Patents and the measurement of technological change: A survey of the literature *

Bjørn L. BASBERG
Department of Economics, University of Trondheim, N-7055 Dragvoll, Norway

This paper starts out by reviewing the literature that in different ways utilizes patent data as a source of information in measuring technological change. The main focus, however, is an assessment of patent statistics used as a technology indicator. This is done by investigating the relationship between patenting and the innovation process. The analysis reveals many, and well-known, problems. The second part of the paper therefore reviews the research directed at improving the quality of the patent statistics as a technology indicator. This has been done in a number of ways depending on the focus of the analysis. In general we may conclude that it seems necessary to utilize the data at the lowest possible level of aggregation to overcome the problems of validity.

1. Introduction

How to measure technological change has concerned economists, economic historians, historians of technology and research analysists for a long time. However, no widely accepted method has been developed so far. Many methods exist, and they all have their advantages and disadvantages according to how they are used. One method is to use data and statistics on patents. In this paper we will review the literature that utilizes patent information in this way. We will emphasize the special problems which are associated with this method and point to ways of overcoming these problems.

It is important to emphasize that most available methods of measuring technological change are indirect measures of the process. By this we mean that any indicators we might use, will be able only to shed light on certain aspects or parts of the process. We will use the expression technology indicator. An "indicator" will be no more than a proxy that may help to discover trends. General definitions like the following will show this vague character:

> Science and technology indicators are series of data designed to answer a specific question about the existing state of and/or changes in the science and technology endeavor, its internal structure, its relationship with the outside world and the degree to which it is meeting the goals set it by those within and without [56].

The literature on patents may be listed under three main categories. One deals with the legislation and the functioning of the patent system. Another deals with the rationale of the system. A third area is covered by the literature that uses patents as technical information. Research using patent statistics as a technology indicator falls into this last category. Some important works, however, deal with all three areas [27,41,60,89].

Studies that use patent statistics as a technology indicator can also be divided into three broad groups. One direction of research deals mainly with the relationship between technological change as measured by patent statistics, and economic development [1,7,28,35,40,49,55,91]. This is the core area of the field, and arguably the most important research within this area has been the work done by Jacob Schmookler ([80], a complete bibliography is included in [30]). His research is described as "...so rich and so suggestive that it has to be the starting point for all future attempts to deal with economics of inventive activity and its relationship to economic growth" [65, p. 92]. Schmookler's main conclusion is that inventive

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activity is endogenously determined by economic variables. This result has initiated a debate on "technology push" versus "demand pull" [10,24, 48,65,66,67,76,82,87,88,93], of which a substantial part has been focused on the extent to which the methods employed have shaped the conclusions ([15, p. 274]; [95]). Schmookler's works have had a central position in the whole methodology debate on patent statistics used as a technology indicator, and we will turn back to it later on.

Patent statistics have also been used to analyse the diffusion of technology from one country to another. This is done by measuring flows of patents between countries, and such information may be used in calculating the so called "technological balance of payment". Data on licences and royalty payments and receipts are also used in this kind of research [9,18,21,34,78,83].

Finally, a third group of studies are concerned with the analysis of the innovation process itself in order to assess and evaluate the output of research activity. This has often been done by looking at the relationship between R&D, patents and productivity [23,32,39,43,44,52,75,77].

2. Patents in the innovation process

2.1. The main questions

The use of patent statistics rests on the assumption that they are reflecting inventive activity and innovation. Secondly, the ready availability of the data is of some importance. It is possible to reconstruct complete time-series back to the middle of the nineteenth century (for some countries even further back) based on the patent registers. Patent statistics may also be used in comparisons across industries and nations ([33, p. 39ff; 59; 71, p. 76]).

The main questions in the debate on the usefulness of this approach have been the following;

(1) To what extent are patents used commercially? If patent data are to have any practical value as an indicator of technological change, it is necessary to show that the number of patents which indeed do lead to innovations is significant. Related to this is the question of the varying value or quality of the patents. Obviously one cannot assume any uniformity, and this represents a problem when patents are counted. There is also the question of the varying time intervals separating patenting and commercialization.

(2) If patent data are to be used in comparisons across firms or industries, it is of importance to know whether the patent system is used uniformly by the participants in the comparison. It is possible to protect an invention in several ways, and the attitude towards the use of patents may vary.

