INFLUENCE OF RESEARCH AND DEVELOPMENT EXPENDITURES ON NUMBER OF PATENT APPLICATIONS: SELECTED CASE STUDIES IN OECD COUNTRIES AND CENTRAL EUROPE, 1981-2001

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Abstract

Investment in R&D encourages innovation, which in turn, spurs economic growth. This paper presents a model to test whether that the number of patent applications is dependent on R&D expenditure, especially R&D expenditure in the business sector. This paper shows: 1) that a strong positive correlation exists between R&D expenditure and patent applications, 2) that R&D investment creates patent applications with a time-lag, which is different from country to country, 3) that the number of patent applications in developed countries depends more on R&D expenditure in the business sector than on R&D gross domestic expenditure.

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1. Introduction

Innovations are the fundamental impulse that sets and keeps the capitalist engine in motion (Schumpeter, 1950) and therefore causes economic growth. They comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including the knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. The basic statistical variables are R&D expenditure and R&D personnel (Statistics on science and technology, Part A, 2003).

Innovation helps producers to satisfy the diverse and fast-changing consumer demands in the current global climate of increased

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competition and sophisticated customers. They are allowing firms to keep their competitive advantage.

The modern economy is driven more and more by new technology, ideas, and innovation and less and less by physical capital accumulation. Economy with a high degree of innovation - original patented products - will be more independent on the market and more aggressive against competition; therefore it will be an active entity, taking over other competitive companies. The economy becomes stronger and is more capable of connecting because of its successfulness. It is more attractive to foreign investments (Celan, 2002). The location of innovative activity is clearly not random. From what we observe in practice it is clear some countries have a tendency to generate more ideas, knowledge, and new technology than others.

Until recently, the need of less developed countries to invest in technology has not been emphasized in economic thought. Technological development was considered to be endogenous to the demand for new technologies as induced by other changes in the economy such as changes in the composition of (domestic) demand and changes in the relative factor prices. The supply of new technologies was guaranteed by the “off-the-shelf” of technologies already developed in more advanced countries (Timmer, 2003).

At the beginning of the 1990s, due to the abolition of the socialist economic structure, the Central and Eastern European Countries (CEE) were suddenly forced to thoroughly transform their political and economic systems (Radosevic, 2001). This drastic situation is unique in history. With the transformation process, high expectations arose regarding policy, economy, and science (Walter, Bross 1997). This process included strengthening and fusion of previously dislocated business functions like marketing, R&D and finances, discarding of the social functions and the de-verticalization of previously vertically integrated chains of production and supply (Radosevic, 2001).

This study focuses on the relationship between expenditure in R&D and the number of patent applications. The purpose of this study is to examine if the business sector is the most important institutional sector for patent applications. We are going to test four hypotheses:

H1: If R&D expenditure is increased more patent applications than the average would be created.

H2: If a country promotes R&D in the business sector - BERD (Business Enterprise Expenditures on Research and Development), the number of patent applications will increase more than if the country promotes R&D in general.

H3: It is better to measure the number of patent applications with regards to BERD than GERD (Gross Domestic Expenditures on Research and Development).

H4: Number of patent applications is expected to increase a few years after R&D expenditure (time-lag), but is different between countries.

2. R&D performance evaluation measures

Geisler (1994) suggests that R&D studies can be divided into:
- input-related approaches,
- output-related approaches,
- input-output approaches.

Traditionally, measures have been related more frequently to R&D input than output, because of the belief that there should be a positive relationship between the amount of resources allocated to R&D and R&D output and, therefore: the higher R&D expense, the higher the output (Chiesa, Masella, 1996). But this study falls under Geisler's categorization as an input-output approach. He defines input-output approaches as "economic assessment of the R&D process and its performers". Inputs in the R&D process are resources and funding (Winthrop et all, 2002). In our study we are going to focus only on R&D expenditure as an input.

