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In Search of a Useful Measure of Technological Innovation (to Make Economists Happy without Discontenting Technologists)*

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ABSTRACT

This article presents an exploration of the methodology and measurement of technological innovation. It is based upon already available surveys and especially upon the SPRU data bank of innovations in Britain. The methodology proposed could be applied to the joint CNR-ISTAT survey being carried out on innovation diffusion in the Italian manufacturing industry. It is suggested that the empirical investigations already available or in progress should be exploited in order to develop a satisfactory theory of technological innovation. The article is also a contribution to the OECD move debate in order to reach an international standardization of methodologies and classifications of innovative activity.

The author introduces a distinction between the *objects* and the *subjects* of technological change, and on this basis he makes a comparison between the two approaches, which emphasize alternatively "evolutionary" or "revolutionary" characteristics of technological change. It is argued that many of the present-day controversies arise from misunderstandings between those working in this field on the concepts and measurement methods employed. As a consequence, the debate has been continuing on different and noncomparable topics.

It is argued that a standardization and a more accurate methodological precision on measuring technological innovation could have the salutory effect of removing the suspicion of heresy, which has so far kept the economics of technological change out of thoroughbred economic theory.

> It would be absolutely superfluous to state the nature and number of the advantages of an instrument so excellent for the observation on both land and sea. But, leaving aside earthly considerations, I turned to heavenly speculation; and clearly saw the moon as near as though but two earthly radii distant. After this, to my spirit's incredible delight, I many times observed both the fixed and wandering stars. Since I saw they were very thick, I began to study a way to measure their distances, which I finally found. On this point it is well that all those wishing to devote themselves to similar observations should be forewarned. In the first place, it is necessary to prepare a most accurate telescope, which represents the objects clearly and distinctly, not covered by any haze, [. . .] in fact, if the instrument is not so, one will try in vain to see all the things I saw in the heavens.
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> Galileo Galilei, *Sidereus Nuncius* (1610)

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1. Premise

This article is intended as a contribution to the definition of a conceptual framework for the measurement, the determinants and the impact of technological innovation.[1] Innovation is, in fact, commonly regarded by all schools of thought as the basic phenomenon of economic development. In more specific spheres, innovative activity is understood as the causative variable of productivity growth [54], of the volumes of international trade [48], of product competitivity [6, 30], of countries' growth differentials [12, 43], or even of the dynamism of social systems [38, 63].

However, the unanimity with which its importance is recognized is not matched by adequate development in methods for its measurement. The methods for measuring technological innovation are, in fact, more rudimentary than for other aspects of economic and social life, such as production, employment, and investment.

This is also due to the fact that the innovative process is difficult to define and measure. Innovations are made up of multifarious elements, sometimes tangible but very often intangible. Even less tangible is the measurement of technological capacity, which often has to be defined in terms of "tacit knowledge" [47], or assessed with approximate yardsticks, such as the workers' educational level, which lie out side the core of economic variables. The various attempts to define and measure the determinants and impact of technological innovation have constantly run up against conceptual problems or problems of empirical monitoring. This is probably one of the reasons the study of technological innovation has been confined to the "underworld of the heretics" of economic science. Innovation has often been considered a problem relevant to engineers and technologists rather than economists. The hypothesis underlying this essay is that many of the difficulties involved in giving a satisfactory scientific stature to the economics of technological change arise from the difficulties in offering satisfactory methods of measurement and that only by perfecting the latter will it be possible to attain full recognition as a part of economic science.

2. From Which Viewpoint Should Innovation Be Measured?

Few economists have emphasized the importance of inventive and innovative activity in economic life as much as Joseph Schumpeter. In one of the most significant pages of his *Theory of Economic Development,* he distinguishes five types of innovation:

> 1. The introduction of a new good—that is one with which consumers are not yet familiar—or of a new quality of a good.
>
> 2. The introduction of a new method of production, i.e., one not yet tested by experience in the branch of manufacture concerned, which need by no means to be founded upon a new scientific discovery and can also exist in a new way of handling a commodity commercially.
>
> 3. The opening of a new market, i.e., a market into which the particular branch of manufacture of the country in question has not previously entered, whether or not this market has existed before.
>
> 4. The conquest of a new source of supply of raw materials or half-manufactured goods, again irrespective whether this source already exists or whether it has first to be created.

[1]The following definitions will be employed: following Schumpeter [62], *invention* is to be understood as an idea potentially open to commercial exploitation but not necessarily concretely realized; *innovation* is used as the commercial introduction of a new or better product or as the application of a new and better productive process; *technological capacity* is used as the accumulated knowledge on methods of production; *technological change* is used as the temporal evolution of the productive techniques employed; and *research and development* (R&D) is used as the complex of scientific and technical activities financed and/or carried out both by commercial organizations and public bodies and institutions. Such activities are closely connected with technological innovation but do not represent its entirety.

5. The carrying out of a new organization of any industry, like the creation of a monopoly position (e.g., through trustification) or the breaking up of a monopoly position. [61, p. 66]

This article will only deal with the technological innovations proper, i.e., those classified by Schumpeter in points 1 and 2 and corresponding respectively, in current terminology, to product and process innovations *from the viewpoint of the firm effecting the innovation*.

On the surface, the monitoring of technological innovation does not seem to present any difficulties. The definition of general criteria for the novelty of certain productive proceedings should suffice to distinguish what is innovative from what is not [7]. However, even though individual innovations can be identified with the same facility with which, e.g., we gauge employment figures, it becames far more difficult to define the modalities of aggregation.

Probably the most significant contribution in the field of the measurement and classification of innovation has come from the Science Policy Research Unit of Sussex University [68]. In this investigation, which will subsequently be dealt with in greater detail, each single innovation considered is classified on the basis of three different criteria:

1. *The "technological" group the innovation belongs to*. Homogeneous innovations based on technical and engineering characteristics are grouped in technological categories. In other words, innovations in such technologies as "chemicals," "electronics," "pharmaceuticals," etc., are grouped together. This classification regards *objects*.

2. The prevalent economic activity of the body producing the innovation, which I shall call the *sector of activity of the producing body* (or sector of production). In the case of firms, the activity of the producing body is equivalent to the branch of main economic activity. This second criterion demands the presence of a *subject* to promote the innovation, be it a firm, a government body, a commercial, or a nonprofit institution. While criterion 1 monitors the innovation's "technological group," and hence its object, criterion 2 monitors that of its economic subject.

3. The sector of the utilization of the innovation, understood as the sector of the *first* application of the innovation. Here too, as in point 2, the economic subjects of innovation are considered. However, while point 2 classifies their sector of origin, this criterion classifies their sector of utilization.[2]

The three types of innovation classification may coincide for some innovations, e.g., a chemical process produced by a chemical firm and used by the same firm or others in the chemical industry. In other cases, they may be different, e.g., a coffee machine (under the first criterion, the technological group is that of "machinery") produced by an automobile firm (under the second, the production sector is that of "means of transport") and used in restaurants (under the third, the utilization sector is that of "catering").

It is not always easy to classify each individual innovation on the basis of all three points, and conceptual and monitoring problems arise. Criterion 1 presents considerable difficulties at high levels of breakdown. It is, e.g., hard to distinguish on purely technological grounds certain chemical products and processes from pharmaceutical products and processes. If we restricted ourselves to the analysis of chemical formulae, we would

[2]Strictly speaking, a fourth criterion of classification should also be considered, i.e., the product group in which the innovation is utilized. In other words, two classifications should be considered for the utilization of innovations (one for subjects and one for objects), just as there are two for the production of innovations. But the differences between object and subject in the utilization of innovations are less relevant than in production. While losing little from an analytical point of view, this simplification is of great help in making the system of measurement of innovation described here comprehensible and usable in practice.

often find great similarities between the technological characteristics of chemical and pharmaceutical products and processes. A satisfactory classification from the technological viewpoint must therefore also bear in mind criterion 2, i.e., the type of bodies promoting the innovation, such as clinical laboratories or chemical companies, and criterion 3, i.e., the sectors the innovation is utilized in, such as hospitals or agricultural companies, etc.

