STRATEGIC R&D AND PATENT BEHAVIOUR IN SOME EU-COUNTRIES

by

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Abstract

This paper will be focused on two issues. Firstly, entrepreneurial innovative behaviour will be explained and, investigating the corresponding literature, it will also be concluded that innovation can reasonably be explained by patent behaviour. Secondly, because of the essential role of R&D spillovers, these will be considered in greater detail.
In this respect, strategic R&D behaviour of private enterprises will be analysed under the occurrence of spillovers. Based on imperfectly competitive product markets, optimal R&D and output strategies are mutually compared. A test for various EU countries is provided using the average propensity to patent (APP) as a crude measure for the absence of spillovers. This test is applied on a panel of 22 sectors using OECD, EPO and EUROSTAT data for Belgium, Denmark, Germany, Italy, the Netherlands and the United Kingdom over the sample period 1989-1995. It is found that (coherent) long-run forecasts for the number of patent applications are feasible for Denmark and Germany but not for the other four EU-countries considered.

Keywords: Game Theory, Innovation, Patents, R&D Spillovers

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1. Introduction

Innovation should not be confused with *invention*. An invention becomes an innovation if it can be used in practice, i.e. in economic terms, if it can be commercialised (see e.g. Kabla (1996), p. 57). According to the European Commission (1996, p. 12) innovation is related both to a process and to the result of this process. As a process, innovation means the transfer of a (new) idea into a (new) tradable product, service or production method. The European Green Book of Innovation (1996) proposed innovation as result schematically as:

- the renovation and extension of the existing set of products and services and of the corresponding markets;
- the introduction of new production and distribution methods;
- the introduction of changes in the management, the labour organisation and labour circumstances.

Hence, there are several types of innovation: we may distinguish product innovation, process innovation, market innovation, organisational innovation, social innovation, institutional innovation, financial innovation, etc….

Innovation can be studied on different levels: plants, firms, sectors, regions, countries, unions of countries. A comparison is only possible if a measure of innovation is available. Various indicators exist: the level of Research and Development (R&D) expenditure as an input variable, the number and the kind of patents as an output variable, the balance of trade, the technological balance and entrepreneurial enquiries (see van Leuven (1996), p. 1).

A number of economic and more institutional arguments can now be formulated to prefer patents *vis-à-vis* the other governmental instruments, however, without neglecting the latter. The disadvantages of this choice do not offset the advantages, which becomes also clear from recent inquiries of the innovation behaviour of British, German and French firms (see Arundel and Kabla (1996)) and from recent American studies as Kortum and Lerner (1999)).
During the second half of the seventies and during the eighties R&D expenditures were preferred to patent data in order to test empirically the Schumpeterian hypothesis of a positive relation between the size of a firm and technical progress. But since a number of studies have shown that patents are a reliable indicator of innovative activities (see e.g.. Acs and Audretsch (1989), Griliches (1990) and Arundel and Kabla (1996)) patent data sets are recently used intensively to investigate technological changes on the entrepreneurial, sectoral, regional and country levels (see e.g.. Baldwin (1996) and Patel and Pavitt (1995)).

In the literature strategic innovation analysis is based on the path-breaking article of d'Aspremont & Jacquemin (AJ (1988)) and leads to two essential questions:

- Is R&D expenditure a good measure for innovation activities, or are patents a better measure?
- How can R&D spillovers be measured efficiently?

D'Aspremont & Jacquemin (AJ (1988)) were the first authors to systematically present a strategic analysis on decisions of R&D expenditure and (homogeneous) output quantities under duopoly in a two step game. They showed that with sufficiently large spillovers R&D cooperation (e.g. in the form of a Research Joint Venture - RJV) leads to more output, more R&D and more welfare. If both domestic and foreign R&D spillovers exist an international RJV will generally innovate less than competitive national RJVs (Brod and Shivakumar

(1997)). The basic AJ (1988) model has been extended in several ways, e.g. De Bondt *et al.* (1992) and Kamien *et al.* (1992) introduced differentiated products under output (Cournot) and price competition (Bertrand), Suzumura (1992) has extended to output oligopoly and Leahy and Neary (1997) derive explicit rules for optimal government intervention under perfectly symmetric information. Nevertheless, all these extensions from product homogeneity to product heterogeneity, from duopoly to oligopoly and from the occurrence of national spillovers to that of international spillovers, keep the basic AJ (1988) conclusions unaltered. Hence, optimal R&D and output strategies will be based on this analysis.

Based on graphical representations of innovation and output regimes resulting from the application of a multi-step game to extended problem settings mentioned above, and taking account of a panel data analysis of 22 sectors using OECD, EPO and EUROSTAT data for Belgium, Denmark, Germany, Italy, the Netherlands and the United Kingdom over the sample period 1989-1995, answers to the above questions will be provided. Regarding the first question, patents will be seen to be a reasonable measure for innovation. The second question should be answered by analysing R&D spillovers based on a weighting matrix measuring the *proximity* between the innovator(s) and the receiver(s) of innovation[1]. However, since we do not possess (yet) sufficiently detailed entrepreneurial (patent) data, we have to stick to a crude measure for (the absence of) spillovers using sectoral EPO patent data. In this respect inverse R&D spillovers will be (roughly) approximated by the average propensity to patent (APP) being defined as the number of patents per million of PPP-dollars of R&D expenditure. Efficient long-run innovative behaviour could be detected for Denmark and Germany with decreasing average products of patents corresponding to decreasing returns to scale with an elasticity in the neighbourhood of minus 1 so that in these countries small firms with lower R&D budgets tend to produce more patents per R&D dollar than large firms with higher R&D budgets.

Summarising, we want to explain strategic innovative behaviour utilising a.o. patents (rather than explaining optimal patent behaviour itself) and we would like to analyse R&D spillovers. Therefore, strategic R&D and output behaviour under the explicit occurrence of R&D spillovers will be analysed in section 2 and special attention will be devoted to the relationship between (the number and the costs of) patents and R&D expenditures and more specifically to the role of patents as an indicator of innovation in section 3. The above mentioned application on five EU countries will be treated in section 4, while section 5 will conclude.

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[1] Such as the following types of patent-related R&D diffusion measures based on a proximity weighting matrix:

- an *invention input - output analysis* according to the Yale Technology Concordance analysis which assigns patented inventions to the manufacturing industry and to the using ('consuming') industry by utilising e.g. the International Patent Classification (IPC) system (see Evenson and Johnson (1997));
- a *sectoral and regional split of a matrix of patent applications* where the patent applications are distinguished according to the industry and to the region/country of origin, according to the country for which protection is proposed and according to the period (year) of application (see Kortum and Lerner (1999));
- a *citation analysis of patents* which measures technology spillovers based on those patents of other firms/industries/regions/countries which are cited in a patent application (see Jaffe *et al.* (1993));
- a *co-classification method of patents* where patents are classified according to two or more narrowly related technological sectors and where corresponding spillover measures are introduced (see Grupp (1996)).