Innovation output can be measured using a number of parameters, including the production of knowledge, the improvement of production processes, and the development of new products.

Measuring R&D performance has always posed many problems, which can be related to the nature of the R&D activity (Chiesa, Masella, 1996). Difficulties in R&D measurement include uncertainty, which is very high (Melkers, 1993), multiple consequences - once completed, the R&D output is in itself often highly fuzzy and not definable and, thus, not measurable, its cumulative nature - the ultimate result of R&D activity can be viewed after a period of several years, once an innovation has been brought to the market, but, at this time, the outcome is the result of the efforts of both the R&D unit, other company functions (Chiesa, Masella, 1996), and transferability.

Because evaluating the actual outputs of R&D is so difficult, bibliometrics, the study of publication-based data, serves as one often use proxy (Melkers, 1993). Typically, publication data is used to estimate basic research outputs, while patent data is used to measure "inventiveness, innovation, or technological change" (Papadakis, 1993) of technological development (Holbrook, 1992). As a measure of innovation of inventiveness, patents tend to measure outputs of applied research and development research (Winthrop et all.).

Another measure of innovative output is the number of patent applications. Every innovative output in the research laboratory and the factory is generated as a form of information. Patent application serves as a way for a firm to protect its own knowledge, which could easily be stolen by the competition. The number of patent applications is therefore considered a calculation proxy of innovative output. Of course there are shortcomings in using patent applications as a measure of innovative output. All patents cannot be thought to have equal value. Some represent significant innovation, while others represent peripheral innovation. Some patents are held for only a short period. It is also known that the propensity to patent differs from industry to industry, since the effectiveness of the patent system protecting intellectual property rights is not equal in all fields. Despite these shortcomings, the number of patent applications is still a useful index for measuring the innovative knowledge production of firm (Wakasugi, Koyata, 1997).

Hingley (1997) stated that the transmission of R&D discoveries into patent applications remains an important part of the innovative process. If the relationship can be properly systematized then it can be used as a foundation upon which to build other measures of innovation.

Residents of the contracting states of the European Patent Convention (EPC) currently have two routes for making patent applications in their own country:

- European first patent applications – apply to the European Patent Office (EPO) either directly for a European Patent designating the home country, or indirectly under the PCT system but designating the home country.
- National domestic applications – apply to the national patent office of the home country. A subsequent application is then allowed to the EPO within 12 months, using the "priority" of the original national application.

Many studies find that patents are a sort of indicator of industrial performance. This paper attempts to analytically clarify the structure of a «knowledge production function», as it has been termed by Griliches (1994) and Kondo (1995), with R&D expenditure as an input and patent applications as an indicator of the output of R&D, for different countries (Hungary, the Czech Republic, Slovenia, Finland and OECD countries).

The function adopts patent application as an output rather than patents granted. The patent process has several formal and informal steps that must occur before a patent is issued (Miller, Davis, 1990), consequently it takes few years for a patent to be granted from its date of applications. Therefore it is difficult and, more likely, not meaningful to analyze the relation between R&D investments and patents granted (Kondo, 1999).

3. Institutional sectors

Sectoring means classifying of scientific-research and R&D organisations and R&D units according to principal activity, objectives, economic and legal status, and sources of funds into five institutional sectors: Government Sector, Business Sector, Higher Education Sector, Private Non-Profit Sector and Abroad (SYRS 2003).

3.1 Government sector. Government sector includes scientific-research institutes and other organizations financed from the state budget (SYRS 2003). Governments of most OECD countries spend a lot of money on R&D, either by supporting their own facilities (universities and public laboratories) or by funding firms. Beyond fulfilling certain public needs (defence or health), a rationale for government support is that the social rate of return in R&D is higher than the private rate of return. Subsidization reduces the private costs, therefore increasing the private returns. Although a positive relationship between public funding and private funding might be expected, it is sometimes argued that government support essentially substitutes for, or even crowds out, business funding (Guellec, Ioannidis, 1997).

