibrium Coalition Structures in Markets for Network Goods)* Nicholas ECONOMIDES and Frederick FLYER seek to determine what encourages firms in an oligopolistic industry producing goods exhibiting network externalities to conform to a common standard (compatibility) or to maintain the specific features of their products (incompatibility). On the one hand, compatibility increases the number of available varieties, thereby increasing overall demand in the industry. On the other hand, compatibility makes competition more intense among producers of alternative goods. What will be the nature of the outcome between these opposing forces?[20]

To answer this question, Economides and Flyer consider a symmetrical model in which the goods on offer are identical, with the exception of the standards to which they conform. The quality of the product on offer increases with the number of companies conforming to the same standard. Coalitions conforming to the same standard may be formed. The notion of equilibrium is expressed in terms of coalitions. A coalition structure constitutes an equilibrium so long as no single company wishes to leave the coalition to which it belongs and join a parallel coalition. The conclusions are the following: Perfect compatibility, meaning the conformity of all companies to the same standard only constitutes an equilibrium in those industries in which the network externalities are low. However, in those industries in which the network externalities are high, various standards exist in equilibrium. In these industries, it is even possible for total incompatibility to constitute an equilibrium. In addition, the larger the scale of a coalition among companies having chosen the same standard, the more reluctant its members are to allow another company to adhere to it. This effect is even stronger when network externalities are high. These results are interesting in that they help understand why, for network goods, there may remain instances of high asymmetry, with, on one side, one dominant company together with a large number of smaller companies that survive in the shadow of its standard, and on the other side, other groupings of companies choosing their own standards. The personal computer operating systems industry in the 1990s, which is dominated by Microsoft's Windows standard, could be an illustration for this analysis.

In his article *(Does Standardization Really Increase Production?)* Hubert STAHN returns to the result of Katz and Shapiro (1985) according to which, in an industry with network externalities, the level of overall production is higher when firms choose compatible rather than incompatible goods. This result had been established using the hypothesis of a constant marginal production cost. Stahn succeeds in demonstrating that with the hypothesis of a more general cost of production function, the result does not hold. This is significant, as the widespread belief that compatibility generally increases the overall surplus available is called into question by this analysis. Stahn shows, through a counter-example including three products, that the result of Katz and Shapiro does not hold if quadratic or convex cost functions are considered. In this case, the surplus is at its highest when the three products are incompatible. It is therefore necessary to exercise caution when assessing the effects of compatibility or standardization on social welfare.

5. R&D Investment and Productivity

The fifth heading concerns the analysis of R&D investment expenditure and its productivity. This is far from being a recent problem, however it is clear that investigation into it will never be complete, given the difficulties in terms of concepts, measurement, and estimation methods to say nothing of the varying impact of R&D over time and across countries. Three questions are discussed in the present issue:

[20] This type of question applies to many network activities. For air transport, see Encaoua, Moreaux, and Perrot (1996).

- *the measurement of R&D capital and its impact on productivity;*
- *the financing of investments in R&D (and in physical capital).*

These themes have been discussed in a number of earlier studies.[21] The latter has given rise to a particularly vast body of literature regarding physical investment, though it has rarely been applied to the study of R&D investment.[22] The two articles brought together under this heading are highly representative of current investigation into company panel data, while at the same time providing certain interesting variations in approach and modeling.[23]

The article by Tor Jacob KLETTE and Frode JOHANSEN *(Accumulation of R&D Capital and Dynamic Firm Performance: A Not-so-Fixed Effect Model)* takes as its starting point empirical regularities frequently observed in R&D investment and productivity at the firm or establishment level. Using relatively homogeneous samples of establishments or «lines of business» (rather than companies) in four major Norwegian industries, they first verify that R&D activities are persistent in time (individual differences in the intensity of R&D efforts are significant and auto-correlated); then, they determine that the correlation between different levels of productivity and R&D capital intensity are significantly positive in the cross-sectional individual dimension, but that the correlation between variations in productivity and R&D capital intensity in the time series dimension is much weaker, and occasionally not significant.