2. Strategic R&D and output behaviour with spillovers

In this section strategic R&D and output behaviour of private firms, when (national and international) R&D spillovers may be prominently present, will be studied on the basis of the 'AJ model' in AJ (1988). Indeed, the diffusion of innovation is (almost) always accompanied by externalities or spillovers. According to Griliches (1979) and Jaffe (1996) three types of R&D spillovers may be distinguished:

- *Rent or pecuniary (or market) spillovers* which emerge when R&D intensive inputs and outputs are bought from other firms at a price lower than the market (or quality adjusted) price so that a rent or monetary advantage for the buyer arises. There are two possible reasons for this outcome: first, only a perfectly discriminating monopolist would be able to appropriate all social returns to the innovation and, second, if the downstream buyer is in an imperfectly competitive industry, the buyer will be able to appropriate some of the returns of the innovative product or process it purchased.
- *Knowledge spillovers* which are related to the knowledge diffusion: as a consequence of a sometimes insufficient patent protection, the incapability to keep innovations secret, 'reverse engineering', etc… a part of the (individual) R&D returns will 'leak'. Hence, knowledge spillovers are financial advantages other enterprises can obtain by using R&D results of innovative firms so that this type of spillovers reflects the transfer of R&D knowledge (not necessarily embodied in a product or service as for rent spillovers) from one agent (innovator) to another (receiver of innovation) without adequate compensation. According to Bernstein and Nadiri (1988) knowledge spillovers are either horizontal or vertical where horizontal spillovers describe knowledge flows between competitors and vertical spillovers describe knowledge flows between firms in different industries (both are based on a public good characteristic of knowledge).
- *Network spillovers* which are present when the successful implementation and economic value of a new technology is strongly dependent on other complementary technologies. Following Vonortas (1997, p. 18) network spillovers are present if, by undertaking an R&D project, a firm creates a positive externality to others interested in complementary projects by raising their expected commercial payoff. Network spillovers therefore lead to an implicit coordination problem. Notice, however, that knowledge spillovers are not a prerequisite for network spillovers.

Notice that all three types of R&D spillovers may lead to market failure by adversely affecting the incentives of individual firms to invest in R&D. It should be kept in mind, however, that, empirically, it is sometimes difficult to make a distinction between certain types of R&D spillovers, as e.g. van Pottelsberghe (1997) observed between rent and knowledge spillovers.

From a theoretic point of view, the basic AJ (1988) analysis utilises knowledge spillovers, as will become clear from the brief exposition below.

2.1 Some characteristics about the basic AJ (1988) model

AJ (1988) formulate a two step game for a basic duopoly model: both firms decide simultaneously in the first step about their R&D expenditures x_1 and x_2 and in the second step about the quantities q_1 and q_2 to be produced of their homogeneous final output. The R&D expenditures of the first step determine the production costs of the second step: the marginal production cost of firm i is given by A_i - x_i - βx_j, where A_i is the marginal production cost of firm i (i=1,2) if both firms have no R&D expenditures; the R&D expenditures of firm i, x_i, decrease in a direct way the production costs of this firm and the R&D expenditures of firm j, x_j, decrease the production costs of firm i at a rate of βx_j, with the *spillover parameter* β satisfying $0 \leq \beta \leq 1$. Hence, this parameter indicates how intensive firm *i*s production costs are decreased by the other firm's (firm j) R&D expenditure without any remuneration of firm i to firm j. This is related to the free rider argument for knowledge spillovers with R&D as a public good.

This leads to the following regimes:

(1) regime (NC,NC), with non-cooperation for R&D as well as for production, yielding as optimal R&D expenditure and optimal output for each firm x^* and q^* respectively[2];

(2) regime (C,NC) with R&D cooperation and no cooperation in production, yielding $\hat{x}$ and $\hat{q}$[3] as optimal R&D expenditure and optimal output respectively;

(3) regime (C,C) where cooperation emerges both for R&D and production, leading to the optimal monopoly values $\tilde{x}$ and $\tilde{q}$ for R&D expenditure and output respectively.

Defining a social welfare function $W(x,q)$ as the consumers' maximal willingness to pay less R&D and output costs, its maximising values can be represented by x^{**} and q^{**} respectively.

On figures 1 and 2 it is shown how the solving values of x and q depend on the spillover parameter β, while in figure 3 the value of the social welfare function $W(x,q)$ is shown for the four combinations of x and q, and for all possible values of .

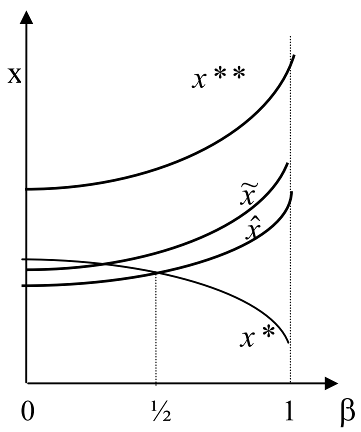

Figure 1

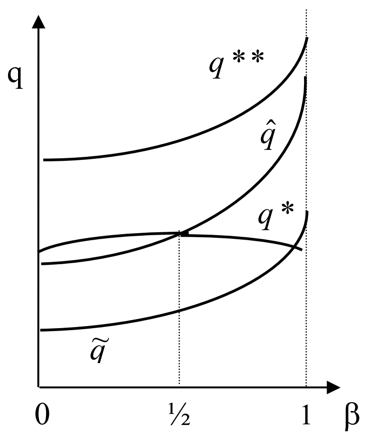

Figure 2

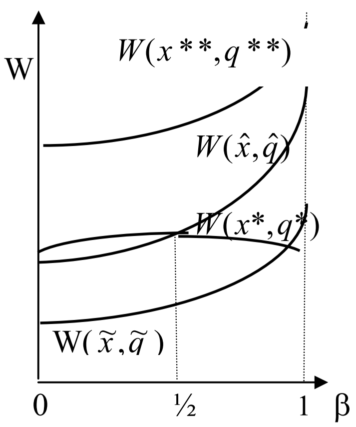

Figure 3

[2] Because of the (assumed) symmetry between these two firms these variables have equal values for both firms.

[3] As already mentioned earlier this regime is characteristic for RJVs between competitive firms in the output market (see e.g. Vonortas (1997) for a recent and clear treatment of the US situation).

From the above figures some interesting conclusions can be derived.