*3.2 Business sector***.** Business sector includes all companies and other organizations, the basic activity of whose is market production of goods and services. This sector mainly covers R&D units, development sectors, departments and development groups in companies (SYRS 2003).

The importance of innovation for a firm's success is well documented in literature (Teague 1999). Furthermore it is suggested that innovation is critical for the survival of countries. Innovation is the heartbeat of economies. Without it firms cannot introduce new products, services and processes. They find it hard, if not impossible to gain a market share, reduce costs or increase profits. In effect, if the pulse of innovation is missing, firms quite simply die out (Guinet and Pilat 1999).

Innovation is a comparative advantage of an economy, because new, improved, more functional products are more attractive for customers they expand the company’s market and give it the advantage of being the first seller in the field (Celan, 2002).

Numerous studies have shown that R&D expenditures constitute the most influential variable in a firm's ability to innovate (Dosi, 1988; Freeman and Soete, 1997). Investment in R&D enables firms to hold a competitive edge over their competitors, at least during the first stage of the innovation diffusion process (Shefer, Frenkel, 2003).

3.3 Higher education sector. Higher education sector includes all universities (public higher education institutions) and research institutes, experimental stations and clinics, which operate under direct supervision and management of higher education institutions or are connected with them. The nucleus of this sector is formed by universities and faculties. University hospitals and clinics are included because of their connection with higher education (SYRS 2003). Universities and other higher education institutions are key elements of the science system in many countries. They perform research and train researchers and other skilled personnel. In recent years, significant changes in the university environment have affected the research-related missions of these institutions. In particular, universities are becoming more diverse in structure and more oriented towards economic and industrial needs, while coping with higher student enrolments, particularly in continental Europe.

With the increasing emphasis on national economic well-being and international competitiveness in OECD countries in the recent years, the production, application and use of new knowledge have become very important. As key locations for both research of new fields and for the training of future researchers and skilled personnel, universities and other higher education institutions have found themselves inevitably drawn into the modern national politics arena. Universities are, however, only one of several research-oriented factors. They are important, and in many ways strategic. Nevertheless the role of universities in the overall national research endeavour is both distinctive and defined by their other aspects, most notably their educational and training functions. Governments, as well as private interests, are also forcing universities to be more relevant contributors to innovation in a context of increasing global economic competition (University research in transition).

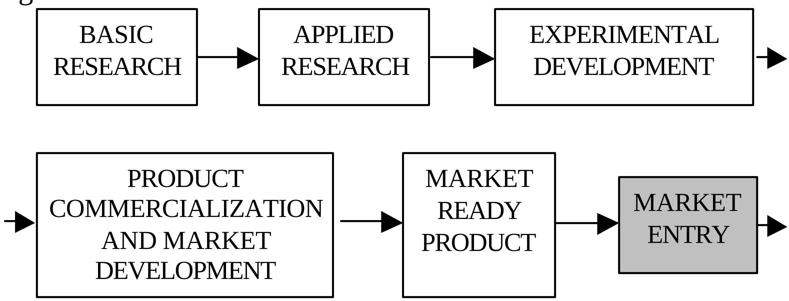
3.4 Private non-profit sector. Private non-profit sector includes private non-profit institutions which supply private person and households. They are financed by their founders, and partly with the funds contributed by companies and the government. According to international conventions, this sector also includes the R&D work of citizens (private researchers) (SYRS 2003).

3.5 Abroad. Abroad represents a special sector, mostly based in the field of financial inflow and outflow in the scientific-research sphere and the R&D sphere (SYRS 2003).

4. The innovation chain

There are multiple players in the innovation chain, whose degree of influence and activity varies along this chain and therefore there are differences in the number of patent applications. For a concept to be developed, commercialized and eventually introduced into the market, there are a number of stages to be followed. Although this is a cyclic process, the chain has been shown linearly with the various key steps shown in Figure 1 for the sake of illustration.