On the basis of these observations and analytic considerations inspired by Penrose (1959) and Uzawa (1969), the two authors suggest an alternative model of R&D capital accumulation (multiplicative or log-linear) instead of the usual linear model.[24] They show that this pattern leads to a simple dynamic model in which the present level of productivity is a function only of the R&D investments made the previous year (rather than R&D capital) and the productivity level of that same year. The major advantage of this model is that it does not require the construction of the R&D capital stock variable.[25] Klette and Johansen, in estimating this model, find that the R&D capital depreciates rapidly, with a depreciation rate in the region of 18%, and that the rate of return on R&D investments are fairly close to the figure for physical investment.

In his article *(Are There Financing Constraints for R&D and Investment in German Manufacturing Firms?)* Dietmar HARHOFF sets out to assess to what extent R&D and physical (equipment) investment decisions in German manufacturing firms are affected by financing constraints. The principal reason for the existence of such constraints (which result from the imperfections of the capital markets) has been thoroughly analyzed in the theoretical literature, and arises largely from the asymmetry of information between the company and its potential creditors. Many empirical studies have shown the existence of financing constraints influencing the physical investment decisions of companies. For Germany, two types of study can be

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[21] See, for example, the overview of econometric studies on company data by Mairesse and Sassenou (1991) and by Griliches (1995).

[22] For a recent example with some survey results, see Mairesse, Hall, and Mulkay (1999). For examples using R&D investment, see Himmelberg and Petersen (1994) and Hall (1993).

[23] Both use GMM panel data estimation methods, making it possible to take into account the nature – not strictly exogenous, but merely predetermined – of certain explanatory variables and the presence of correlated individual effects.

[24] The use of this model was first suggested and implemented by Hall and Hayashi (1988); one can show that a firm faced with such an accumulation pattern will tend to smooth its R&D investment relative to that of a firm facing a linear accumulation pattern with no adjustment costs.

[25] The estimated model also posits a «margin-based» behavior pattern in firms, in order to take into account the fact that productivity measured at the individual level is expressed in terms of nominal value rather than in real terms, and that it may therefore reflect differences in the level of prices faced by the firms and changes in their market power over time. On this point, see Klette and Griliches (1996).

distinguished. Studies on panel data concerning large companies quoted on the stock exchange have mostly concluded that these constraints are absent. However, cross-sectional studies (where it more difficult to control for unobserved heterogeneity) on smaller companies have regularly concluded that such constraints are present and are of considerable importance. No previous study has assessed the impact of these financing constraints on R&D investment in German companies.

Harhoff uses a new panel of German companies involved in R&D, mostly companies not quoted on the stock exchange (236 companies over the period 1987-1994). For this panel he estimates various equations for R&D expenditure and physical investment, beginning with the simple dynamic specifications suggested by Bond, Elston, Mairesse and Mulkay (1997). For smaller-scale companies, these indicate that R&D and investment are highly sensitive to cash flow. This effect is attenuated, yet does not disappear, if the specification tested includes an error correction mechanism. The interpretation of the relation between cash flow and investment does however pose a problem. It may be considered either to express the link between investment and expected profitability, or to result from the existence of financial rationing (on imperfect capital markets). High cash flow can be an indicator of high profits, and may therefore be correlated with anticipated future profits. Thus Harhoff, in the following part of his study, tests a specification of a more «structural» nature using Euler equations derived from the dynamic program of the firm (inspired by Bond and Meghir (1984)). For physical investment, he finds estimates that are consistent with the absence of financing constraints in large companies, but not in small companies.[26] The Euler equations estimated for R&D are not informative, probably because the necessary differencing of the equation for estimation leaves little real variation in the series to be explained.[27]