1. From the point of view of social welfare both R&D expenditure and output of the whole industry are too small for the three regimes of cooperation and for all feasible values of the spillover parameter β.
2. The dependency of the overall R&D expenditure x on the spillover parameter β for the three regimes is complicated; Kamien *et al.* (1992) distinguish a double effect of β on x:
   - competitive effect: a larger value of β leads to a relatively larger advantage of the competitive R&D expenditure; this larger 'competitive leakage' will reduce the (own) R&D expenditure;
   - market effect: a larger value of β leads to lower marginal production costs in the complete industry, and, hence, to a higher demand and output.

   The competitive effect is strong in the fully non-cooperative regime (NC,NC), which is represented by the downward sloping expenditure curve. On the other hand the market effect dominates in the (more) cooperative regimes (C,NC) and (C,C).
3. If there is competition in the output market, R&D cooperation (regime (C,NC)) will lead to a higher R&D expenditure and a higher output than in the fully non-cooperative regime (NC,NC) if the spillover-effects are sufficiently strong. Hence, under high R&D spillovers, R&D cooperation leads to more output, more R&D and more welfare. In the numerical simulation R&D expenditure and output for the industry satisfy $\hat{x} \rangle x^*$ and $\hat{q} > q^*$ with $\beta \rangle 0.5$.
4. If R&D cooperation is accompanied by monopoly in the output market (regime (C,C)) the R&D expenditure $\tilde{x}$ will be always higher and the output $\tilde{q}$ always smaller than in the semi-cooperative case (regime (C,NC)). Indeed, it immediately follows from figures 1 and 2 that $\tilde{x} \rangle \hat{x}$ and $\tilde{q} \langle \hat{q}$ for all values of the spillover parameter β. In regime (C,C) the firms are better off to attract all R&D profits; notice, however, that social welfare is lowest in this monopoly regime (C,C).

2.2 A further digression on R&D spillovers

R&D spillovers emerging within a sector ('intra-industry or horizontal spillovers') are generally higher than spillovers between different sectors ('inter-industry or vertical spillovers'), so that intra-industry spillovers will generally slow down the innovator's incentive to invest in R&D. The innovator may even decide to underinvest if the R&D spillovers are strongly positive. In this case one can benefit from the knowledge of another enterprise so that the innovator will not receive a fair return for his innovation. An example of this case where the innovator is discouraged to innovate further is e.g. illustrated by a French experience in 1988-89, reported by Crépon and Duguet (1996).
Next to the existence of these positive diffusion spillovers, also 'negative externalities' may be observed. These negative spillover effects may emerge from the competition on the knowledge market owing to the competitors' R&D expenditure, i.e. when a firm's innovation entails losses for competitors and maybe even for the whole society (e.g. a drastic innovation of a firm can expel competitors from the market or can create barriers to entry for other firms to enter the innovator's market). Through the existence of negative externalities, the

necessity of the recent reorientation of the public authorities to partnerships and to R&D cooperation (as e.g. the European programmes SPRINT and EUREKA and the encouragement of RJVs in the USA) is stressed.

Note that inter-industry spillovers are (almost) always positive and will stimulate the other firms' R&D efforts since these have no competitive effect on enterprises from different sectors.

From the strategic innovation analysis in this section it is not (yet) clear which is the best innovation measure: R&D expenditure as assumed in AJ (1988) or patent(s) (applications)? This will be discussed in the following section.

3. Patents as an indicator of innovation

As mentioned earlier, innovations are mostly the result of R&D efforts. Nevertheless, R&D expenditures do not seem to be a good indicator for innovations (see e.g. Bosworth *et al.* (1993)). These are not the sole input for innovation and do not guarantee any result at all. Hence, R&D is an input measure rather than an output measure. Moreover, R&D expenditures underestimate: (i) production related technological activities because these often occur outside the R&D department, or because these are developed by firms of other sectors and (ii) information related activities (principally software) since these are generally developed in system departments of firms or in external firms in the service sector (see e.g. Patel and Pavitt (1995)). Therefore, patents are often preferred as best indicators of innovative activity (see e.g. Symeonideis (1996)). In Appendix A advantages of the use of patents as innovation indicators will be compared with its limitations.

Summarising Appendix A we may confirm that the advantages of patenting as a measure of innovation are generally more appealing than its disadvantages. Moreover, in order to improve the innovation system, it is generally necessary that:

(i) favourable conditions can be created to protect R&D results such that firms can obtain a fair return from their R&D investments which will also encourage further entrepreneurial investments in R&D;

(ii) the diffusion of knowledge and new technologies can be organised.

The patent system is practically the sole intellectual property instrument that satisfies both conditions of protection and diffusion.

The causality relationship between R&D expenditure and patenting will be tested empirically in the next section. Since we do not possess firm data for our empirical testing, we have to stick to sectoral data, and, hence, also to measures of the inter-industry R&D spillovers.

4. Empirical tests on the endogeneity of R&D and patent behaviour

From table 1 in Appendix B it seems that there are *large differences in the sectoral averages of R&D intensities*, i.e. the average R&D expenditure as a percentage of the value added for 22 sectors and for six EU countries over the sample period 1989-1995. Belgium has a high R&D intensity in the sectors: 'drugs and medicines', 'professional goods' and 'chemicals excluding drugs', Germany in 'aerospace' and 'radio, TV & communication equipment', Denmark in 'drugs and medicine' and 'professional goods', Italy in 'aerospace', 'radio, TV & communication equipment' and 'motor vehicles', the Netherlands in 'electrical machines excl. communication equipment' (Philips!) and 'office & computer equipment', and the United Kingdom in 'drugs and medicine' and 'oil refining'.

The *number of patent applications* at the national patent offices remained more or less constant since the establishment of EPO in 1978; but, on the contrary, the number of patent applications with EPO, originating from EPC member states, has strongly increased[4]. In this way, the number of Belgian patent applications at the EPO evolved from 604.77 to 908.72 (an increase with more than 50 % in 7 years)[5]. The share of the Flemish patents in the total number of Belgian EPO-patents was in 1995 70 %, of which Agfa-Gevaert takes about one quarter for its own[6]. Other chemical enterprises such as Janssen Pharmaceutica, BASF, Bayer, etc… are less represented because many patent applications are introduced with EPO via the mother enterprise (with e.g. Janssen Pharmaceutica this is the American Johnson & Johnson).

The *average propensity to patent (APP)* of (sets of) firms, measured as the number of patents per million constant PPP (Purchasing Power Parity) R&D dollars (prices of 1990), is generally viewed as a measure for the efficiency of the R&D process. In this respect it measures the intensity with which the R&D inputs lead to patent applications. But the APP is also a crude measure of the inverse R&D spillovers. The inspiration for this interpretation originates from the graphical interpretation of the AJ (1988) analysis in section 3.1. If the

[4] See e.g. Bussy *et. al.* (1996), pp. 14-15, for the example of French patents; during the period 1978-1989 the number of French patents at the French national patent office remained oscillating between 10,000 and 11,000 patents, while the number of French patents at the EPO more than tripled from 1,152 to 4,348.