Problems of a different nature arise in grouping producing and using sectors of innovation. In the first place, it must be remembered that technological change in industrialized countries is produced both by firms and by government bodies and universities. All too often, the economics of innovation considers only the industrial sector and, more specifically, the sector of manufacturing. It is, in fact, difficult to find classifications at the same level of breakdown for both firms and government bodies. Consequently, the role played in the inventive and innovative process by government research bodies and universities is often overlooked.

As regards firms, it is necessary to decide whether to monitor innovations on the level of individual productive units (divisions) or on the level of industrial groups (corporations). This problem becomes particularly relevant when one considers branches of multinational companies. According to the decision that is made, the results of analysis can present considerable differences, especially with regard to the relationship between innovation and firm size.

Finally, we should not consider a *single* sector of utilization under the third criterion. Economic analysis is, in fact, concerned not solely with the first sector to use certain innovations, but also with the diffusion of the innovation into other sectors in the course of time. One of the characteristics of technological innovation is precisely that of penetrating into a number of utilization sectors, often quite independently of the sectors producing the technology. Even when the first sector of utilization is identified, there is no certainty that this is the main utilization sector. Anyone can find examples of innovation that has proved of decisive importance in a different sector from that for which it was conceived.[3] This analytic schema gives more weight to the generation than to the diffusion.

It is certainly a limitation of this approach to present the generation and diffusion of the innovative process as two separate stages. But, it is relevant to stress that while the diffusion process is by definition a temporal one, the classification of innovations proposed here is centered more on cross-sectoral differences. We do believe that the classification adopted here has also some important consequences for the analysis of innovation diffusion, although we will not explore these implications here.

In the case of many finished products, it is by definition impossible to determine a single sector of utilization. Take the case, e.g., of a ball-point pen or a car jack. The fact that finished products are also used as intermediate products increases rather than decreases the difficulty of determination. In many cases, the advantage deriving from an innovation are enjoyed by the consumer as well as by the firm and the public body: Everyone is grateful for the invention of air-conditioning. In other cases, they benefit all industries and consumers to practically the same extent, as in the case of the photocopier.

More direct relations between firms are established as a rule in the case of intermediate products, thus creating the ties between producers of innovation and sector of utilization brought out by many case studies. It is, however, also difficult to identify a sole, or main, utilization sector for some innovations connected with intermediate products.

Moreover, the existence of a sector of utilization still says little about the role played

[3]The gunpowder used in China for fireworks underwent a very different diffusion in the Western world, etc.

by the innovation in question. An innovation used by all the firms in a single industry has a more important impact than an innovation used in only a few firms, even if they belong to different sectors.

Many similar problems are encountered in the measurement of innovative activity. However, if we were put off by the difficulties, we would have to study technological change solely in historical and qualitative terms, i.e., methodologies with which thoroughbred economists have never been too happy. Thus, if the study of technological change is to be brought out of the heretics' underworld, it is necessary to roll up our sleeves and get down to studying innovations *also* in the quantitative dimension of change.

The problems regarding classification are, in fact, common to every such attempt and, at the cost of some simplification, make it possible to create a classification grid for each individual innovation. On the bases of the criteria illustrated above, each innovation **inn n** monitored can be distinguished by three references j, i, and k, referring respectively to the technology forming the innovation, the activity of the producing body and the sector of first utilization:

$$\textbf{inn n}_{j,i,k}$$

Let us hypothesize that for each individual innovation, each of the three characteristics is registered on the basis of the same classification. For example, the SPRU data bank uses the Standard Industrial Classification (SIC) for all the three criteria. We will therefore have the same classification where: $j = 1,2 \ldots, n$; $i = 1,2 \ldots, n$; $k = 1,2 \ldots, n$. This will give us a frame of reference for the insertion of the single innovations registered similar to a cube, since the number of the js is equal to the number of is and ks (Figure 1). Each square of the cube **INN** will contain a specific number of innovations with a common technological group, sector of activity of the producing body and sector of main utilization:

$$\textbf{INN}_{j,i,k} = \textbf{inn1}_{j,i,k} + \textbf{inn2}_{j,i,k} + \ldots + \textbf{inn n}_{j,i,k} \qquad (1)$$

This cube makes it possible to solve a large number of problems regarding the measurement of innovation. The cube may be broken down into three square matrices **A, B,** and **C** (Figures 2–4), which will, for the sake of convenience, be referred to in the following.

Matrix **A** registers innovations in terms of technological group and sector of the activity of the producing body. The rows of the matrix show how industries distribute the innovations created by them among the various technological groups. The columns show how the production of innovations of each technological group is distributed among the various industries.

The information necessary to construct this matrix is available through the SPRU data bank. This matrix has been constructed for Italy, with different methodologies and statistical sources, by Bisogno and Di Palma [4] and by the author [2]. Bisogno and Di Palma dealt with the expenditure on research and development (R&D) broken down into sectors of origin and fields of research and thus identified the distribution of research fields among the various sectors of origin. Among the merits of this analysis is the fact that a breakdown of data is given for the public and private sectors on the one hand, and for basic and applied research on the other. Unfortunately, the data considered are from 1965.

Substantially analogous is a matrix using patents as proxy measure of innovation

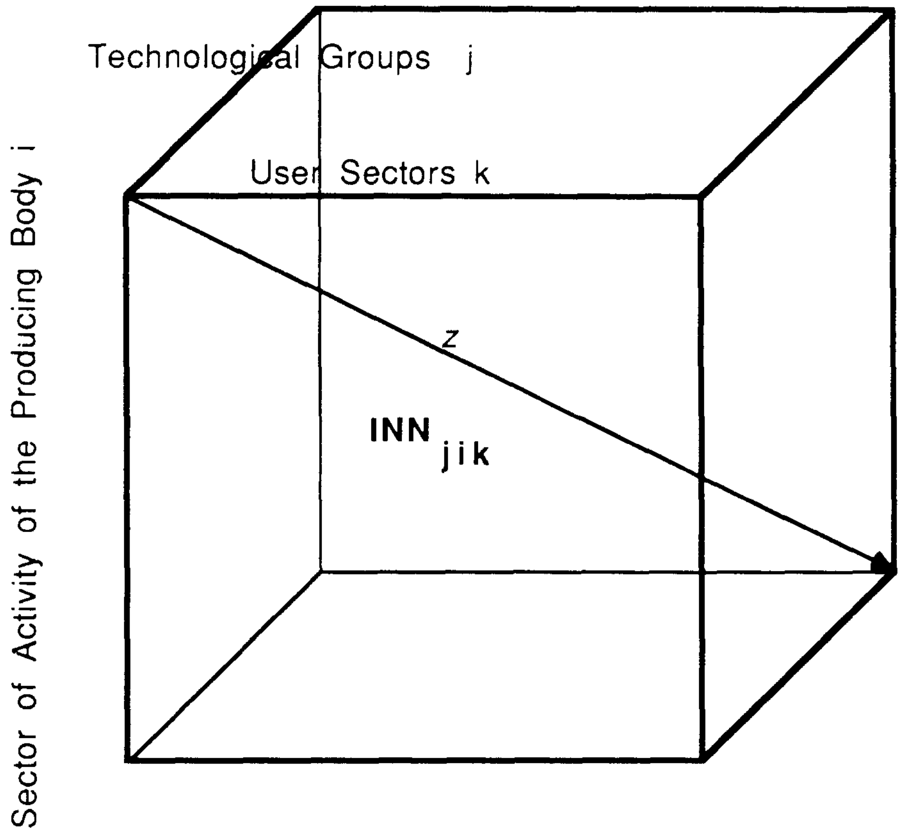

Fig. 1. Classification of innovations according to three criteria.

[2]. This matrix considers the sector of activity of the firm to which the patent is issued and the technological content of the patent itself. It was thus possible, for example, to establish that a very high percentage of the innovations produced by the automobile industry relates to robots and machine tools. The same study revealed that the greatest number of innovations produced by Italy in bioengineering stem from the fuel industry.

Matrix **B** registers innovations on the basis of technological groups and sectors of utilization. It is therefore analogous as regards technology to an input–output table. The rows subdivide the innovations used by industries among technological groups. The columns subdivide the utilization of the innovations of each technological group among the various industries. Applications of this matrix have been made by Scherer [56–58] for the United States and by Robson et al. [49] and Soete [66] for the United Kingdom. Soete was able to give a quantitative dimension to known facts, such as the very strong dependence of the textile industry upon the technology of textile machinery. Scherer's analysis indicates the extent to which the various industries use the technology of, e.g., scientific instruments.