(3) In comparisons between countries, there is a question whether the patent institutions can be compared. If patent legislation and the practice of the patent offices vary significantly, this will of course affect the validity and usefulness of any comparisons.

(4) Finally, we have the inherent problems of all historical timeseries analysis. In our case, we must assume that the institutional framework and the attitudes are relatively stable over time if we are to have results of any value.

In the following we will go into these questions in greater detail.

2.2. Patents in innovation models

As a point of departure one may ask if patenting plays any substantial role in the innovation process at all? Since patents used as a technology indicator obviously are a somewhat imprecise measure, it is important to find out what relationship patenting has to other activities which lead to innovation. If patents are to be used as a technology indicator, there most be a fairly unambiguous relationship between patents and the innovation process.

In stagewise models of innovation, patenting is often used as an element in certain stages. The stages are usually of the following kind; research, invention and development, innovation and production, diffusion. One example is a model employed by Campbell and Nieves where patenting is categorized in a third "reduction-to-practice" stage before the R&D stages [12, p. 3.2.]. Roberts does a more usual thing when he lets patent application be the final activity of the development work (his second stage) [64]. Freeman operates with patents as an output indicator for inventive work, which is the second step in his model [23, p. 8]. Evenson categorizes the activities a firm goes through in order to change its technology, and shows how patenting is variously used in these processes [18, p. 90]. This is also done by Arnow in her five stage model, which shows activities and which indicators are reflecting them [2]: Stage 1, the use of resouces for research and development; Stage 2, results of knowledge production (new use of knowledge will result in patent applications and later in patent grants); Stage 3, the use of results of new knowledge in improving technology (may involve purchase of patents); Stage 4, use and effects of new technology; Stage 5, diffusion of new technology (sales of patent licenses).

Most models relate patenting to the development phase as an output indicator of R&D-activity, and a positive relationship between R&D and patenting is, as mentioned earlier, empirically well documented.

2.3. The relationship between patents, inventions and innovation

The question of the relationship between on the one hand patenting and on the other hand invention and innovation, is of crucial importance and was discussed already by Maclaurin [42]. In fig. 1 we have shown in a general way the quantity of

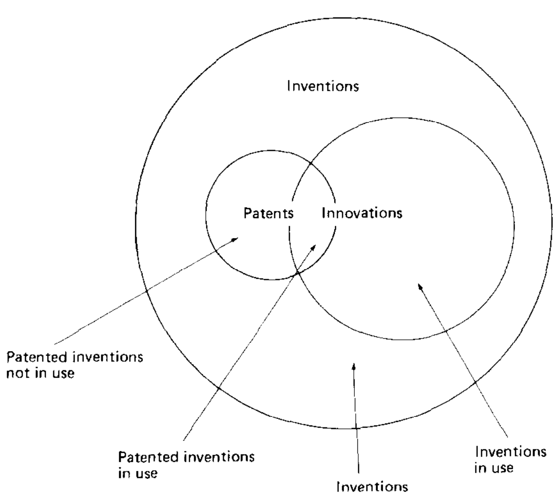

Fig. 1. A generalized picture of the relationship between patenting, invention and innovation.

and the relationship between inventions, innovations and patents which are made for example within a year in a firm, industry or country. Only some of these inventions are patented. Furthermore, a smaller part of the inventions will become innovations. Some of the innovations will be patented. The interesting part of the figure will most often be the innovations. Patent data will obviously contain some innovations, but they will also contain inventions without any commercial value. The sizes of the different parts of the figure are of course arbitrarily chosen and may vary across sectors and in time.

The figure also seeks to show graphically the relationship between invention and innovation. We will not go into the many possible explanations of why inventions are or are not put into practice, but just stress that there are no simple correlations. The relationship does not really lend itself to any simple graphical representation because of the varying time lags between invention and commercialization ([17, p. 305]; [25, p. 95]).

In fig. 1 we suggest that a rather small share of the total number of inventions are patented. How large this share is, depends on the sector and of the point in time under investigation. Schmookler, for example, has assumed that not more than half the number of important inventions have been patented. Furthermore, the fraction of inventions being patented seems to have decreased throughout the twentieth century ([79, p. 18]; [25]). In any list of important inventions or innovations, there are never any difficulties in finding a number which have never been patented [27, p. 105ff].

2.4. Patents or trade secrets

An invention will most likely be protected in one way or another if it has some potential economic value. Two alternatives are essentially open; patenting or secrecy. We will mention some considerations that may affect such a choice. This will help us understand why in many cases, inventions and innovations are not patented [53].