Figure 1: The innovation chain



Source: Sharpe, 2002

For our analysis the first three stages are important, therefore we are going to discuss them.

4.1. Basic research. Basic research is experimental and theoretical work, the main objective of which is to obtain new knowledge on the basis of basic phenomena and observed facts (SYRS 2003).

It analyses characteristics, structure and relationships to check hypotheses, theories or laws. Results of basic research are not patentable and are usually not sold to potential users but they are usually published as scientific articles or sent directly to interested parties. Usually scientists work in basic research, setting their own goals and mainly organizing their work themselves (Frascati, 1992).
It is oriented into the future, but there is a possibility that some of the discoveries will never be used. The results are often unpredictable. Because they are often groundbreaking, mistakes are not rare; some of them can appear after a few years or decades. Basic research does not have positive or negative results. Although it is seen successful if the scientist confirms his hypothesis, the scientific advantage is the same if the results are positive or negative. Of course the scientific work should be done correctly. If it is so, the result can have national or even international significance. Because of such nature of the work, the results are usually not suffering from time constraints (Likar, 2001). Pure basic research leads to the improvement of knowledge, without persuading long-term economic goals and advantages of society and without the direct purpose of using these results for solving practical problems or practical use. Oriented basic research is intended for discovering new, needed knowledge, which could be the basis for solving current and expected problems and taking advantage of opportunities (Frascati Manual, 1992).

In this article we are going to focus on the business sector, because the business sector is the most important sector of R&D performance in most countries. This sector produces most patent applications, which we are going to use as a measure of output. Therefore we are going to compare the influence of expenditure on R&D in the business sector (BERD) with the number of patent applications and the influence of gross domestic expenditure (GERD) on the number of patent applications.

4.2 Applied research. Applied research is also original research, aimed at obtaining new knowledge. It is aimed at attaining specific practical goals and purposes. The results of basic and applied research are connected in science as a system of knowledge of phenomena and laws in nature and society (SYRS 2003). Their purpose is to find out how we can use the findings of basic research or to define new methods or new ways for achieving goals. They include the use of available knowledge and its improvement, which is necessary for solving individual problems (Frascati Manual, 1992).The purpose of applied research is to transfer knowledge into practical use, so concrete results of actual problems are expected as soon as possible. The methods are usually not known beforehand, even though research is connected with transferring knowledge into the next links of the chain, the time limits sometimes cannot be kept (Likar, 2001).

4.3 Experimental development. Experimental development is the systematic usage of knowledge obtained by research and experience. It is aimed at producing new materials, products or devices and at creating new processes, systems and services or improving the already existing ones. It is hard to clearly define the line between experimental development and production, so that it would be applicable in the whole industry, instead a number of conventions and criteria should be designed according to the type of the industry (Frascati, 1992). Inside development is usually used only for developing new internal methods and product, and for copying the competition. If copying, the demands the research divisions face are slightly lower, but they still have to find their own developmental way of solving the problem. The demands are even further reduced by buying and transforming patients into methods or products.

5. Time-lag

Cleary, it takes time to perform research and to publish results in journals or to apply for patents. Depending upon the discipline, it can often take 2 years or more to publish a journal article once it is written. Similarly, the patent process has several formal and informal steps that must occur before a patent is issued (Miller and Davis, 1990).

Analysis of the time-lag between R&D expenditure and patent applications:
- Greif (1985), using German data, concluded that the time-lag was between 1 and 2 years, by observing the peaks and troughs of the changes in nominal R&D expenditure and the changes in the number of patent applications,
- Hall et al. (1986), using US company data, did not find a time-lag between R&D and patenting, using a distributed lag model; they concluded that there seemed to be a contemporaneous relationship between them,
- Kondo (1998) claims that the time-lag between R&D expenditure and the patent application is found to be between 1.5 and 1.7 years, from the early 1970s to the middle of the 1980s in the industry of Japan as a whole.