[5] Remark that we do not work with integers. Because of the EPO usage the patents are assigned proportionally to the countries/regions from which the applicants originate. Also the assignment to technological classes is proportional. This classification is made according to the scientific-technological criteria of the International Patent Classification (IPC) and does not correspond to the sector division of the production activities (NACE-Eurostat). Therefore, a concordance table has been used, which was kindly put at our disposal by Dr. Bart Verspagen (Merit, University of Limburg, Maastricht).

[6] The evolution of the Belgian patent applications at EPO between 1989 and 1995 is:

	1989	1990	1991	1992	1993	1994	1995
Flemish Region	254.3	340.87	349.92	480.51	577.26	609.66	617.2
Walloon Region	91	100.98	142.43	146.72	163.39	176.15	171.8
Brussels Region	60.14	76.27	49.77	79.21	79.37	83.89	93.19
Not classified	199.33	178.72	66.09	36.12	53.56	31.49	26.53
Total Belgium	604.77	696.84	608.21	742.56	873.58	901.19	908.72

(*Source: EPO Statistics (1997)*)

From the regional EPO-statistics of Eurostat it seems that the Flemish region is strongly present in the sectors 'professional goods' (high R&D intensity), 'office & computer equipment' (high propensity to patent) and 'drugs & medicines' (high R&D intensity) and also well in the sectors with moderate R&D: 'wood products & furniture' (Pat/RD = 1.42); 'textiles, clothes, etc.' (R&D int. = 1.84) and 'paper, paper products & printing' (R&D int. = 1.77). Wallonia is strongly present in 'chemicals, excluding drugs" (high R&D int. = 11..81) and 'ferrous basic metals' (R&D intensity = 5.25).

whole R&D quantity is patented (or kept secret) the spillover parameter β is equal to zero (no public good characteristic); on the contrary, if all the R&D results are made public immediately R&D becomes a public good and the spillover parameter β becomes unity. The larger the APP, the smaller the R&D spillovers, since a large part of the R&D activities are protected then. From table 1 in Appendix B it seems that, of all EU countries studied, the lowest APPs and, hence, the largest R&D spillovers seem to occur in Belgium. As already indicated in section 2.2 *large differences between the sectoral APPs*, and, hence, large differences in the presence of R&D spillovers, between sectors and countries can be observed. Between 1980 and 1989 the following industrial sectors were dominant: 'electrical capital goods', 'equipment for country transport', 'mechanical engineering' and 'basic chemicals' (see Bussy *et. al.* (1996), pp. 20-21). From table 1 in Appendix A it also follows that between 1989 and 1995 the APP was strongest in Germany and The Netherlands[7], and to a somewhat less extent in Denmark, the United Kingdom and Belgium[8].

The following 'specialisations', and, hence, low R&D spillovers are striking: 'office & computer equipment', 'food, beverages, tobacco' and 'rubber & plastic products' in Belgium, 'drugs and medicines', 'oil refining', 'other transport' (strongly increasing), 'ferrous basic metals' and 'non-electrical machinery' in Germany (1989-1993), 'electrical machinery excluding communication equipment', 'chemicals excluding drugs' and 'metal products excluding machinery' (strongly increasing) in Denmark, 'textiles, clothes, etc.' (as a consequence of a peak in 1993) and 'paper, paper products & printing' (peak in 1992 and strongly decreasing) and 'non-electrical machinery' in Italy, 'radio, TV & communication equipment' (strongly increased), 'shipbuilding', 'motor vehicles' (decreasing), 'non-electrical machinery', 'non-metallic mineral products' and 'wood products & furniture' in the Netherlands (1989-1994) and 'professional goods' in the United Kingdom.

In this empirical part we firstly analyse a dynamic panel data model where we investigate the (Granger) causality between the number of patent applications (remember that the costs of EPO patenting remained more or less constant over the sample period!) at EPO per country (divided over sectors and time) and the corresponding R&D expenditure in constant (1990) prices. In a first step we explain the number of patents through real R&D expenditure (with a minimum lag of one year)[9].

A linear and dynamic panel data model in the form of an *Error Correction Model* (ECM) with two lags at the maximum will be estimated for each country separately. This will be made for these relations where the number of EPO patents is explained as a (log)linear function of the relating R&D expenditure and the sectoral value added. But, still, an alternative reasoning

[7] The observed Italian average APP was even higher than that of Germany and The Netherlands, but if you take the average APP excluding one extreme value (26.2 APP for the Italian Paper, paper products & printing industry), then the observed Italian average APP is considerably lower (1.26 compared with 3.01).

[8] Notice that the mean of the propensity to patent is only related to two cross sections in Belgium, i.e. for the years 1989 and 1991; no R&D data are (yet) available for the other years so that the Belgian APPs are particularly unreliable.

[9] A delay of R&D expenditure of one year at the minimum is absolutely necessary since more than 75 % of the firms applying for a European patent at EPO request at their national patent offices for a national protection, precisely to avoid the risk of multiple refusal. So, these firms come one year later to the EPO, in other words, a one year lag implies that a contemporaneous relationship between the patent applications at EPO and the corresponding R&D expenditure already exists. This is not so obvious, although, as already stated before, we do not possess exact information about the timing of patenting, be it early or late in the innovation process.

could be followed. As argued in section 3 the number of patent applications can be interpreted as a reasonable indicator of innovation, certainly when patent application is of life importance for the firm (as in the pharmaceutical sector). In general, the number of patent applications is related then to changes in technological opportunities: favourable (expected) evolutions in the technology will be accompanied then by an increase of the number of patent applications. In this respect, patent applications can also be correlated with (future) R&D expenditure, certainly if the timing of patent application is long before the timing of innovation. Hence, R&D expenditure can also be explained from the number of patent applications lagged with minimum one year, where (lagged) patents are causal for innovation expenditure (see Geroski *et al.* (1996)). It follows from the statistical estimations of the ECMs for all countries that *a linear ECM* is better suited for our sectoral sample (about the first half of the nineties) than a log-linear ECM. According to shortage of space only some ECM models are presented in the appendix.

We have estimated dynamic versions of the error variance components model for panel data using ECMs (see appendix C)[10]. From the results in the first table (table 2) of Appendix D, it follows that linear long-run relations between the number of EPO patent applications and the level of R&D expenditure occur in Germany and Denmark, and the other three European countries investigated only show significant short-run behaviour. For Germany the long-run regression coefficient amounts $\hat{\beta} = -\hat{\lambda}_2 / \hat{\lambda}_1 = 0.044 / 0.175 = 0.25$ and for Denmark $\hat{\beta} = -\hat{\lambda}_2 / \hat{\lambda}_1 = 0.091 / 0.22 = 0.41$, which is consistent with the findings in table 1 since the average Danish APP (1.65) is lower than the average German APP (2.01), and the $\hat{\beta}s$ should be (somewhat) inversely related to the APPs.