In the first place, the invention may not be patentable due to an explicit exclusion specified in the patent law. The legislation may vary from one country to another. Within new technologies – such as today's microelectronics or bio-technology – there may further be some uncertainty as to the patentability of new inventions. The inventor may therefore choose to keep the invention secret. Another reason for secrecy has to do with the economic expectations. If the inventors cannot afford to pay for the patenting or consider the expected income as uncertain or lower than the costs, they will not patent. A third reason for not patenting is when it is considered easy for a competitor to "invent around" the patent. Mansfield, for example, has found that a competitor's patent did not cause additional costs connected with the process of inventing around it of a size large enough to be an effective barrier. A patent would often delay the imitation only a few months, and therefore be useless [45, p. 132ff].

The expected economic life of the invention will also play a role when deciding strategies for protection: If the expected life is much longer than the maximum patent life (usually twenty years), it will be rational to keep the invention secret. If, on the other hand, the expected life is very short, keeping the invention secret will also be preferred. This is the case in rapidly developing fields such as microelectronics where an invention might be obsolete before the patent is granted.

2.5. Patents and commercialization

The process of patenting is often long and expensive, and it is reasonable to expect that the inventor or his sponsors expect profits from the invention [38, p. 36]. On the other hand, there is, of course, an element of uncertainty. Prospects may fail, and it is obviously not difficult to find examples that "the economic importance of an inventions has little relation to its patentability" [60, p. 17].

An American investigation in 1958 found that as much as 75 percent of all patents that were studied were assumed to have economic importance, but not more than 57 percent were actually in use ([69]; see also [80, p. 47ff]; [72]). When it comes to the reasons for not utilizing the patents, it seems that lack of demand and competitive strength are important, but also rapid obsolescence [68]. A firm may very well apply for a patent without any intention of exploiting it commercially, but only to prevent competitors from making use of the invention [50].

There are obvious differences in quality between patents that are used and those that are not. However, even among the patents that are used commercially, there are differences. Some patents have been the basis for new successfully products, firms or whole industries. Others may be small improvements and have insignificant economic importance. It is obvious, as emphasized by several authors, that patents to some extent are incomparable ([38, pp. 22 and 23], [50], [75, p. 1098]).

2.6. Basic innovations or improvements?

Aggregated patent statistics do not make a distinction between the patents that lead to basic innovations and those leading only to minor technical improvements [15]. If we look at Schmookler's graphs for total patenting in several sectors, what is he then actually analyzing? What does a peak in patenting really reflect? Schmookler interpreted his data with great care, and assumed that they might indicate inventive activity. But even if innovations are excluded from the interpretations, the question remains whether the patent statistics indicate basic inventions, improvements, less important inventions or even diffusion.

It is possible to argue that a basic invention which leads to a patent, will be both preceded and succeeded by less important patents within the same technological areas. A peak in aggregate patenting activity will then presumably indicate the technological breakthrough. This is illustrated in fig. 2(a). If, on the other hand, we want to trace general innovative activity, the use of aggregate patent statistics may well be insufficient. Schmookler does not distinguish between patents that lead to innovations and those which are never used. It is possible to assume that basic innovations will fluctuate differently from total patent activity, for example as we have shown in a general way in fig. 2(b). In this figure the basic innovations will generate later patent activity, and the timing of technological change will be other than when total patent statistics are interpreted in isolation. Such a pattern is documented for the chemical industry by Walsh [94]. This author has, however, found for another industry that the timing of basic innovations and the peak in patenting did coincide [4]. It is probably impossible to make any generalizations on these relationships, and detailed knowledge about the industry under investigation is necessary when dealing with aggregated patent statistics.