Let us have a close look at these studies. Scherer presents a matrix of technology flows in the United States in 1974. As a proxy measure of innovative activity, Scherer considers the R&D financed by the 443 largest firms in the United States. The sectors of utilization are identified on the basis of the patents issued to the firms themselves. This methodology has some limitations; in the first place, it assumes that R&D represents

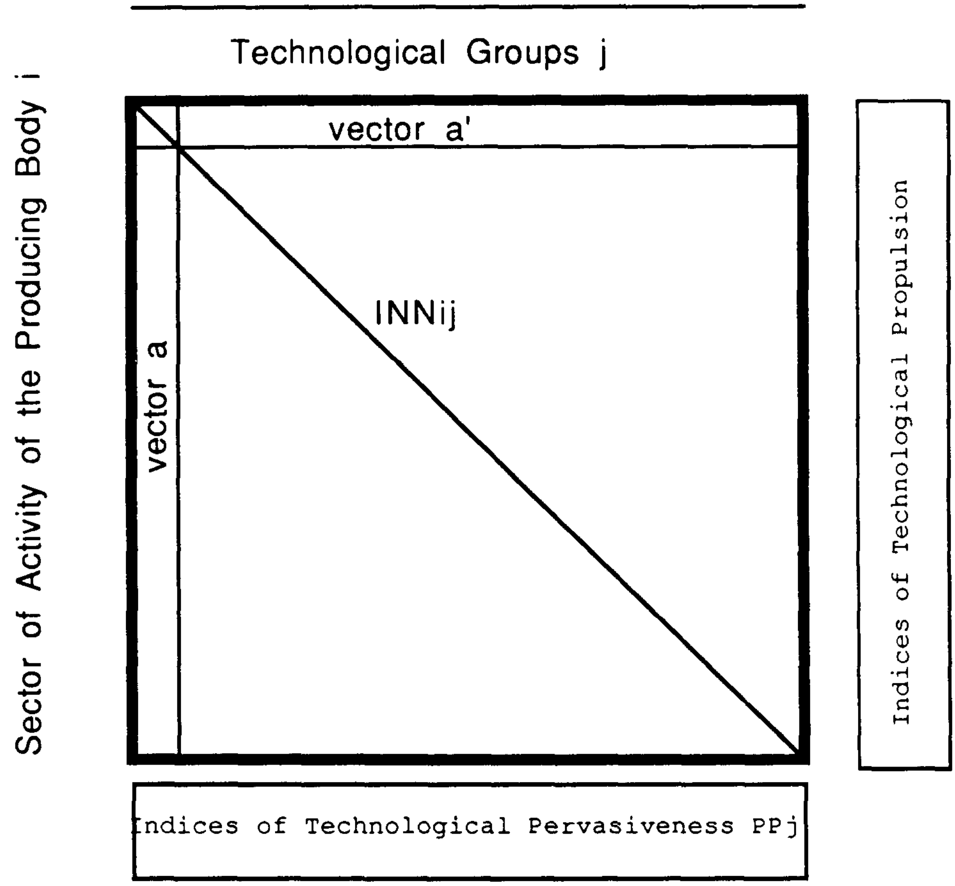

Fig. 2. Matrix A: Technological groups by sector of activity of the producing body.

the whole of innovative activity; in the second place, it fails to take into account the innovative activity of small and medium-sized firms.

Nevertheless, Scherer's contribution has some considerable advantages, including the fact that the data presented are available in monetary units (U.S. dollars). This eliminates the problem of the different commercial value of individual innovations, and the technology flows are, in fact, measured directly in money terms.

Since it uses data on R&D expenditure, Scherer's matrix does not make it possible to distinguish between incremental and radical innovations. However, since it considers R&D flows relative to a single year, it is reasonable to consider the innovations as largely incremental in character.

Analogous in aim are the analyses of Soete [66] and Robson et al. [49], which were carried out with the SPRU data bank. The information gathered refers to over 4,000 significant innovations introduced in Great Britain from 1945 to the present day. The statistical sources of Scherer and the SPRU differ considerably: The former refer to the United States and the latter to Great Britain; the former are based on incremental innovations and the latter on radical ones; the former refer to a single year, the latter to almost 40 years.

Matrix C registers innovations in terms of sector of activity of the producing body

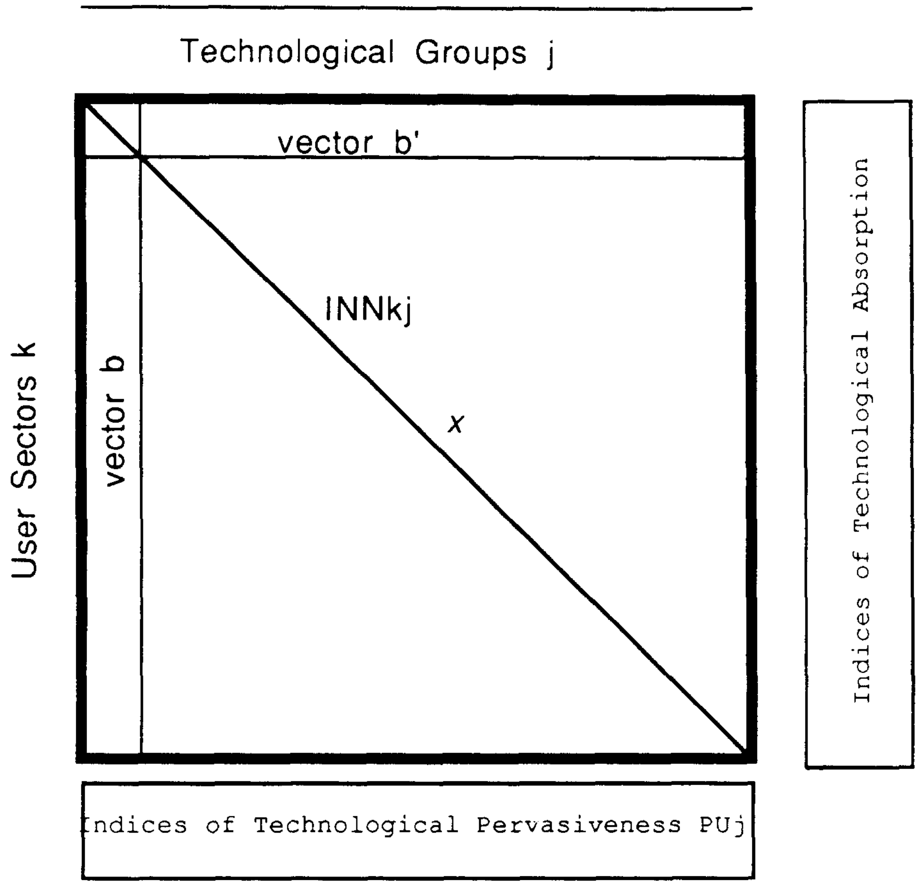

Fig. 3. Matrix B: Technological groups by user sectors.

and sector of utilization. The rows show the industries to which a given industry transfers technology. The columns show the industries from which a given industry acquires technology. Matrices similar to **C** are those presented by Séguin Dulude [64] and by the *Financial Times*. Séguin Dulude's matrix is constructed on the basis of patents issued in Canada. She considers the sector of economic activity of the firms to which the patent is issued and the sector of utilization of the patent itself. This analysis shows, e.g., that a third of the innovations utilized in the textile industry are produced in firms producing machinery. The *Financial Times* (the data are given in Freeman and Soete [17] and in Soete [66]) instead classifies technological agreements between firms that have been made known to the press. From the data given, e.g., it transpires that the innovations produced by firms belonging to the industries of agricultural machinery are used half in agriculture and half in the mining sector.

3. A Taxonomy of Innovations

The method of classification described implicitly assumes that all innovations have the same technological and economic relevance, a simplification that obviously does not correspond to reality. Every single innovation has, in fact, a different technological, economic, and commercial value. Furthermore, it frequently happens that the technological and economic values of an innovation fail to coincide.