6. Model for R&D - Patent dependence

Kondo (1999) used four models for the R&D patent function with the R&D expenditure as an input and patent applications as an output (a linear model, a linear dynamic model, a log-linear model, a quasi-log linear dynamic model). He found out that among them, a linear dynamic model has the highest coefficient of determination. This suggests that R&D expenditure contributes to the increase of patent applications directly as well as through technology stock as well. He found out that logarithmic models show worse performance compared to corresponding non-logarithmic models. Especially, the estimates of constants are not good since their t-values are small.

This result suggests that patent application increases in proportion to the increase of R&D expenditure and technology quantity rather than exponentially with the increase of R&D expenditure and technology quantity. We used three models for the R&D patent function with R&D expenditure as an input and patent applications as an output. Models are presented in Figure 2. As an input we used R&D gross domestic expenditure (GERD) and expenditure in the business sector (BERD). We used BERD, because the business sector largely finances patentable research, probably leading to better results.

Figure 2: Models for the R&D patent function

• A LINEAR MODEL P(t) = a + b*GERD(t-m) P(t) = a + b*BERD(t-m)	Where: - a and b are coefficients, - P(t) is a number of patent applications at the period t, - BERD(t) is R&D expenditure in business sector at the period t, - GERD(t) is gross domestic expenditure on R&D at the period t - and m is time-lag.
• A LOG-LINEAR MODEL lnP(t) = a + b*lnGERD(t-m) lnP(t) = a + b*lnBERD(t-m)	
• A POWER MODEL $P(t)=a*GERD(t-m)^b$ $P(t)=a*BERD(t-m)^b$	

7. Analysis

Like Kondo (1999), we found out that the logarithmic model shows worse performance than the linear model; and the power model shows similar results to the linear model. Therefore we are going to focus on the results of linear regression.

The period covered by the analysis is from 1981 to 2001. This time period is largely dictated by the availability of data on R&D. Data on business enterprise R&D expenditure (BERD) and gross domestic expenditure on R&D (GERD) are in million dollars in constant 1995 prices and PPP (GDP calculated by purchasing power parity) from OECD. The quality, or at least the comparability, of national R&D data is also open to question, since each country collects and aggregates information from the public and private sectors, according to its own definitions (Hingley, 1997). Therefore in this study we are going to use the number of patent applications to the EPO (European Patent Office). Least-square regressions were carried out varying time-lags by the step of 1 year to find time-lag between patent application and R&D expenditure.

Data for the analysis are collected from the OECD, Main Science and Technology Indicators, May 2003. The detailed statistical analysis was performed with the program package SPSS version 11.

Table 1: Regression results

HUNGARY	data from 1990 to 2001	determined time lag = 3 years
Patents (t) = -23,78 + 0,07 * GERD(t-3)		R^2 = 0,67 Std. Err. of the estimate = 8,28
Patents (t) = -29,20 + 0,20 * BERD(t-3)		R^2 = 0,90 Std. Err. of the estimate = 4,48
CZECH REPUBLIC	data from 1991 to 2001	determined time lag = 2 years
Patents (t) = -72,63 + 0,07 * GERD(t-2)		R^2 = 0,75 Std. Err. of the estimate = 8,77
Patents (t) = - 74,34 + 0,11 * BERD(t-2)		R^2 = 0,52 Std. Err. of the estimate = 12,00
SLOVENIA	data from 1993 to 2001	determined time lag = 1 year
Patents (t) = - 32,84 + 0,14 * GERD(t-1)		R^2 = 0,44 Std. Err. of the estimate = 5,61
Patents (t) = - 11,34 + 0,17 * BERD(t-1)		R^2 = 0,57 Std. Err. of the estimate = 4,93
FINLAND	data from 1981 to 2001	determined time lag = 0 years
Patents (t) = - 404,54 + 0,47 * GERD(t)		R^2 = 0,97 Std. Err. of the estimate = 61,34
Patents (t) = - 290,67 + 0,67 * BERD(t)		R^2 = 0,98 Std. Err. of the estimate = 59,08
OECD	data from 1981 to 2001	determined time lag = 1 year
Patents (t) = - 39183,7+0,24*GERD(t-1)		R^2 = 0,98 Std. Err. of the estimate = 2790,97
Patents (t) = - 36616,7+0,35*BERD(t-1)		R^2 = 0,99 Std. Err of the estimate = 2350,20