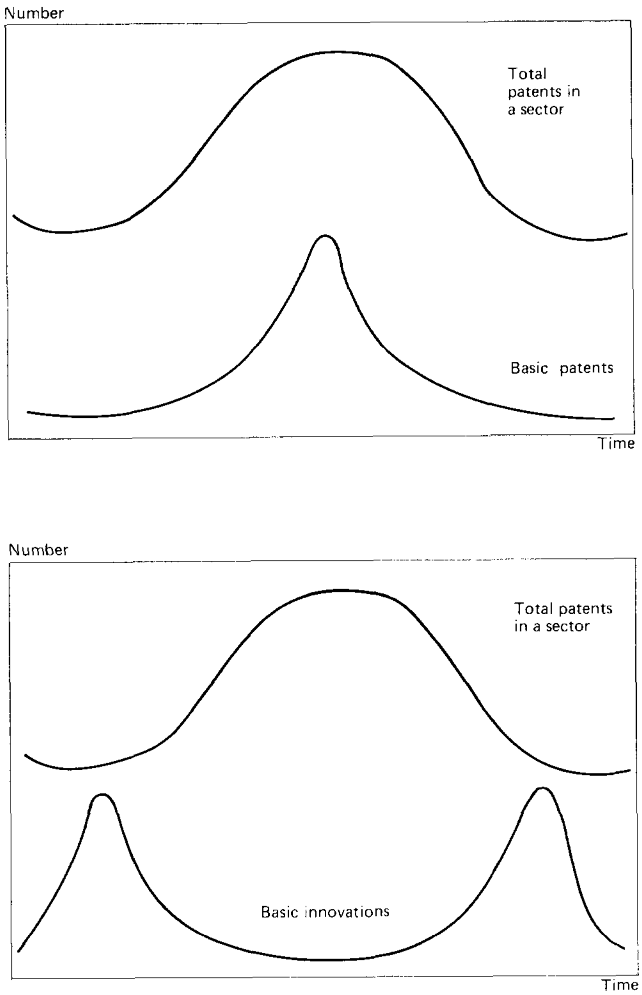

Fig. 2. A possible relationship between total patent statistics, basic patents and basic innovations in the same sector.

2.7. Variations across sectors

If we want to study technological development in different firms, industries or nations, the problem arises that patent policy may vary considerably [46]. In comparisons across nations, we have the additional problem that the patent legislation may vary. For this reason differences in the number of patents granted do not necessarily only reflect differences in the number on inventions. Seen against this background it is maintained that patent statistics should be used as information on technological trends only *within* an industry or country [62]. A precondition is of course that habits are fairly consistent within the chosen industry or country. This may not be taken for granted. Even between individual firms there might be significant differences in policy [75, p. 1098]. For example it is common to assume that patenting varies with firm size. Research has shown that small firms use patenting more frequently than larger firms [81]. Furthermore, small firms seem to use a higher percentage of their patents commercially than larger firms [70, p. 51].

2.8. Changes over time

One of the advantages of patent statistics used as a technology indicator, is the possibility of constructing long and complete time-series. If these are to have any real value, a first precondition is that the quality of an average patent remains more or less unchanged. Secondly, the relationship between patents and inventions in a chosen area should be pretty constant. Finally, attitudes as to the use of the patent system must remain substantially constant [71, p. 69]. These preconditions do not always hold. Consequently, time series of patent data must be interpreted with great care ([7, p. 155ff]; [63, p. 158]). In several countries the domestic patenting has leveled out or fallen since World War II. The reason might be a decreasing interest in patenting much more than a decrease in inventive activity [26,37,38,79,80]. An explanation of the falling trends may also be found in the shift from independent inventors towards an increased government involvement in research and development. In effect this makes protection through patenting less important [38, p. 36].

3. Improving the patent information

It is possible to maintain that in using aggregated patent statistics, sheer quantity will secure meaningful mean values [7, p. 156]. This is, however, a too simple way of getting around the problems of this method, and we will review several possible ways of dealing with the question of quality. In some ways the debate about patent statistics has not advanced since the 1950s and 60s when Schmookler published his important works [31]. The same pros and cons are still applied. When it comes to ways of using and improving the presentation of patent statistics, so as to overcome the problems of validity, there has, however, been some advance. This will hopefully be shown in the following examples.

3.1. "Important" patents

Perhaps the most obvious way to improve the value of patent data, is to differentiate between patents according to their quality. Baker has done this, and his criterion is that "an invention is important or significant if the history of some subject could not be written without reference thereto" [3]. In the first place, important technological areas are defined, and then important inventions within those areas are picked out. Using Baker's data for English patents back to 1961, Clark et al. have made a distinction between "master patents" and "key patents" [14, p. 310ff]. Master patents are defined as the first patents in an area to become economically successful, while key patents refer to the most important patents overall. Series of both data correlate, but they show quite divergent trends from those based on time-series for total patenting. This illustrates the important point that conclusions drawn from analysing patent data, depend on the type of data used.