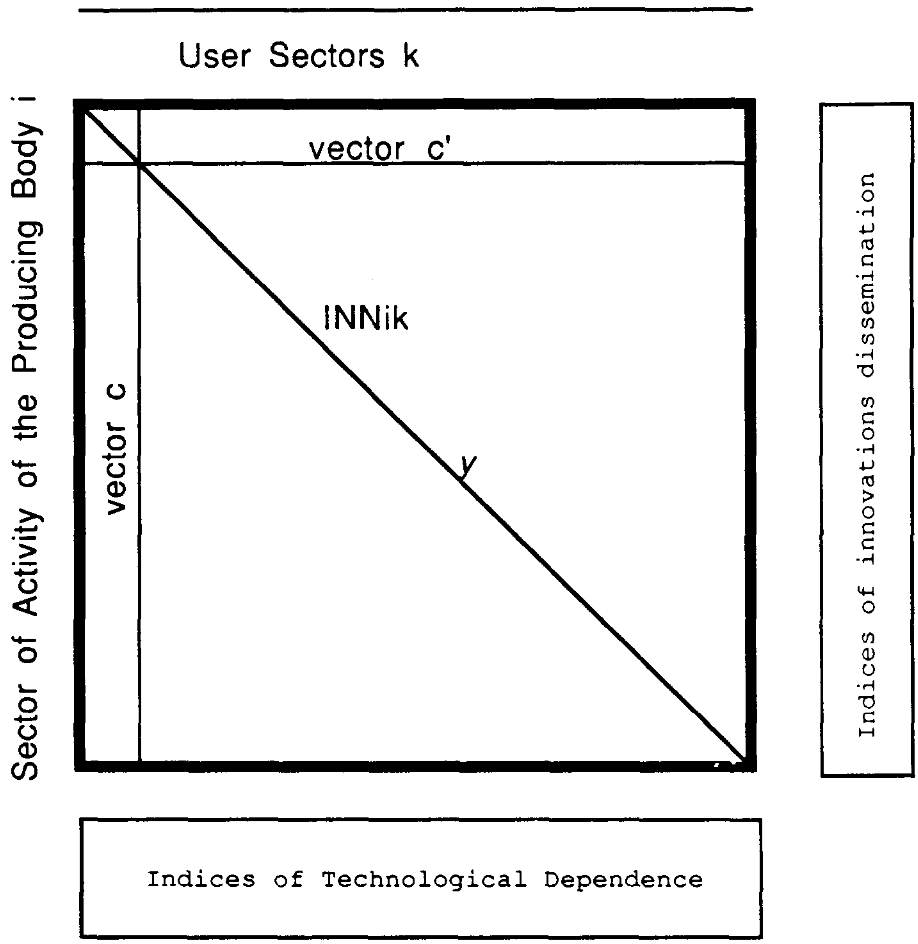

Fig. 4. Matrix C: Producer sectors by user sectors.

There have been many attempts to assess individual innovations on the technical and engineering bases (for an excellent summary of this approach, cf. Sahal [52]; cf. also Saviotti and Metcalfe [55]). The aim of such analyses is to provide a more rigorous measurement and evaluation of the innovative activity—already undertaken or to be started—on specific products and research projects. They make it possible, e.g., to compare the performance of tractors on the basis of such parameters as fuel consumption, speed, traction force, and so on, i.e., an exclusively sectoral approach and one that does not allow analysis of the interindustrial and macroeconomic dynamics of technological change.

On the other hand, the taxonomy of innovations proposed by Freeman [14] and Freeman and Perez [16] has a more strictly economic profile. Freeman distinguishes four types of innovation, descriptions of which follows.

INCREMENTAL INNOVATIONS

Incremental innovations follow each other continually and, however they might vary in the rate and direction, constitute the permanent basis of the innovative process. None of these innovations is capable of substantially modifying the economic dynamics, even if, when they are taken as a whole, they can have a considerable effect on productivity growth and on economic development. Examples of these innovations are those devised to reduce automobile fuel consumption.

RADICAL INNOVATIONS

Unlike incremental innovations, radical innovations are not uniformly distributed in time. They do, however, arise frequently and tend to shift from one technological group to another. They consist both in capital goods, such as numerical control machines, and consumer goods, such as the television.

NEW TECHNOLOGICAL SYSTEMS

This type of innovation has pervasive influence on the economic system and modifies the conditions of production not only in the principal sectors of production and utilization, but also in many other industrial and service sectors. It is, in fact, no longer a matter of a single innovation, but of a number of innovations associated by their common technological basis. Examples of new technological systems are provided by innovations in the fields of synthetic materials or electrical household appliances.

TECHNOLOGICAL REVOLUTIONS

Finally, there is a fourth and still more substantial type of innovation, that which brings about changes in techno-economic paradigms and is associated with the major economic cycles. A case from the past is that of the steam engine; a more recent one is the conveyor belt. However, this type lies outside the scope of the present discussion.

To monitor innovative activity, it is therefore necessary that *one* of the definitions of innovation be taken as a unit of measure. As for new technological systems and technological revolutions, it is not possible to define them *ex ante,* since they can only be assessed on the basis of the economic effect taking place *ex post*. The economic impact of technological change is, in fact, shrouded in a mist of uncertainty, which becames thicker the nearer we approach to innovations of significant importance.

Neither can the scientific sophistication contained within individual innovations be taken as a criterion of economic reference. While there is reason to question the scientific value of the container, there is absolutely no doubt that it brought about a dramatic technological change in many industries. On other occasions, however, inventions of great scientific sophistication have brought about significant changes in the economic system, as in the case of chemistry innovations at the end of the nineteenth century.

It must be remembered that new technological systems and technological revolutions are in no case and in no way identified from the economic standpoint with a single innovation. They are, in fact, made up of a number of interconnected innovations. It is, therefore, a question of identifying them according to the classification of incremental or radical innovation. The cube system of measurement is thus suitable for identifying technological systems and revolutions on the basis of objective criteria, inasmuch as it allows the clustering of innovations in certain areas and sectors to be identified and, therefore, the technological systems and revolutions to be determined (see below).

The SPRU data bank has chosen *radical* innovations as its monitoring unit. While there are, for statistical reasons, practical limitations to the creation of a sufficiently wide sample, radical innovations do provide a more secure basis than incremental ones. However, where possible, the true unit of measurement at the basis of the cube should be innovations as such—and, therefore, predominantly the incremental. In fact, each radical innovation involves a number of minor innovations, and it is precisely the latter that enables us to analyse economic impact. The laser, e.g., is unquestionably a radical innovation. If, however, it were monitored just the once, its effect on many sectors of production and utilization would be missed. By monitoring instead *one* radical innovation together with several incremental innovations, we would be able to consider its applications, e.g., in the optical, pharmaceutical, textile, and other sectors.

4. On the Concept of Technological Pervasiveness

The classification of innovations described above makes it possible to define precisely the concept of technological pervasiveness, which recurs frequently in studies on technological change. On the historiographical level, e.g., Gille has attempted to reconstruct the *technical system* in various societies by examining the interconnections set up between available technologies and the methods of production adopted:

> It seemed to us that the concept of technical system, understood as a consistent complex of mutually compatible structures, should give an interesting picture of the material world of humanity from its origins, the material world of everyday life. [19]

Substantially analogous to the concept of technical system is the previously mentioned idea of *new technological systems* used by Freeman and his school:

> [Our] alternative theory places greater emphasis on the role of scientific discoveries, on the technical and social inter-relatedness of "families" of innovations and on the many follow-up innovations made during the diffusion period. We call these clusters "new technology systems," because although they are associated with the rapid growth of one or more new industries, they often also have wider effects on the industries and services. [15]

At the heart of their theory of technological change over the long period lies the *diffusion* of specific groups of innovations. However, unlike the traditional theory of diffusion, this approach stresses the fact that each new application of specific technological knowledge creates, explicitly or implicitly, an additional technological capacity. It is, therefore, not so much a question of considering a linear process of invention followed by innovation and finally diffusion, as of considering how the original innovations are transformed by economic agents in the process of diffusion.