6. Profits from Innovation

Obviously innovation is seldom an end in itself, and for a fuller understanding of its effects it is important to assess the relative advantages gained by the innovator. The measurement of individual firm performance is however a delicate matter, and there are few appropriate indicators available.[28] Innovating companies face three types of uncertainty: technological, strategic, and market. Technological uncertainty refers to the fact that companies that have decided to devote R&D resources to the application of a discovery are never sure beforehand that they possess the expertise necessary to transform the discovery into a technically viable industrial project. Strategic uncertainty arises from the fact that a company allocating funds to the development of an industrial project is never sure of being the first to introduce the corresponding innovation onto the market. Market uncertainty refers to the fact that the existence of potential buyers of the innovation is rarely guaranteed at the moment when the company chooses an industrial R&D project. This uncertainty is often the most difficult for companies to overcome, and the commercial performance of the innovation is strongly affected by it.

Three topics related to the measurement of innovative performance are discussed in this issue:

- *the degree of asymmetry or skewness in the ex post distribution of innovation profits;*

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26 Additional survey data reported in the paper does suggest that the sensitivity to cash flow of investment in small companies may reflect true financing constraints, rather than mere problems of an econometric order.

27 It is well known in the empirical innovation literature that R&D is a rather smooth series at the firm level, probably because it consists primarily of the salaries and other expenses associated with scientists and engineers that are costly (in terms of lost human capital) to hire and fire. See Hall, Griliches, and Hausman (1986) or Lach and Schankerman (1988).

28 See Kleinknecht (1996)

- *the effects of trade restrictions on innovative performance;*

- *the impact of different types of innovation on commercial performance.*

In their article *(The Commercial Success of Innovations: An Econometric Analysis at the Firm Level in French Manufacturing)* Corinne BARLET, Emmanuel DUGUET, David ENCAOUA and Jacqueline PRADEL emphasize the observed market uncertainty about the success of innovation using a performance indicator provided by the proportion of total sales of a company accounted for by recent innovative products (i.e. products marketed for less than five years). The use of this indicator of the commercial success of innovations has spread thanks to the increasingly frequent Innovation Surveys (particularly in European countries), in which it is generally available in interval form, not only for the total sales of innovating companies, but also for export sales.

The article is based on the first large-scale survey of innovation in French industry (the 1990 Innovation Survey), and it studies how the commercial performance of innovating companies varies according to the nature of the innovation (process or product, the imitation or improvement of an available variety or the creation of a new variety, brought about by market forces or technological advance, etc.). The article also compares commercial performance in terms of total sales and exports. Because performance figures for innovations were requested and reported in large interval ranges (0-10%, 10-30%, 30-70% and above), the authors use maximum likelihood estimation of an ordered probit model to analyze the data. They find that the proportion of innovative products is lower for exports than for total sales, but that the innovative *content* of exported products is higher. In addition, innovations in the form of product imitation or improvement only perform well commercially in sectors in which the level of technological opportunity is low, whereas completely new products perform better commercially in sectors in which the level of technological opportunity is high. With the diffusion of the Innovation Surveys across countries, this type of study should facilitate international comparisons for the purpose of examining differences among the various measures of the commercial success of innovations, interpreting more effectively the results of such analyses, and testing their reliability.

Celia COSTA CABRAL, Praveen KUJAL and Emmanuel PETRAKIS *(Incentives for Cost Reducing Innovations under Quantitative Import Restraints)* examine the question of whether the existence of import quotas or voluntary export restrictions leads to an increase or reduction of incentives for cost-reducing R&D. They continue the work of Reitzes (1991) by studying the question within the framework of a differentiated product model. They demonstrate that the effect of the quotas varies depending on how restrictive they are relative to unrestricted trade, and on whether one is assessing the effect on a company in the country which fixes the quota (the domestic company) or the effect on a rival company in the country on which the quota is imposed (the foreign company). The main conclusion is that there exists a threshold effect. If quotas are not excessively restrictive, the domestic company reduces its R&D expenditure, whereas the foreign company increases its R&D expenditure. Highly restrictive quotas have the opposite effect. This conclusion weakens the «infant industry» argument on which protectionist commercial policy is based: fixing import quotas does not encourage the protected company to build up a competitive long-term advantage, unless the quotas are very high.