Soete et al. have also used Baker's concept and classified innovations and patents according to importance in the following way:

Radical innovation	– A new class of patents created
Major innovation	– A "family" of patents
Important innovation	– A number of key patents
Minor innovation	– Two or more patents
Incremental innovation	– Not necessarily patented [86]

A final example is Townsend's work on innovation in the British coal mining industry [92, p. 52]. Each patent is given weight from one to four according to its importance. He further shows how his conclusions depend on the way the weights have been distributed.

A problem with these methods has to do with the subjectivity in estimating the quality. A more objective method is to let the quality be decided by the effective life of the patents. The maximum life of patents is in most countries between 15 and 20 years. However, few patents are protected for such a long time [20]. The annual fee which in most countries is progressively increasing, may be compared to the expected income from the invention. The more profitable the invention is, the longer will the patent life probably be extended. Consequently, the patent life will be an indication if importance. Based on such calculations, large differences have been found in quality [73]. Changes in effective patent life over time have also been found. However, one may ask whether such changes reflect changes in the quality of the invention or changing institutional conditions ([8]; [16, p. 18ff]).

3.2. Patenting abroad

There are many reasons for applying for a patent abroad. Such a patent might protect an existing or a potential export market. Furthermore, licenced production will very often have a patent as a precondition [74, p. 52ff]. Foreign patents are used as technology indicators because, on average, they are expected to be of a higher quality than domestic patents. It is reasonable to assume that only inventions with significant profit expectations in a larger market will be patented abroad because of time and costs involved in such processes [27, p. 42]. In addition the quality is explained by the international legislation governing the priority of foreign applications.

Patents abroad are used in two different ways. With UK as an example, we may on the one hand study UK patenting abroad because this may indicate the technological level in the UK. On the other hand, we might study foreign patenting within the UK from the viewpoint that this, too, reflects technological conditions and trends in the UK. In the first case patenting abroad reflects characteristics of the technology of the country of origin. In the latter case, foreign patenting in the UK reflects conditions in the receiving country. It is possible to argue for both these methods. More generally stated; foreign patenting is affected both by factors within the donor and the recipient country [11].

One reason for using foreign patent data is to make it possible to enter into comparisons between countries. By comparing the patenting activity of several countries in a third country, the difficulties caused by differences in patent legislations are overcome. But which country should be used as the third country? One possibility is to study total foreign patenting [19]. In limiting oneself to one country, however, a natural choice would be to study foreign patenting in a country with a dominant positions both economically and technologically. France, FRG, the UK and the US are among them. Their positions as receivers of patent applications from abroad have changed over time, and the US is today the leading country. In a study of the pharmaceutical industry in several nations from 1900 to 1963, however, foreign patenting in the UK was used since that country in this period was the most important as a patenting country within that particular area [62]. Another example is a comparison of European semiconductor manufactures after World War II which investigates foreign patenting in France [90, p. 107ff].

3.3. Foreign patenting in the US

Pavitt and Soete maintain that "each country has the same propensity to patent in the USA in relation to the size of its innovative activities", thus making such data a useful technology indicator ([58, p. 41]; see also [85]). Evidence of their view is found in the higher correlation between domestic R&D and US patenting of a country than between R&D and domestic patenting of the same country. Pavitt and Soete use data for foreign patenting in the US among others to analyze the relationship between technological change and foreign trade, and conclude that "technological performance is the most important trade explanatory variable..." [84].

However, it is possible to find an alternative explanation for patenting abroad, and especially in the US, Schiffel and Kitti found that a country's export to the US together with the domestic patenting explain the US patenting of that country [78]. Countries that are close trade partners will usually also have a strong patent flow between them. Studies concluding that neighbouring countries have especially high intercountry patent flows [18,83], are therefore no more surprising than studies showing that the same countries are close trade partners. Alternatively to Pavitt and Soete, it is therefore maintained that "the propensity to patent in another country is probably related to the perceived potential of the market in that country" ([50, p. 17]: see also [47]). Regardless of such disagreements, an important factor which favours the use of foreign patenting in the US as a technology indicator, is, as mentioned earlier, the average quality of such data compared to domestic patent statistic [5].

3.4. Reference and citations

One way to find out about the quality of patents is to study what is called patent-to-patent citation networks ([13, p. 161]: [54]). Usually a patent application will refer to other closely related patents much as a research paper has a list of references. The more often a patent is referred to, the more important it is likely to be. A very thorough investigation following this approach is done by Campbell and Nieves [12]. They determine the quality of a patent by a combined analysis of references in the application and citations by other applications.