Finally, as in Tsetsekos (1992) for the USA, the relationship between R&D expenditure and the APP (as inverse spillover measure) has also been estimated by ECMs. Here, it seemed that a log-linear relationship was better than a linear one for all EU countries considered. For Denmark e.g. this resulted in the following ECM panel data model for the period 1989-1994 (no data for Danish R&D expenditure in 1995; the $\overline{R}^2$ for the linear model was 0.006):

$$\Delta \log \hat{y}_t = 0.328 - 0.11 \log y_{t-1} - 0.116 \log x_{t-1} - 0.325 \Delta \log x_t + 0.105 \Delta \log y_{t-1} \quad \overline{R}^2 = 0.18$$

(t-ratios) (2.3) (-2.32) (-1.71) (-4.48) (1.24)

(no heteroscedasticity, DW=2.06, $\hat{\rho} = -0.032$)

with y_t the R&D expenditure and x_t the APP, with a long-run elasticity of patent propensity with respect to R&D expenditure of about -1, i.e. of -0.116/0.11=-1.05.

The long-run relationships between the number of EPO patents, the R&D expenditure and the (average) propensity to patent can be consistently presented in the following picture (figure 4), from which it is clear that through the positive intercept in the 'patent production function' the average product (i.e. the ratio between the expenditure for patents, i.e. in terms of the number of patents (since the unitary EPO patent costs were approximately constant during the sample period), and the R&D expenditure) is decreasing, which corresponds to the above decreasing returns to scale in the relationship between the R&D expenditure and the APP.

[10] This econometric inference was not performed for Belgium since our sectoral data bank comprises R&D data for only two years (1989 and 1991).

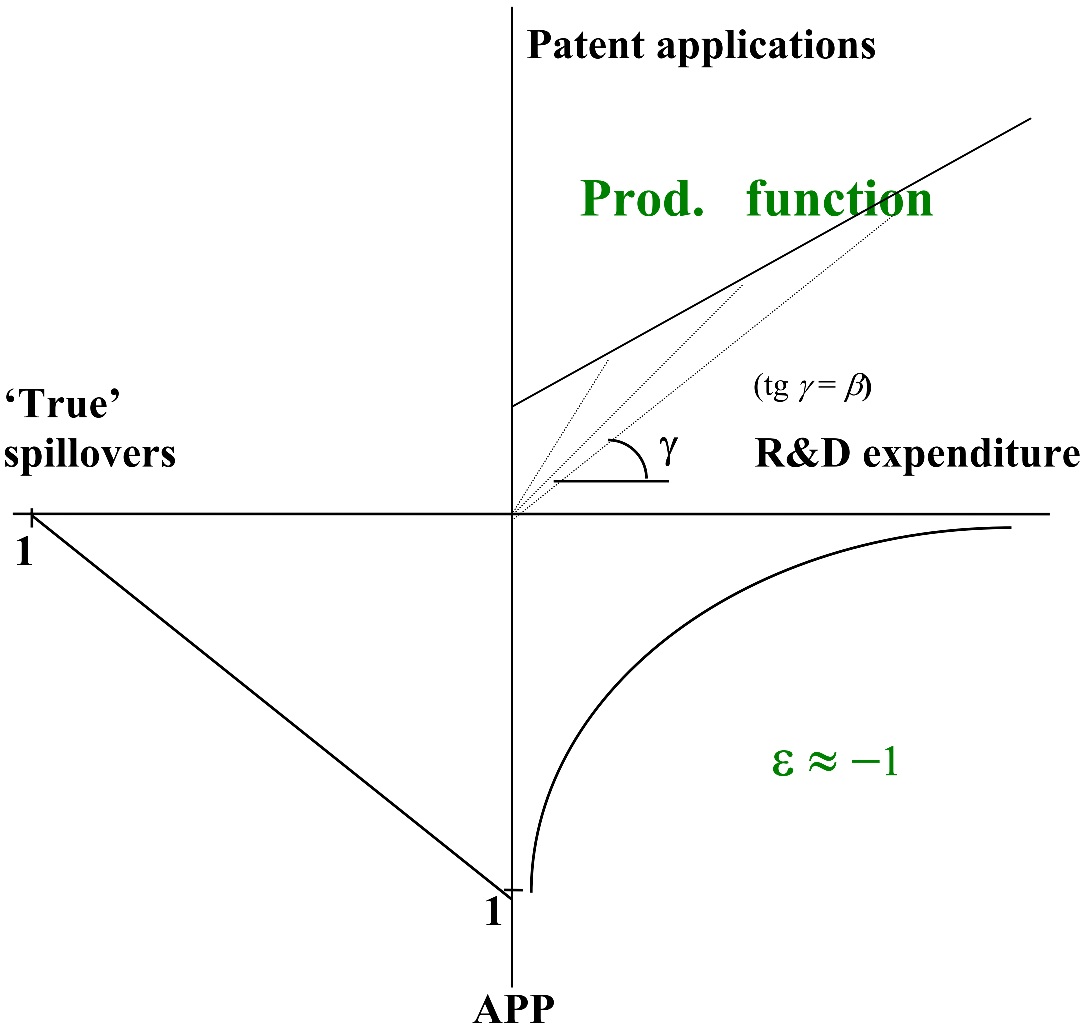

Figure 4 : R&D Long-term behaviour in Denmark and Germany

5. Concluding remarks

The object of this study was the R&D and patent behaviour of private enterprises (and of governments), with an application on sectoral data of some European core countries (except for France for which no sufficient OECD sectoral R&D data were available) for a panel of 22 sectors over the period 1989-1995. Data originated from OECD, EPO and EUROSTAT.

We can summarise the conclusions of this paper as follows:

1. First of all, it was argued that the number of patent applications was mostly a reasonable measure for entrepreneurial innovations, although the exact timing of the patent applications is often long before the major timing of innovation.
2. Since the available data did not allow us to provide efficient measures for the proximity between the innovator(s) and the receiver(s) of innovation, we defined, on the basis of a graphical inspection of the strategic and cooperative model of d'Aspremont and Jacquemin (1988) for R&D and output behaviour, a crude measure for the absence of R&D spillovers as the average propensity to patent, i.e. as the number of patents per million of PPP dollars of R&D expenditure.
3. From the data comparisons it seems that of all EU countries studied (Belgium, Denmark, Germany, The Netherlands, Italy, and the United Kingdom - not yet sufficient sectoral data for France)), the lowest (average) propensity to patent can be observed in Belgium, and, through our interpretation, the highest R&D spillovers. Germany and The Netherlands, and to a lesser extent Denmark, possess a relatively high propensity to patent.
4. The following long-run mechanism could be observed for Denmark and Germany. A loglinear inverse relationship between R&D expenditure and the (average) propensity to patent with a negative elasticity in the neighbourhood of -1, so that smaller enterprises with smaller R&D budgets have the incentive to apply for more patents per R&D dollar invested than large firms with large R&D budgets. Consistent with this observation we found that a positive long-run linear relationship exists between the R&D expenditure and the number of patent applications (sometimes, as for the Dutch data, with the number of (lagged) patents as a causal variable for future R&D expenditure). Taking account of the inverse relationship between the APP and the R&D spillovers, the observed mechanism at this point is fully consistent.