In his article *(The Size Distribution of Profits from Innovation)*, F. M. SCHERER attempts to ascertain the *ex post* distribution function for the profits resulting from technological innovations, and more precisely, to assess the degree of asymmetry in this distribution. The question is important for two reasons. First, on the statistical level, some early data suggested that moments of order one and two of the data generating process may not be finite, and therefore conventional central limit theorem properties may not hold, implying that asymptotic values may not be approximated more closely as larger samples are drawn. For example, this phenomenon would occur if the underlying distribution were Pareto and the estimated slope coefficient of the log cumulative distribution were less than unity in absolute value. Second, from an economic standpoint, the more skewed the distribution, the more difficult it is to form a varied portfolio of research projects or patents with a moderate and predictable variance, which would complicate the financing of innovative activities, since investors might find it difficult to reduce their risk enough through diversification.

To estimate the distribution of innovation outcomes, Scherer uses a variety of sources, including patent portfolios of American universities, profits realized by approved pharmaceutical products, stock market yields for newly established hi-tech companies, and a cohort of German patents that were regularly renewed until expiration. He finds that the Pareto distribution does not typically provide the best fit. The less skewed log normal distribution appears to fit the data better. More skewness is evident for distributions of individual patent values than for whole innovations or firms (both of which may entail multiple patents). Nevertheless, the similarity of the distribution outcomes across different samples and measures of innovative output seems to indicate that analogous stochastic processes underlie the generation of innovation profits. An interesting avenue for future research is opened up by these findings.

7. Spillovers

The final heading grouping together the articles in this issue concerns the **measurement of spillovers** from the dissemination of knowledge, or research and innovation spillovers, which are known to play a crucial role in the analysis of the economics of innovation. The existence of research spillovers implies that there is a difference or wedge between profitability or the private returns on research and the social returns on the research. These spillovers generally being positive (unlike, for example, pollution spillovers), the private returns are lower than the social returns. This may cause an insufficient level of private investment in research from the collective or societal point of view and is the major justification for intervention by public authorities not only through the patent system but also through public research programs, financial assistance and subsidies, tax incentives, and so forth. In principle, the degree of state intervention should be related to the degree of research spillovers and to the insufficiency of appropriation mechanisms for knowledge and innovation. This is particularly true when spillovers cannot be internalized privately within institutions or within the existing economic system. The latter characteristic may especially be the case for fundamental research, and whether it has a purely scientific purpose or is application-based, whether it is original research or an adjunct to already established programs. Such research pursues non-commercial interests (or those which are only partly commercial, more frequently in medium- and long-term projects rather than short-term projects), and the conditions for its success are relatively uncertain.

Understanding these features of scientific research make it easier to understand the economic importance of public management of research spillovers. It is extremely difficult to assess these spillovers, in terms not only of prospective assessment, but also of their retrospective assessment. Econometricians have only been working in this field recently, and their early research has produced results which are still rather fragile on the whole. Among the range of questions concerning spillovers, two recent issues are considered here:

- *the assessment of knowledge spillovers between countries, and comparison with spillovers within given countries;*

- *the analysis of policies toward competition, coordination or cooperation among companies doing R&D in the presence of spillovers.*

In his article *(Looking for International Knowledge Spillovers: A Review of the Literature with Suggestions for New Approaches)* Lee BRANSTETTER provides a critical review of empirical studies assessing international knowledge spillovers. He calls upon the theoretical contributions of Grossman and Helpman (1991), showing the structuring role of spillovers in international exchanges and the possibility for several long-term equilibria. The establishment of these equilibria depends on the initial situations of the countries, though it must be added that spillovers within countries dominate spillovers among countries. He also evokes the important distinction, developed notably by Griliches (1978, 1992), between pecuniary spillovers, linked to the exchange of goods in the marketplace and dependent on the pricing system for such goods, and non-pecuniary spillovers, linked to «intangible» exchanges (the dissemination of knowledge) and independent of the pricing of market goods.[29]