3.5. Reclassification

To study the patent data at the lowest possible level of aggregation may also be one way of dealing with the quality problems [6]. Patenting for example within a firm will give data of less noise than data for patenting within an industry or a whole nation.

Some of the most accessible patent data are data for patent classes or subclasses. However, if the focus of interest is in analysis of the relationship between patenting and economic activity, we are faced with the problem that patent classification and industry classification are not comparable in any direct way. Patents are classified according to technological systems or principles, and therefore have to be reclassified when used in economic analysis. Schmookler pioneered this area of research [30, p. 87ff]. Later, such reclassifications have been made permanent in for example the databases of the Office for Technology Assessment and Forecast (OTAF), making the patent data accessible to analysis in an economic context [57, 5th report]. Since both patent and industry classification differ between the US and the European countries, there have been specific reclassifications for the European data [29,36]. The reclassification is not unproblematic, and there has been some debate on Schmookler's work. A patent may both be reclassified to the industry where the invention took place, or to the user industry. The patent owner will most likely represent the industry of origin, and the researcher needs a detailed knowledge of different industries to be able to find the actual user industry of the invention. Schmookler himself tried to reclassify according to the user industry, and there seems to be a general consensus about this approach (see for example [7] and [77]).

3.6. *Applications and grants*

Patent legislation may change over time and cause difficulties in the interpretation of the patent data. For example, the number of years an application is pending changes. The problem may be reduced by using data for applications instead of data for patents granted. The applications reflect the inventor's interest in obtaining protection and show his evaluation of the importance of his invention [12, p. 3.9]. The choice is, however, not a simple one. Data on patents granted do also have several advantages. The most obvious one is that the average quality may be higher than for applications because of the screening done by the patent authorities.

Empirical studies in the field have emphasized these arguments differently, and both data for applications and grants are used. We find Schmookler's solution somewhere in between, as he uses data for patents granted at the point in time where they were applied for ([31]; [80, p. 21].

3.7. *Assignment data*

One way of using patent data in order to increase information and validity is developed by the Japanese Patent Office and adopted by OTAF ([57, 7th report; see also [12, p. 3.12.ff]). While annual changes in the number of patent applications are said to reflect technological activity, the annual changes in the number of assignees reflect the interest in the technology. A combination of these two measures are assumed to indicate the degree of maturity of the technology. The change from one year to another is described graphically by a vector representing the two variables. The result is a dynamic vectorial pattern of the rate of change of the technology in question over the time period of interest. If both data increase, the technology is said to be in a developing stage. If both decrease, the technology is mature and on the way down. Combinations of increasing and decreasing activities of the two variables describe the research and development stage.

4. Conclusions

We have reviewed literature on patent data used in a variety of ways as an indicator of technological change and development. There is a whole spectrum of choices between using information on the single patent, groups and classes of patents and finally data for total patenting activity. Furthermore, there is a choice between cross-section data and time-series data. Used in the latter way, patent data are almost unique, since it is possible in the case of several countries to construct complete series of data back to the eighteenth century. Further, data from different stages in the patenting process may also be used. Finally there is a choice between data for domestic and foreign patenting.

The type of data that is chosen depends of course on the purpose of the analysis. If the focus is on how the patent system works, it might be useful to look at the relationship between applications and grants, patent policy etc. An historian of technology might be interested in the patentees, the single patents and their technical specifications. On the other hand, students of long-run development, theories of long waves and the relationship between economic and technological change, may find it useful to analyse aggregated patent statistics in a quantitative way. Finally, cross-section data are a useful tool in comparative studies of industries and countries.

We have pointed to a number of problems connected to the use of patent statistics as a technology indicator. As clearly may be seen from the review, there is still a need for further research perhaps especially focused on the micro-level relationship between patenting and innovation [59]. The severity of the problems with these data is probably the background for some characteristics common to many works in the field: After making reservations and decisive critique of the method in general, the data *are* used as if real reservations had not been made. This is of course a result of some kind of trade-off. On the one hand, the limitations of the data are perceived. On the other hand, we are aware of the general lack of other adequate technology indicators, especially in the analysis of historical data in long-run perspectives. Schmookler put it the following way in a much quoted phrase:

> We have a choice of using patent data cautiously and learning what we can from them, or not using them and learning nothing about what they alone can teach us [80, p. 56].

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