The innovations on which attention is focused are those that, when diffused, generate new innovations. This apparently innocuous consideration is, in fact, a fundamental development of the Schumpeterian economics, as it takes us beyond a certain schematism present in Schumpeter's own original formulation. It should be remembered that significant innovations can generate innovations—or whole families of innovations—in very different technologies. For example, the invention of the internal combustion engine was followed by innovations in the fields of both transport and fuel.

This criterion does not consider only the "technological" power of single innovations but must also be linked to the possibility of penetrating the social and economic system. This explains, e.g., the crucial role Freeman attributes to the new information technologies based on microelectronics. Such technologies characterize a phase of development in that, unlike nuclear technology for example, they have a far wider range of applications.

It is therefore important to distinguish between two different types of pervasiveness:

The first type of pervasiveness has general economic effect via the reduction of major input costs. The example of energy supply is one of those. Surely, a dramatic change in energy costs due to the exploitation of new scientific discoveries would provoke an enormous amount of innovations in all the other industries. But that does not mean the development of "local" technological skills in the field of energy technologies. A traditional economic technique such as the input–output analysis is able to give account of the economic impact of this pervasiveness.

The second type of pervasiveness consists of the direct use by a certain industry of the innovative activity created in other technological areas. The economic impact of this technological change is much less visible in an input–output analysis, and it deserves the development of appropriate measurement tools.

If these evaluations are not to be wholly subjective, they require systems of measurement. The proposed classification of innovations makes it possible to analyse the concept of technological pervasiveness in two different ways. A given technology j may be more or less pervasive according to whether it is considered from the viewpoint of its production or of its utilization. The measurements of the two levels of pervasiveness often completely fail to coincide. For example, the technology of road vehicles is strongly concentrated among a handful of firms and has all the characteristics of a limited oligopoly. At the same time, however, it is one of the most pervasive from the point of view of utilization.

How does the three-dimensional analytic grid allow measurement of these two different levels of pervasiveness? We thus see that each technological innovation belonging to technological group j will have been promoted by one of the sectors of activity of the producing body i. Aggregation gives us the square matrix **A** of order $n \times n$ of the technological innovations for sectors of production (Figure 2). Application of Utton index [69] to each technological group gives an index of pervasiveness in production for each vector column of the matrix:

$$PP_j = 2*\Sigma_i\ i*\mathbf{r}_{ij} - 1 \qquad (2)$$

where $\mathbf{r}_{ij}$ is the relationship $\mathbf{INN}_{ij}/\Sigma_i\mathbf{INN}_{ij}$. and where the i sectors should be ordered according to the ranking of their shares. This index has the property of being equal to 1 if the innovations belonging to technology j are concentrated in a single sector of production, and of being equal to n if the innovations are equally distributed among all the industrial sectors considered, i.e., if the technology under consideration is pervasive to the highest degree. The range of variability of the index is therefore equal to $1 \leqslant PP_j \leqslant n$.

An index providing substantially the same results is constituted by the reciprocal of Herfindahl's index

$$HPP_j = 1/\Sigma_i\mathbf{r}_{ij}^2 \qquad (3)$$

where $\mathbf{r}_{ij}$ is the relationship $\mathbf{INN}_{ij}/\Sigma_i\mathbf{INN}_{ij}$.. Also, in this case, the range of the variability of the index is $1 \leqslant HPP_j \leqslant n$.

It is an obvious hypothesis that the pervasiveness of technological innovations in the nuclear sector is very low, and that the index will therefore approach unity in this technology. In other words, very few innovations in nuclear technology are produced by public or private bodies whose main concern is not the nuclear sector. On the other hand, the pervasiveness in the production of mechanical technologies is intuitively much higher. The results given by the PP_j and HPP_j indices provide some primary information as to the facility for entry (and readiness to enter) of producing sectors into determinate technological areas.

It is possible to construct a symmetrical index for the pervasiveness of utilization of specific technological capacities. In this case, the technological innovations $\mathbf{INN}_{kj}$ of the square matrix **B** of order $n \times n$ of the technologies for the sectors of utilization (Figure 3) provide for each row an index of pervasiveness in utilization equal to:

$$PU_j = 2*\Sigma_k\ i*\mathbf{r}_{kj} - 1 \qquad (4)$$

where $\mathbf{r}_{kj}$ is the relationship $\mathbf{INN}_{kj}/\Sigma_k\mathbf{INN}_{kj}$. and where the k sectors should be ordered according to the ranking of their shares. The index can vary between $1 \leqslant PU_j \leqslant n$.

In many cases, there will be considerable differences between the indices of pervasiveness in production PP_j and in utilization PU_j. A first approximation allows us to put forward the hypothesis that the indices of pervasiveness are generally higher if they are calculated in utilization rather than production. However, in this discussion it is not so important to propose a general hypothesis as it is to observe that considerable differences can be found between the two indices and that these differences are not uniform among the various technologies.

In extreme cases, where the pervasiveness of specific technological products assume high levels of concentration in production and levels of sustained pervasiveness in utilization, it comes about that intermediate filter structures are created to adapt technological capacity of user sectors to the rate of technological change of production sectors. In the case of automobile technology, e.g., a filter of technological capacity has been created that is represented by service structures, by mechanics, by motor vehicle electricians, by tire fitters, etc. Something similar to what happened in automobile technology is now taking place in computer technology: A rapid increase in pervasiveness in the sectors of utilization is being accompanied by the birth of a substantially oligopolistic producing structure together with a capillary network of services and technical support.

In the case of nuclear technology, however, something very different is taking place. The *results* of this technology are pervasive to the maximum degree, since all sectors are users of energy. However, given its intrinsic nature (i.e., plant costs), nuclear technology has not involved the birth of local transfer structures of technological capacity. It may, in fact, be questioned whether energy users really make use of nuclear technology. It seems more accurate to say that they consume the *products* of nuclear technology.

These measurement systems enable us to verify the existence of a technological system, since it is possible to identify those families of innovations that play the crucial role attributed to them. In other words, it is a question of establishing which technologies determine a particular phase variously defined in the literature as a "technological regime" [34, 35] a "technological system" [15], a "paradigm" [9], a "style" [46], and a "guidepost" [53]. The large number of metaphors used is probably an indication of the need to achieve a certain standardization on the unit of measure adopted, which will allow the technological direction undertaken by the innovative process to be defined on an objective base and not only on a terminological one.

These definitions refer in the first place to the relationship between the *technologies* available and their utilization. At this initial stage of discussion, it is not relevant which *bodies* determine and promote technological capacity and change so much as the nature and dissemination of the .echnology in question. In this sense, the identification of "technological regimes" should be made on the matrix B.

5. Producer and User Sectors

Patterns of production and use of innovations vary across industries both in intensity and direction. It has often been pointed out that there are industries that carry out the function of generating significant numbers of innovations used throughout the economic system (as in the scientific instrument industry), just as there are firms of some sectors that utilize innovations originating in all the technological sectors (e.g., aeronautics).

The system of measurement described enables us to calculate positions of industries systematically. In the first place, it makes it possible to identify which industries are *net* producers and users of innovative activity. Matrix **C,** in fact, indicates for each industry the difference between innovations produced and those utilized:

$$\mathrm{Dif}_i = \Sigma_i \mathbf{INN}_{ik} - \Sigma_k \mathbf{INN}_{ik} \qquad (5)$$

Naturally, the difference does not change if the innovations produced and utilized in the same sector are excluded from it, i.e., those for which $i = k$.

Matrix **C** also makes it possible to deduce the interconnections existing between industries. For example, the close links between the industry of textile machinery and that of textiles will be indicated by the fact that most of the innovations produced by textile machinery firms are utilized by textile firms. Matrix **C** also makes it possible to analyse for each sector those sectors from which it obtains and to which it supplies technology. The level of technological dependence of a sector of utilization k is measurable through the relationship between the innovations that the sector produces itself and the total number of innovations it uses:

$$\text{Dep}_k = \mathbf{INN}_{ik}/\Sigma_i\ \mathbf{INN}_{ik} \tag{6}$$

where Dep_k varies from 0 in the case of total technological dependence, to 1, in the case of total independence. For each sector of utilization k, i.e., for each vector column **c**, an index of concentration of technological dependence can be applied. One index is that of the concentration of dependence of sector k on the first m sectors of activity of producing bodies:

$$\text{Con Dep}_k = \Sigma_m\ \mathbf{INN}_{ik}. \tag{7}$$

Or an index taking into account the dependence of a sector of activity from all the sectors of production i, such as the Herfindahl index:

$$\text{HCon Dep}_k = \Sigma_i\ (\mathbf{INN}_{ik} \neq \Sigma_i\ \mathbf{INN}_{ik})^2 \tag{8}$$

What concerns the analysis of industrial innovation is not, in fact, only the existence of technological dependence, but the way in which this dependence is distributed among the various sectors. On the other hand, analysis of matrix **C** in vector columns furnishes indications of the part played by sector i in transferring innovations to other sectors (a full exploration of this suggestion is to be found in DeBresson [8]).