Branstetter then presents the methods and models implemented by econometricians to assess the effective importance of spillovers. The principal model used is the production function model, where production is increased by internal research capital for the company or the sector, and by research capital external to the company or sector. This external research capital can itself be divided into research capital within sectors or within countries, and research capital among sectors or countries. Internal research capital is measured by the cumulative sum of past R&D investments by the company or sector, usually depreciated with a constant depreciation rate (often in the region of 15%). The various components of external capital are measured as the weighted sums of capital of other companies, other sectors, of the country or of other countries. In principle, the weights are chosen to reflect technological proximity between the research fields of other companies and those of the company under consideration, or between those of other sectors and those of the sector under consideration. The closer the technological proximity among companies or sectors, the greater the probability of spillovers. The choice of weighting may also be based on other considerations. For example, for calculating international research capital, levels proportionate to the volume of trade for the sectors and countries under consideration are often chosen. This was done notably by Coe and Helpman (1995) in a frequently quoted article, in which the two authors find a high level of international research spillovers. In the last two parts of his contribution, Branstetter presents this article in detail alongside the criticism it provoked, notably from Keller (1996), and then summarizes his own results concerning research spillovers in the United States, in Japan, and between the two countries. Keller showed that Coe and Helpman's results persist and are even improved by random choice of the weights used to measure international research capital variables, thus casting serious doubt on whether their results are indeed due to direct spillovers.

On the basis of two panels of high-tech companies in the United States and Japan, for which R&D and patent behavior is known, and drawing heavily upon Jaffe (1986), Branstetter obtains estimates showing that spillovers within countries are higher than spillovers among countries. These last spillovers prove not to be statistically significant. The author concludes his review by highlighting both the difficulties inherent in econometric studies attempting to evaluate spillovers and the necessity for such studies.

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[29] Pecuniary spillovers result when the benefits of quality-improving innovations are passed onto buyers in the form of lower prices rather than being captured by the seller. That is, they typically reflect a fairly competitive post-innovation environment in an industry. A good example is the market for peronal computer components such as disk drives, where innovation has lead largely to lower prices for higher densities and speed rather than high margins for the manufacturers.

Jeffrey BERNSTEIN (*Factor Intensities, Rates of Return, and International R&D Spillovers: The Case of Canadian and US. Industries*) seeks to estimate private and social returns on R&D in eleven manufacturing industries in Canada and the United States, and research spillovers among industries (in a single country) and among countries (between Canada and the United States for a single industry). He works on aggregate annual data for the eleven industries and the two countries, over the period 1962-1989, and he estimates a system of factor demand equations (four equations for physical capital and research capital, labor and intermediate consumption) rather than a production function. He finds that the social returns to R&D in the two countries are distinctly higher than private returns, due to significant positive spillovers. As expected, domestic spillovers are predominant in the case of the United States, while for Canada, the reverse is true: spillovers originating in their powerful neighbor prevail over home-grown spillovers. One of the conclusions of the study is thus that R&D investment may be too low from a social point of view in both countries. Another is that research coordination and cooperation are of great importance, and that information and knowledge dissemination networks between Canada and the United States possibly ought to be developed beyond mere commercial exchanges and agreements.

Henri CAPRON and Michele CINCERA (*Exploring the Spillover Impact on Productivity of World-Wide Manufacturing Firms*) constructed a panel of 625 major manufacturing firms with substantial research activities for the period 1987-1994. These companies, for the most part American (378), Japanese (133) and European (101), account for some 30-50% of the R&D expenditure in their respective countries, in the United States, in Japan and in Europe.[30] For this sample they obtain estimates of the elasticity of sales with respect to internal research capital that is highly significant and higher than the figures for most previous studies (including for the temporal dimension). Their estimates of the external capital elasticity are comparable to those of several recent studies, notably Jaffe (1986) and Branstetter (in the present issue). Spillovers are deemed to be mostly intra-national for the United States and international for Japan. They appear to be much lower (and not significant) for Europe. However, the authors conclude by emphasizing the fragile nature of their estimates and the difficulties that must be faced when attempting the econometric assessment of spillovers in general.