First hypothesis (H1), that more R&D expenditure produces more patent applications, is accepted quantitatively here. For all countries the coefficient b is positive. The fact that the increase of R&D expenditure causes the increase of patent applications could be interpreted in two ways. More R&D expenditure will enlarge the frontier R&D activities, improve the probability of R&D success and eventually increase the number of patent applications. Another interpretation is that company researchers come under increasing pressure to apply for patents as a justification for their R&D budgets. Even in the latter case, however, they cannot apply for patents unless they achieve something.

Second hypothesis (H2), that the number of patent applications will increase more if the country promotes R&D in business sector more than in general, is valid also for all countries, coefficient b is higher in BERD than in GERD.

Third hypothesis (H3), that it is better to measure the number of patent applications with regards to BERD than GERD, is valid for all countries, except The Czech Republic. The number of patent applications depends more on BERD than GERD expenditure (R^2BERD> R^2GERD).

Comparing the coefficient of determination we see that Hungary, Slovenia and the Czech Republic also host a number of unknown (mostly random) factors, which also influence the number of patents alongside the R&D spending. Patents in the developed states mostly depend on GERD and BERD expenditure (R^2>0.97).

One of the reasons for the differences in coefficients is in the characteristics of the present development of economy. Slovenia, Hungary and the Czech Republic are former socialist countries. For these countries it is characteristic that, during socialism, enterprises were reduced to production units, while innovation processes were governed by the government and the party hierarchies. The closed character of these economies, though of varying degrees in different countries, only enforced their technological stagnation. Differences in the degrees to which enterprises were constituted as business units and the degree to which economies were open, have overwhelming influence on the way different CEE countries have modernized their industrial systems during the 1990s. In addition, differences in interaction between the national industrial systems and the international value chains, which took place during the 1990s across different CEE countries, can explain to great extent differences in depth and breadth of industry restructuring. These differences are leading to very diverse outcomes in terms of growth, the type of market economy that is emerging in different countries, as well as in terms of innovation and technological capability (Radosevic, 2001).

If we compare the coefficients of determination of BERD in the CEE states we discover that Hungary has a small number of random factors influencing patent applications. In contrast to other countries of Central and Eastern Europe, Hungary began the process of transition from a centrally planned economy to a market economy in the 1970s. Hungary has significantly broadened the scope of its economic reform program since 1990, and has achieved substantial progress in the market-oriented structural reform during the recent years (NSF EUROPE, 1993). Selling companies to foreigners yielded good results, since companies owned by foreign investors spend more money on R&D (Bejakovic, 2003).

The last hypothesis (H4), that the number of patent applications should be quantitatively related to the number of applications for patent protection some time later (time-lag), but is different between countries, is also valid.

The time-lag between R&D expenditure and patent application has been found analytically for all countries, except Finland. The most important products of Finland are high-tech products, especially telecommunications equipment. High tech products have to be introduced into a market quickly. The determined time-lag between R&D expenditure and patent application for other countries varies from country to country and it is longer for less developed countries.

8. Conclusion

R&D investment appears to have paid off in the increase of patent applications. The analysis showed a positive correlation between R&D and patent applications. The analysis also showed that the increase of R&D expenditure in business sector increased the number of patent applications more than increase of R&D on general. Model for R&D – patent dependence is valid for developed countries.

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