The classification of innovations described above is somewhat simplistic, since it somehow assumes that innovations are in the first place "produced," and in the second place "utilized." The reality of innovation is, in fact, much more complex. It is extremely difficult to determine how far the two aspects overlap. Full understanding of innovative activity therefore involves consideration of the interrelations existing between producers and users (cf. Rosenberg [50, 51]; von Hippel [70]; Ergas [11]; Lundvall [25]; Cesaratto [5]), which, however, calls for a detailed sectoral analysis. There is undoubtedly a considerable difference between innovations acquired directly on the market (i.e., wholly incorporated in produced goods) and those that are produced in response to specific requests.[4]

[4] It is important to note that a specific innovation may require the availability of very different technological capacity from the viewpoints of the producer and the user. In the case of the automobile, e.g., the user must be able to develop a specific technological capacity of his own, that of driving the car. A sustained rhythm of technological change cannot last without the creation of suitable technological capacity. Even without establishing one-way causal nexuses, a significant correspondence can be found historically between the rate of technological change and the creation of technological capacity. Of significance in this context are the predictions made at the beginning of this century, according to which the diffusion of automobiles would not be able to go beyond a certain quantitative level because of the impossibility of finding sufficient drivers. The prediction failed to take into account the fact that technological capacity could be created much faster than imagined, so much so that it was actually codified in legislation regarding the issue of driving licenses. It must also be noted that for neither a worker in the car industry nor an engineer involved in automobile design is the ability to drive indispensable. When one decides to measure innovations and technological capacity, one must be able to find a way to distinguish, at least conceptually, between the technological capacity required to produce specific innovations and that required to use them.

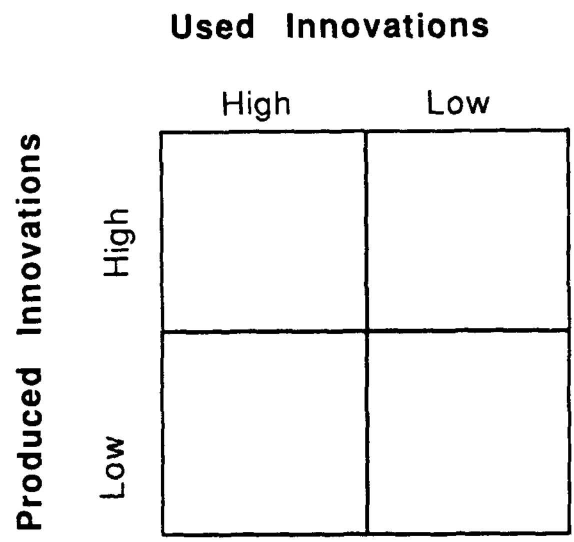

Fig. 5. Classification of industries by innovative intensity.

6. Sectoral Boundaries and Trajectories of Innovation

Simpler analysis of the interrelations between sectors, such as that considered in the preceding section, does not provide information as to the technological nature of the innovations produced and/or utilized in a specific sector. In order to identify the technological spheres in which the various industries operate, it is necessary to return to matrices **A** and **B**.

On the row vectors of matrices **A** and **B**, it is possible to calculate indices of distribution of technological capacity analogous to those of technological pervasiveness. The difference lies in the fact that, whereas the latter regarded the distribution of the innovations of a technological group among the various sectors, the former consider the distribution of the innovations of an industry among the various technological groups. The aim of this section is to conceptualize the measurement of distribution of innovations by industries across technological areas.

Matrix **B** will furnish information as to how variegated is the spectrum of the technological activities utilized in an industry. Vector **b**′ defines the *technological absorption* of a sector. Matrix **A**, on the other hand, will provide an analysis of the distribution on the innovations produced by the industries. Vector **a**′ defines the *technological propulsion* created by the industry. Vectors **b**′ and **a**′ provide indications of the extent of the *technological boundaries* of the various industries, i.e. to their capacity to receive and/or produce innovations of different technologies.

According to Nelson and Winter [34, 35], a technological regime defines the boundaries within a specific trajectory moves. Analysis of vectors **b**′ (matrix **B**) and **a**′ (matrix **A**) makes it possible to give a quantitative image of both the boundaries and the course of the completed trajectory. Moreover, they clearly establish that the boundaries and trajectories may be considered in two completely different spheres, i.e., that of the technologies produced or that of the technologies utilized. This differentiation is anything but secondary and, in fact, enables us to divide the sectors into four categories (Figure 5).

Since each sector has a different economic importance, the innovations produced or utilized by industries must be standardized through an indicator of the economic dimension of the sector, such as numbers of employed, added value, or sales. In this way it is possible to divide the sectors, as in Figure 5, into:

1. those characterized by rapid technological change measured by both production and utilization of innovations,
2. those characterized by frequent production of innovations, but substantial limitation in utilization,
3. those that frequently use innovations, but seldom produce them,
4. those characterized by scarce production and utilization of innovations.

This taxonomy of industries (which, at a higher level of disaggregation, can be applied to individual firms as well) seems far more fruitful than the generally used one of high, medium, and low technology, as it allows the definition of technological intensity on the basis of at least two variables, rather than solely on the basis of the intensity of the production of innovations.

The study of vectors $\mathbf{a}'$ and $\mathbf{b}'$ is particularly interesting from the viewpoint of dynamics. In fact, comparison of the two periods of time shows the trajectory followed by the industries, from the viewpoint of both innovations produced and those utilized. It is actually possible to see how the technologies employed in each industry have evolved over time. For example, the shift of the automobile industry towards electronic technology can be measured by comparing two different periods of time. This method also makes it possible to see if an industry orientated towards the introduction of new technologies first obtains them from other sectors (thus appearing as shifts of utilized innovations) and subsequently becomes able to produce the technologies utilized internally (shift in produced innovations). A third stage may also be hypothesized, in which the innovations produced by the industry are utilized in other industries.

This analytical procedure is substantially analogous to the study of technological diversification. It offers a higher degree of accuracy, as it is capable of distinguishing between what is determined by propulsion (i.e., production of innovation) and what takes place through absorption (i.e., utilization of innovation).

7. A Taxonomy of Innovative Firms

From the experience of the SPRU data bank, a taxonomy has emerged that is aimed at identifying not the economic and technological characteristics of innovations but the typology of innovative firms [40, 41]. The taxonomy proposed by Pavitt is intended to distinguish firms on the basis of the channels through which they acquire their technological know-how and effect their innovations.

Pavitt subdivides firms into four categories:

Supplier Dominated Firms

These do not produce the majority of their innovations internally but obtain them from their suppliers. The industries in which such firms are typically found are traditional manufacture, building, and agriculture.

Scale-intensive Firms

The principal technology strategy for these firms consists of reducing production costs by exploiting economies of scale. The typical sectors for firms of this kind are those of materials and, above all, those based on the conveyor belt.

Specialized Suppliers

These are firms of generally small and medium size that live in symbiosis with the firms they supply with machinery and high-tech capacity. The typical sectors are those of machinery and scientific instruments.

Science-based Firms

These are firms in which we find great investment in R&D. They are characterized by the fact that they produce internally the majority of the innovations they use. Typical sectors are those of chemicals and electronics.

Chesnais [6] has further developed this taxonomy and included a fifth category of firms, i.e., those directly working under public commissions. Firms of this kind are typical in aircraft, weapons, energy, and telecommunications. Pavitt et al. [45] have further developed this taxonomy, including an *information intensive* category of firms (for a discussion and an empirical test of Pavitt's taxonomy, see Archibugi et al. [3]).