We would prefer that future research should introduce micro-data (entrepreneurial data), where horizontal R&D spillovers could be estimated and tested. Also uncertainty in the form of real options should be attributed a fair treatment.

APPENDIX A: ADVANTAGES OF AND LIMITATIONS TO THE USE OF PATENTS

A.1 Advantages of the use of patents

A.*1.1 Economic Arguments*

There is a *double economic rationality* to prefer patents instead of other governmental instruments such as investments in governmental research, direct governmental subsidies to private research projects, favourable tax tariffs for private firms in case of governmental R&D.
A *first* economic argument is that by taking patents the involved (technological) information is diffused. In general the inventor possesses more information about the invention than other agents as competitors, consumers and government. Through this asymmetry of information the innovator can obtain a competitive advantage and perfect competition no longer exists. This asymmetry can be offset through a patent because the inventor has to publish his innovation in order to obtain a temporary monopoly for his innovation. This will lead to a lower output and higher prices (lower welfare), but also to the revelation of new knowledge (see de Laat (1997a), pp. 3-4 and p. 149). However, as implied by the above observation, de Laat (1997a, pp. 37-56) has shown that welfare is not deteriorated through the asymmetric distribution of information among the economic agents.
A *second* economic argument to prefer patents is their flexibility. The returns of patents depend on various factors as their protection period, the degree of protection against imitation and the minimal improvement being necessary to obtain a new patent (see de Laat (1997b), pp. 370 and 384).

A.1.2 Some more institutional arguments

Published patent documents are among the main sources of technological knowledge, which is to a large extent only accessible through patent information. Herewith double work can be prevented, technological trends can be forecast and new products and processes can be introduced through licensing with the patent applier. Also the exact firms for new technology and know how can be retrieved through patent information.
Further, patent data sets are precisely available from official national and international patent offices, which cannot be said for other innovation measures (as temporary secrecy, most research alliances as licence agreements and research joint ventures[11], even for R&D expenditure and entrepreneurial enquiries). Hence, patent data sets are used more and more in international comparisons (see e.g. Archibugi and Pianta (1992) and already cited studies).

A.2 Limitations to the use of patents

Despite all the above advantages many entrepreneurs will not choose for patents in many cases. This has to do with the restrictions of patents as an indicator of innovation.

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- First of all, *not all inventions and not all innovations lead to a patent*[12], principally with process innovations where competitors often apply ‘reverse engineering’ so that it will be more difficult to prove imitation. Therefore, in very many cases the entrepreneur will be able to realise a strategic advantage with e.g. a temporary secrecy in stead of applying for a patent on process innovation (see Kabla (1996), pp. 61-63). Moreover, the value of a patent for the firm should be higher than the profit, which the firm can obtain from its innovation without patenting. These restrictions have

[11] With the exception of US RJVs according to the 1984 National Cooperative Research Act (NCRA) and the 1993 National Cooperative Research and Production Act (NCRPA) which are published by the US Federal Register (see Vonortas (1997)).
[12] Since patents are not only taken for innovations but also for some non-economic inventions, a certain overestimation as measure of innovation might result from this.

as a consequence that different sectors have different propensities to patent[13]. In general, highly technological sectors (with the exception of the computer sector) will have a higher propensity to patent than other sectors (see Kabla (1996), p. 64).

- *Much patenting activity is defensive and strategic* (see Narin *et al.* (1987)), not fitting in the simpler model of the patent as a straightforward transitional step between R&D and production. As Spender and Grant (1996, p. 7) indicate: "Strategic patenting may be less to do with building up new knowledge than with sealing off an area from exploitation by others, so adding value to the patents already held. The sheer quantity of patents may mean little on its own.".
- In many cases patents are industry oriented rather than service oriented and are more important for large enterprises than for small ones (see Bosworth (1996), p. 6). *A priori a higher propensity to patent for large enterprises* is easily explained: large firms have more financial means and a larger research group than small firms; various inventions as a result of R&D efforts may rise so that the possibility for more innovations and a larger number of patents may arise (see Kable (1996), p. 63).
- Similarly, a different pattern of propensity to patent can generally be observed for exporting and non-exporting firms. The more a firm is export oriented the higher the propensity to patent that firm might know. It will be inclined to protect its products by applying for patents in its customer countries (see Grupp *et al.* (1996), p. 12).
- Further, *different systems of patenting with different legal settlements exist*, so that patented inventions may differ significantly (between countries and over time) in technical quality and commercial value. Different national patent systems exist already for a long time; in Europe already since the end of the 19th century. The European patent system is much more recent. In the light of the general aim for integration, the European Commission has tried to unify national patent systems. The first step towards patent unification was the 'Treaty of Strasbourg' in 1963. This required European countries to conform parts of their national patent laws to the statements of this Treaty, although it was not implemented until 1980. The second step towards a common European patent system was taken in 1973 with the 'European Patent Convention' (EPC), which was signed at Munich on the 5th of October 1973 and which was implemented from the 1st of July 1978. At that time the European Patent Office (EPO) with principal office at Munich was founded with the participation of Belgium, (West-) Germany, France, Italy, the Netherlands, Luxembourg, Sweden, the United Kingdom and Switzerland; then from 1979 with Austria, with Liechtenstein from 1980, with Greece and Spain from 1986, with Denmark from 1990, with Monaco from 1991, with Portugal and Ireland from 1992 and with Finland as eighteenth member state from 1996. Currently, the EPO has foundations in Munich, The Hague (Rijswijk), Berlin and Vienna, but is, as it is clear from its composition, not an establishment of the European Union. A European patent is a patent that is centrally granted by the EPO in Munich and provides protection in one or more of the above member EPC countries. In 1995 eight member states were indicated for protection on the average, and the eight mostly designated countries were in order of magnitude: Germany, the United Kingdom, France, Italy, the Netherlands, Spain, Switzerland and Sweden (see van Leuven (1996), p. 14). Important national patent offices are obviously the United States Patent and Trademark Office (USPTO) and the Japanese Patent Office Tokyo Cho (JPO-TC). The USPTO puts high requirements to the novelty characteristic. In this way the USA stimulate large or radical innovations and refrain from innovations originating from marginal improvements and from imitations. The JPO-TC attributes less importance to the novelty requirement so that marginal improvements, possibly originating from imitation, are stimulated in Japan. A direct consequence is that the number of patents in Japan is much higher than in the USA: in 1995 2700 patent applications per million of inhabitants in Japan, 491 in the USA and 257 in Europe (see van Leuven (1996), pp. 12-13)). Nevertheless, a comparison of the patent applications in 1995 with the EPO, originating from the three large economic blocks Europe (EPC), the USA and Japan, shows for six highly technological sectors (air transport, genetic manipulation, computers, communication, semi-conductors or chips and lasers) that Japan has a relatively important market