In their article *(Innovation Spillovers and Technology Policy)*, KATSOULACOS and ULPH undertake to show how knowledge dissemination spillovers affect the levels of research in companies. Unlike most microeconomic work devoted to the subject, this article adopts an approach which considers that these dissemination spillovers are endogenous variables, i.e., variables resulting from strategic choices on the part of the companies rather than exogenous parameters outside their control. Taking as a starting point the model of d'Aspremont and Jacquemin (1985), which gave rise to much research on the ownership of cooperative and non-cooperative research in the presence of spillovers, the authors present two important distinctions. The first emphasizes the differences among three strategies: information sharing, research coordination, and cooperation. In the case of information sharing, companies commit themselves independently to research activities by determining the corresponding investment expenditure and then, according to the results obtained, deciding on the amount of information they wish to share. When research is coordinated, the timing of the decisions is reversed, with the level of spillover being decided before the R&D levels. Finally, cooperation consists in

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[30] Most of these companies engage in multinational activities, and the variables of the study (sales, staffing levels, R&D, etc.) cover all of these activities, not simply domestic operations. For the companies in their sample, the authors also matched data relating to the number of European patents registered by major technological field (there are 50 such fields). On this basis they could construct indicators of technological proximity enabling them to assess external national and international research capital. Following Jaffe (1986), they consider 18 relatively homogeneous technological groupings based on several classification methods, and construct four external research stock packages, introducing a distinction between local (technological sector-specific) stock (national and international) and strictly external (to the technological sector) stock (national and international). The local national stock for a company may, for example, be obtained as the weighted sum of past R&D expenditure of the companies of a given country belonging to a given technological grouping, etc.

choosing jointly the whole set of variables. The second distinction relates to the nature of the products on which research is carried out. According to whether the products are independent, substitutable or complementary, the motivation for choosing the methods of sharing, coordination or cooperation differ. By adopting the traditional social surplus as a welfare criterion, the authors discuss the relevance of technological subsidy policy for research activities in each of the cases studied. This work is thus both a useful clarification of the many methods of cooperative research in the presence of spillovers and a decision-making tool for state intervention concerning the formation of joint ventures.

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On perusing this overview of the presentation of recent developments in the economics and econometrics of innovation, and more specifically of the way the articles in this special issue contribute to the field, the reader will perhaps share the twofold feelings of the editors.

The first perception is that the economic analysis of innovation has many facets that are difficult to enumerate, given the degree to which the appropriate methodologies shatter the traditional boundaries of economic analysis and create close interdependence among fields within the discipline that are normally considered separate. The boundaries between microeconomics and macroeconomics are becoming blurred, and substantial links are being established among growth theories, the economics of labor, the economics of science and research, the analysis of methods of apprenticeship through experience, the study of dissemination and diffusion processes, competition analysis, the study of incentives and ownership rights, the management and organization of companies, the financial environment, the legal framework, the social structure, the intervention of state authorities, international trade and many other fields within economics.

The second feeling, a corollary of the first, is that investigative methods have themselves received benefits from this widening of perspective. The economics and econometrics of innovation should no longer be perceived as distinct and separate fields of investigation, but rather as complementary means of analyzing the same issues. While people's specializations naturally make them inclined to choose the approach in which they have, comparatively, the greatest advantage, a dialog has definitely begun. New databases, frequently qualitative, are now available and new empirical investigation methods are being perfected. The economic importance of innovation is such that theoretical and empirical studies come together on many issues. Has it been possible to achieve unified representation? Not yet, and probably never. However, the editors do hope that this volume, while demonstrating the diversity and wealth of a flourishing field, has contributed to the case for integration and dialogue among those engaged in different approaches to the problem.

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