Pavitt's taxonomy of innovative firms thus has completely different objectives from Freeman's taxonomy of innovations. In this taxonomy, the concept of pervasiveness is altogether absent. It regards solely the identification of the *subjects* at the basis of technological change, and not the content of such change, which is mainly represented as a relationship of interdependence between firms. Pavitt's working hypothesis is that the content of the technology accumulated by a firm conditions, and often determines, its productive structure—in other words, there is a feedback between the objects already produced and/or used by a firm and the subsequent evolution of the subject, i.e., the firm itself.

This taxonomy identifies a particular type of subject, i.e., firms, and ignores other subjects, such as public research structures and also, in its first formulation, state-related companies, which are implicitly considered in Freeman's taxonomy when they promote innovative activity.

For each type of firm, Pavitt indicates the typical core sectors. However, a firm's branch of economic activity and its classification in the taxonomy do not wholly coincide. An electronics firm may, e.g., be *scale intensive* rather than *science based* if economies of scale predominate within it and if its principal strategy is that of reducing production costs, rather than that of producing its technological base internally.

The system of measurement proposed does not therefore allow direct testing of Pavitt's taxonomy, since the sectors of production and use of innovations are classified there on the basis of the firms' main branch of economic activity. It is in some way surprising that Pavitt's taxonomy arose directly from the experience of the SPRU data bank but is not rigorously testable through it.

In some cases, fundamental differences are found between the individual firm and the industry it belongs to. Let us take, e.g., the firms defined as *specialized suppliers*. According to Pavitt's taxonomy, such firms usually produce machinery or scientific instruments, are of modest dimensions, and have a low level of technological diversification. If, however, we consider the distribution of innovations of the whole industrial sector, we find that, contrary to expectations, there is a very high degree of diffusion of innovations among the most varied technological groups. Pavitt's expectations are, however, not yet contradicted. More detailed analysis carried out on firms rather than on the industry as a whole confirms that the innovations produced by the firms belong to a restricted number of technological groups (the empirical information is supplied by Archibugi [2]). This example demonstrates the profound difference between analysis carried out on the level of industry and that carried out on the level of individual firm.

The way in which Pavitt uses information about industrial sectors to construct his taxonomy of innovative firms refers to the *typical* sector on firms' economic activity. Since the cube takes industries into account, it can supply, if not definite proof, then at least strong evidence. In particular, expectations include the following:

1. That the typical sectors of *science-based* and *specialized suppliers* firms are those with a positive difference between innovation produced and that utilized; at the same time, however, that the sectors belonging to the *science-based* firms have a greater tendency to use the innovations created internally, while the *specialized suppliers* are above all characterized by the fact that the innovations they produce are utilized elsewhere.

2. That the typical sectors of *supplier-dominated* firms have a negative difference.

3. That the typical sectors of *scale-intensive* firms tend to strike a balance, but also produce and utilize innovations in a wider variety of technological sectors than the other categories.

8. Continuity and Breaks in Technological Change

Freeman's taxonomy of innovations and Pavitt's of firms are therefore intended to respond to different problems. Nevertheless, a marked difference of emphasis is found between the implications of the two taxonomies (Soete [66] has already explored these differences). In Freeman, stress is laid on discontinuities in technological change. As Freeman recalled at the Venice Conference on innovation diffusion, in no way could automobile technology have evolved from the steam engine. The dynamics of technological change are therefore characterized for him by a sequence of breaks and subsequent recomposition.

Pavitt, on the other hand, lays emphasis on the cumulative aspect of innovative activity, pointing out that what firms will do in the future is strongly conditioned by what they have done in the past. The nature of technological knowledge is therefore of a clearly evolutionary cast:

> Our theory of technical change, which stresses the cumulative and differentiated nature of technical change, suggests that accumulation and complementarity of skills in existing organizations typify the diffusions of a new technology system rather than destruction and displacement. Most of the evidence suggests that this is the case. [42, p. 45]

Consideration of the two taxonomies makes it clear that the terms *continuity* and *breaks* refer to two different spheres that are mutually *noncomparable*. While Freeman indicates the dynamics belonging to a technology and, hence, to an object, Pavitt considers firms and, hence, economic subjects that create, use, and transform technology. In this perspective, the two analyses are not necessarily in contradiction; nothing prevents a firm in one sector from developing a revolutionary technology connected with the nature of its technological knowledge or with the possibility of exploiting a presence on the market. Such cases are, e.g., those of chemical-pharmaceutical firms diversifying towards biotechnologies and automobile firms diversifying towards mechanical engineering and machinery. In some cases, such as computer science, the formation of a new industry has involved both firms with a knowledge of the technology, i.e., electronics firms, and firms already active in the market, i.e., those of office appliances [29].

Radical technological changes often determine profound modifications in the market structure and composition of the firms in an industry. Schumpeter has already pointed out that "it is not generally speaking, the owner of the stagecoach who introduces the railway" [61]. In other words, the rise and establishment of a technological revolution often determines the setting up of new firms and industries, thus bringing about the innovation competition dear to neo-Schumpeterians [35].

Numerous anecdotes could be narrated to indicate, one by one, the evolutionary or revolutionary aspects of technological change. It is, however, doubtful whether this course can lead to a real understanding of the phenomenon. What is to be stressed here is that the importance of the terms *continuity* and *breaks* is to be qualified in two senses: 1) in the first place, if they refer to the object of technological change (technologies) or to the subjects that promote it (firms, universities, etc.), and 2) that, even where the same phenomenon is being tackled, it is necessary to clarify the temporal dynamics referred to.

The flourishing debate on scientific procedure that has taken place over the last 25 years is instructive in this sense. There is, in fact, general agreement by now on the fact that emphasizing revolutionary or evolutionary factors is often connected not only with the individual temperament of the scholar, but with the temporal horizon considered. While continuity emerges in a short- or medium-term perspective, in the long-run view, differences and clashes appear stronger, and consequently revolutionary change emerges. It is not by chance that Freeman emphasizes the revolutionary nature of technological change in the long-wave context, while Pavitt, focusing on cross-industry differences, stresses the evolutionary procedures of the innovative process and the complementary relationships between economic agents.

If there is, however, a sense in which the taxonomies of Freeman and Pavitt can help to explain the reality of technological change, it is through their interconnection. The central point where both taxonomies merge is that of making possible the study of how certain changes in objects, i.e., in the nature of technological knowledge, are associated with changes in the structure of subjects, i.e., in firms and in the industrial structure.

We speak of "association" because it does not appear possible at present to define a causal nexus proceeding from the characteristics of the technological objects to the structure of the economic subjects, or vice versa. Firms are, at the same time, in control and at the mercy of the innovative process. While their research and innovation strategies do determine the direction and rate of technological change, they are its "victims" in that it forces them to modify their structures (Rosenberg [50] speaks on this point of "Technological imperatives.")

Pavitt's taxonomy may also be seen as a succession of historical periods. The rise of each category of firm corresponds to a phase of capitalist development and to a particular way of introducing innovations. In fact, each category of firm has been the protagonist of a technological revolution and of its subsequent long wave in economic life. In this sphere, the capitalist system seems capable of creating new economic subjects in step with the availability of new technological objects, without being obliged to destroy the old.

Both Freeman [13] and Pavitt [40] refuse to give a definition of technological change in exclusively "endogenous" or "exogenous" terms. A substantial homogeneity is to be found between their theses (for reviews of the debate, cf. Mowery-Rosenberg [32]; Antonelli [1]). However, also in this case, we find a difference of emphasis that can be traced back to their taxonomies.

From the taxonomy of innovations, it is deduced that the endogeneity of technological change dependent upon market demand is mainly associated with innovations of an incremental nature, while the growth of new technological systems, and even more of technological revolutions, depends on factors that are less under control of market mechanisms and may be traced back to technological opportunities. This taxonomy also stresses that firms are not the only creators of technological capability. The chemistry and electronics of our century can hardly be conceived without Bismarck, in the first case, and without NASA, in the second case (for a systematic account of the role of government in technological change in the United States, cf. Nelson [33]).