[13] The average propensity to patent is defined as the ratio between the number of patents and the R&D expenditure of a certain firm/sector/region/country.

share only in semi-conductors (33 %), but that the European industries (obviously in their home markets) have a strong position in the air transport (with a market share of 55 %) and in genetic manipulation (45 % market share) and that the USA is strong in computers (52 % market share) and in semi-conductors (40 % market share). Between 1991 and 1995 Japan lost market share in all six highly technological industries, the EPC member states' market share increased in four out of the six mentioned industries and the market share of the USA increased even in five of the six highly technological industries (principally at the expense of the Japanese industry; see van Leuven (1996), pp. 18-19).

- *In comparison to the USA and Japan the costs of European patents are high*[14]. The costs for a patent application with the EPO are on the average 20 % higher than those of a project application with the USPTO and the JPO-TC (in 1995 on the average 14,500 DM for an approved patent at the EPO with a protection in eight European member countries, of which 9,900 DM for official costs, translation costs excluded, compared to 11,700 DM at the USPTO of which 3,000 DM for official costs and 11,600 DM at the JPO-TC of which 2,200 DM for official costs; the principal costs in Japan and in the USA are expenses for external patent lawyers: 7,400 DM and 6,300 DM respectively *vis-à-vis* 'only' 2100 DM in Europe). To diminish this competitive disadvantage it was recently decided to decrease the costs of application for EPO patents with 20 % from the 1st of July 1997 onwards.
- The *maximal protection of an EPO patent is 20 years* from the date that the patent is requested. In Japan this is 18 years and in the USA it was 17 years until 1995 (also 20 years since then). It should be remarked, however, that an EPO patent can generally be obtained only after four years from the moment of application, while it is often less than two years for an USPTO patent (no translation problems!). Nevertheless, most of the firms (with the exception of pharmaceutical and some other enterprises[15]) will not protect their innovation for the maximal period (see e.g. Duguet and Iung (1996), pp. 3-4) because of obsolescence and of growing imitation probability over time. Research has revealed that the average period of patent protection in Europe is 11 à 12 years for larger countries and even only 9 à 10 years for smaller (EPO-Report (1996), p. 655). Kabla (1996), p. 60, has even shown that a patent holder has paid on the average two to four times the original patent application price after 10 years!
- New patent applications are obviously also slowed down through the existence of various alternatives for the appropriation of intellectual rights and of returns such as the registration of designs, (temporary) secrecy, copyrights, trade marks, etc.… Patents require novelty, copyrights originality and trade marks distinctiveness (not generic as e.g. with 'aspirin' or 'thermos'. In contrast to patents, trade marks are mainly important for smaller enterprises and also for services; see Bosworth (1996), pp. 18-22).

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[14] The *total costs of a patent consist of three parts* (see Kabla (1996), p. 60):
(i) the inevitable direct costs necessary to obtain a patent and to maintain the patent in its legality (renewal costs);
(ii) the possible costs of a cause;
(iii) the indirect costs which are difficult to determine since this is the advantage that other firms obtain when the innovation information is published.

[15] Concerning the long period of incubation for pharmaceutical patents (extensive tests on animals and volunteers and the sometimes long pre-registration period of new drugs cause that a new drug can be introduced in the market only after 10 years on the average!), the pharmaceutical sector was granted a longer patent protection period of 25 years (under certain conditions).

APPENDIX B: DATA ON R&D EXPENDITURE, PATENTS AND OUTPUT

Countries: BE: Belgium, DE: Germany, DK: Denmark, IT: Italy, NE: Netherlands, UK: United Kingdom.
R&D Expenditure: from OECD (1997) and **Value Added**: from OECD (1996).
Remark: "mva"= 'missing value added' data

The R&D Expenditure and the Value Added are measured in millions of PPP $ (Purchasing Power Parity units); these are originally measured in national currencies and are transferred to millions of US $ by using the Purchasing Power Parities (PPPs) published by the OECD. For more details, see: Sections VII and VII of OECD (1995).

The PPP-values (expressed as 'national currency per US$') used by us are:

YEAR	1989	1990	1991	1992	1993	1994	1995
COUNTRY							
Belgium	39,96096	39,45	39,27829	37,56593	37,30306	37,36062	37,65243
Denmark	9,53031	9,393	9,20508	9,09243	8,78591	8,72599	8,62506
Germany	2,10361	2,088	2,09956	2,05372	2,10287	2,07337	2,06554
Italy	1375,547	1421	1467,036	1450,197	1533,828	1536,391	1588,697
Netherlands	2,20469	2,165	2,19027	2,12308	2,13438	2,12827	2,07765
United Kingdom	0,58969	0,6023	0,63689	0,61222	0,63735	0,6468	0,6701

Source: Eurostat (1996), only obtainable from 1989 onwards.

Table 1 Sectoral R&D intensities and sectoral APPs (periods: 1989-1995 and 1989-1994 respectively)