The taxonomy of firms, on the other hand, tends to emphasize sectoral differences. The innovative activity of *specialized suppliers* depends heavily on the investment decisions of *supplier-dominated* firms (principally *demand pull*), i.e., endogenous market mechanisms. In *science-based* firms, however, technological opportunities precede the introduction of new products, and innovation thus appears as essentially exogenous, i.e., *technology push*.

9. On Technological Indicators

Finally, we arrive at the possibility of measuring innovation. Our previous remarks are greatly complicated when we turn from methodological considerations to empirical test. In this case, we are forced to use approximate measures of technological capacity and innovations, with all their defects and shortcomings. The technological indicators most frequently used in economic studies are: a) statistics of R&D in terms of personnel employed and of expenditure, b) the technological balance of payments (TBP), c) patent statistics, and d) direct monitoring of innovations introduced. It should be noted that only two of the four indicators were explicitly devised for the study of technological change, i.e., R&D statistics and monitoring of innovations. The remaining two, TBP and patent figures, arose for reasons independent of the measurement of technological change, to which they were subsequently applied.

Let us attempt to make some brief comments on the actual and potential use of these technological indicators.

STATISTICS OF RESOURCES DEVOTED TO R&D

These statistics are aggregated on the basis of the sector financing and spending money on research. From the end of the 1960s, some international organizations—such as the OECD [36] and UNESCO [65]—have annually gathered data on expenditure and numbers of researchers broken down for countries and branches of economic activity.

Resources devoted to R&D do not represent the total amount of resources destined for innovation. In all sectors, and overwhelmingly in the engineering sectors, a large proportion of innovative activity takes place outside research laboratories, e.g., in design and planning, or in the production shops themselves. Moreover, there is no guarantee that allotting a certain amount of resources for R&D will produce a uniform rate of innovation. Because of the high level of uncertainty present in scientific and technological research, a linear relationship between input and output is more likely to be lacking here than in other areas of economic life. Despite these limitations, resources devoted to R&D are one of the most powerful indicators of inventive and innovative activity.

In the generally available presentation of data, R&D expenditure and personnel are aggregated on the basis of the prevalent branch of economic activity of the sector making the expenditure. The available data give no information about the projects of scientific and technological research carried out in firms or about the sectors of utilization. On the basis of the classification described, R&D resources only provide a measure for criterion 2, i.e., the sector of activity of the body producing the innovative activity. There are some exceptions, such as that of Scherer (mentioned above); where data have been broken down in a more thorough manner and indicate the specific type of technological sector of the research carried out (criterion 1) and the sector of utilization (criterion 3).

The Italian statistical bulletin on scientific research (Istat) [22], contains a matrix, unfortunately not too detailed, based on firms' branches of economic activity and the groups of products on which the firms carry out research. The matrix is analogous to **A**.

An indirect way of obtaining information on flows of R&D from the sectors of activity of producing bodies to the sectors of utilization is by connecting the R&D expenditure vector to the input–output table. Operations of this type have been carried out for the United States by Terleckyj [67], and for Italy, with a more accurate methodology, by Momigliano and Siniscalco [31].

The application of this approach implies that the sectors of utilization of the R&D carried out by an industry are proportionally the same as the sectors of goods and services in the input–output tables. There is, however, no real certainty that R&D flows of an industry have the same direction as the industry's products. The application of this methodology produces no certainties, only indications. However, in the absence of definite proof, analyses regarding flows between sectors are, in any case, valuable.

TECHNOLOGY BALANCE OF PAYMENTS

This balance measures transactions between firms and sectors of different countries [28]. Unlike R&D data, the TBP regards technology transfers with a commercial objective and thus excludes noncommercial inventive and innovative activities, such as the majority of those carried out by the public sector. The type of product that forms the object of the transaction is representative of the technology transferred (criterion 1); the branch of activity of the selling sector indicates the sector of activity of the firm producing the technology (criterion 2); the branch of activity of the purchasing firm indicates the sector of utilization of the technology (criterion 3). However, an individual country possesses data for each agreement of technology transfer solely of its own firms. The information available will thus be that given under criteria 1 and 2 or under criteria 1 and 3. The TBP therefore furnishes, alternatively, the information for matrices **A** and **B** but not **C**.

Among the merits of the technology balance of payments is that of giving data in terms of currency and thus indicating economic relevance of each individual technology transaction. Moreover, data on the TBP are available for a number of countries and thus make international comparison possible.

However, the TBP, by definition, provides no indication of the amount of resources devoted to innovative activity but, at best, only of the amount of technological activity internationally transferred. In other words, all those technologies that are not the object of commercial transaction are excluded. Among these are, e.g., the technologies used exclusively within the producing firm, which do not therefore involve direct payments between different bodies. Finally, the TBP does not, by definition, regard the flows of technology transferred within a country.

PATENT STATISTICS

Patent statistics are a technological indicator on which increasing emphasis has been laid in recent years. They are available for many countries, broken down for the country of origin of the invention for which the patent is requested and for the technological category of the invention. Patent statistics are available in almost all industrialized countries and in many developing countries, broken down for very detailed technological sectors. They probably represent the most precise and reliable classification of technological products in terms of criterion 1. From the name of the body to which the patent is issued, it is possible to reconstruct the sectors of the bodies to which the producers of innovations belong and, with the necessary processing, these enable us to construct a matrix analogous to **A**. Both these items of information are available for many countries.

However, unless patents are analyzed individually, they provide no information as regards the third criterion of classification, i.e., the sector of utilization of the innovative activity. There are studies that have carried out individual analysis for each patents, e.g., that of Schmookler [59, 60], but they represent exceptions rather than the rule. At present, the only data base in the world to furnish information for each patent regarding technological content, the sector of activity of the producing body, and the sector of utilization is the Canadian Patent Office [10]. This is the statistical source used in Seguin Dulude's essay.

DIRECT MONITORING OF INNOVATIONS CARRIED OUT

As well as the first three technological indicators, there is also the possibility of directly monitoring the innovations carried out. However, as with all monitoring, a sample is used rather than the totality, which inevitably involves the introduction of subjective criteria owing to the methodology adopted. The OECD has recently been moving towards as standardization of methodology, as is attested by the recent conference on innovation statistics [37]. As Hansen points out in a review of direct investigations of innovations [21], there are two different ways on the basis of which innovations can be surveyed.

The first is in terms of innovations, i.e., objects. This methodology was adopted by the SPRU, which made use of sectoral experts to identify significant innovations. Here, it is a matter of working back to the sectors of production and utilization from information regarding individual innovations.

The second is that of asking firms (and possibly other bodies involved in producing or utilizing innovations), i.e., subjects, to indicate relevant innovations produced and/or used by them. This procedure was adopted in the Italian survey on innovation diffusion. The advantage of this procedure is that it gives a far wider basis of innovations than the previous method. However, a DeBresson [7] points out, asking a horse how many legs it has is not always a totally satisfactory approach.

Both methods have advantages and disadvantages which Hansen considers at length in the review mentioned above. Suffice it to say that the first system makes it easy to test Freeman's hypotheses, since it starts from the objects, while the second appears more suitable for testing Pavitt's taxonomy since, subjects form its point of reference.

10. Conclusions

It is difficult to present methodology without results. However, the study of technological change is a complex phenomenon, and so far we have had a considerable number of applied studies overlapping without a standardization of methods of measurement. No small part of the controversies regarding technological change is due to misunderstandings between the various authors as to the methods of measurement adopted. The principal aim of this article is to provide a framework of reference for the multifarious forms in which innovative activity presents itself. Greater methodological clarity will probably be able to reduce misunderstanding, if not to settle existing divergences. This seems the main task today, if the theory of technological change is to enjoy the same academic status as other branches of economic science.

The aim of this article is not, however, solely methodological. The OECD is attempting to effect an international standardization of statistics regarding innovation similar to that carried out in the 1960s for R&D and codified in the *Frascati Manual*. For a change, Italy finds itself in an extremely favorable position: the ongoing Cnr-Istat study [23] will offer a quantity of data never before available to those studying technological change, but it will be necessary to analyse them. All the multifarious forms in which innovative activity presents itself and which are here underlined can be tackled thanks to the data provided by this investigation. It is therefore to be hoped that the information is used both to give a complete examination of innovation in an industrialized country as Italy and to develop a theory capable of removing the suspicion of heresy so far surrounding the economics of technological change.

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