		R&D Expend as % of Value Added (aver. 1989-95)						**Patents per mln 1990 PPP $ R&D Exp. (averages: 1989-94)**						
No	**Sector**	**BE**	**DE**	**DK**	**IT**	**NE**	**UK**	**BE**	**DE**	**DK**	**IT**	**NED**	**UK**	**Average**
1	Electric mach., excl. comm. equip.	ova	8,80	5,55	4,18	115,84	10,45	0,06	0,60	1,10	0,47	0,41	0,34	**0.49**
2	Radio, TV & communic. equipm.	ova	19,05	17,01	18,05	7,95	14,87		0,19	0,27	0,13	0,58	0,32	**0.29**
3	Chemicals exc. drugs	11,81	11,00	3,62	4,71	11,53	8,83	0,24	0,46	1,50	0,55	0,31	0,35	**0.57**
4	Drugs & medicines	25,33	18,61	27,15	ova	24,87	31,99	0,29	0,80	0,51	0,25	0,46	0,24	**0.42**
5	Oil refining	1,52	0,72	0,00	4,37	1,99	5,12	0,49	0,63		0,10	0,21	0,22	**0.32**
6	Shipbuilding	ova	2,59	3,33	4,73	0,46	2,03		1,08	0,28	0,31	2,24	0,63	**0.99**
7	Motor vehicles	ova	10,55	0,00	13,13	12,74	9,73	0,21	0,17		0,09	0,32	0,17	**0.19**
8	Aerospace	ova	56,95	0,00	30,01	10,44	20,89		0,02		0,00	0,02	0,01	**0.01**
9	Other transport	ova	3,38	ova	3,07	ova	4,23	0,09	10,22	0,61	1,18		1,99	**2.82**
10	Ferrous basic metals	5,25	1,07	5,82	1,27	3,18	1,42	0,16	0,63	0,24	0,23	0,14	0,50	**0.28**
11	Non ferrous basic metals	0,00	1,11	1,82	1,98	3,69	1,91		0,74	1,78	0,32	0,42	0,46	**0.81**
12	Metal products, ex machines	0,00	1,95	0,69	0,54	1,01	0,99		2,17	7,18	3,01	3,59	4,36	**3.99**
13	Professional goods	20,87	4,04	16,55	1,92	3,85	3,77	1,08	4,12	1,14	3,07	7,02	7,71	**3.29**
14	Office & Computer equipment	ova	12,48	14,50	20,22	41,84	16,54	3,43	0,41	0,54	0,15	1,09	0,47	**1.12**
15	Non-electrical machinery	ova	6,72	5,09	2,36	2,18	4,83		1,07	1,07	1,20	3,62	0,77	**1.74**
16	Food, beverages, tobacco	1,62	0,45	1,34	0,31	2,13	1,16	0,85	0,65	0,73	0,47	0,45	0,28	**0.58**
17	Textiles, clothes, etc.	1,84	0,67	0,36	0,06	0,70	0,36	0,33	2,06	2,87	7,47	1,01	1,34	**2.40**
18	Rubber & plastic products	1,72	2,21	1,47	1,26	1,57	0,75	0,48	0,14	0,21	0,11	0,13	0,29	**0.21**
19	Non-metallic mineral products	1,18	1,51	1,31	0,25	0,56	1,13	0,32	1,39	3,22	1,42	3,77	1,41	**1.93**
20	Paper, paper products & printing	1,77	0,34	0,19	0,04	0,19	0,26	0,41	4,96	5,09	26,20	3,16	1,97	**6.45**
21	Wood products & furniture	0,85	0,60	0,26	0,05	0,10	0,23	1,42	1,08	2,62	5,95	7,62	2,24	**3.36**
22	Other manufacturing, n.e.c.	0,94	1,29	13,46	0,33	0,51	1,54	0,47	10,69	0,36	17,34		5,21	**7.23**
Theo 1	Average APP per country over all sectors (about which data have been mentioned)							0.61	2.01	1.65	3.01	1.93	1.49	**1.80**
Theo 2	Average APP per country excluding one extreme value (indicated with shaded area) with respect to the sectoral (non-weighted) average over all countries (see last column)							0.46	1.60	1.34	1.26	1.61	1.19	**1.50**

APPENDIX C: AN ERROR CORRECTION REPRESENTATION FOR PANEL DATA

An *Error Correction Model* (ECM) with maximum two lags can be described in the context of a dynamic panel data model as follows.

In case of one endogenous variable per sector, e.g. $y_{i,t}$, and one explanatory variable per sector, $x_{i,t}$, the ECM-representation relates the current change in $y_{i,t}$ to the previous deviation of $y_{i,t-1}$ from its long-run path: $\alpha + \beta x_{i,t-1}$, to the current change in $x_{i,t}$ and to the past changes in $x_{i,t}$ and $y_{i,t}$ $(i = 1,2,....,N; t = 1,2,....,T)$. This ECM can be written for (a maximum of) three lags as a stochastic error variance components model for sector i:

$$\Delta y_{i,t} = \lambda\ (y_{i,t-1} - \alpha\ - \beta\ x_{i,t-1}) + \delta_0 \Delta x_{i,t} + \delta_1 \Delta x_{i,t-1} + \delta_2 \Delta x_{i,t-2} + \gamma_1 \Delta y_{i,t-1} + \gamma_2 \Delta y_{i,t-2} + u_{i,t}$$ [16],

where the error terms have a decomposition as $u_{i,t} = v_i + e_t + \varepsilon_{i,t}$, with the mutually independent error terms v_i, e_t en $\varepsilon_{i,t}$ are assumed to be distributed according to mutually independent white noise error processes, where λ is the de error correction or equilibrium adjustment parameter. This parameter should be negative and smaller than one in absolute value if the ECM is required to be stable. In general, the parameters α en β are unknown so that we can rewrite the above long-run relationship as:

$$\lambda(y_{i,t-1} - \alpha\ - \beta\ x_{i,t-1}) = \lambda_0 + \lambda_1 y_{i,t-1} + \lambda_2 x_{i,t-1} \qquad ,$$

such that in the case of substitution of this relationship in the above ECM, the latter relationship can be estimated in one step. Remark that, if $\hat{\lambda}_1$ and $\hat{\lambda}_2$ are not significantly different from zero, a long-run relationship cannot be detected, and only a short-run relationship between $y_{i,t}$ and $x_{i,t}$ can be found.

Estimation is performed with the help of the procedures 'TSCSREG' en 'AUTOREG' from SAS Version 6.12.

In Appendix C tables with the best estimates of the above ECMs are given, together with a test on first order autocorrelation (Durbin-Watson, incl. the estimated coefficient of autocorrelation) and on heterocedasticity (Lagrange-Multiplier test on first order autoregressive conditional heteroscedasticity - ARCH, incl. the probability size of the test which should preferably be larger than 0.05).

[16] A panel data model with varying parameters over the industries, as e.g. a Seemingly Unrelated Regression (SUR) model, can also easily be written down. In this study we restrict ourselves to a dynamic error variance components model with constant coefficients over industries. Remark that we have only a very limited number of time observations for this study, i.e. yearly data from 1989 until 1995 at the maximum, and that the variation over sectors is much greater than the variation over time.

APPENDIX D : LINEAR ECM RELATIONSHIPS

Table 2 : ECMs for the number of patent applications (as a linear function of R&D expenditure and value added)

COUNTRY	**Parameter estimates**	**t-values**	**Corrected R^2**	**Durbin-Watson h ($\hat{\rho}$)**	**Lagrange Multiplier (p-level)**
GERMANY					
INTERCEPT	53.608	1.410	0.3377	1.951	0.0027
PAT1	-0.175	-3.540		(0.024)	(0.9586)
RD1	0.044	1.856			
DRD	0.299	5.603			
DVAL	0.008	2.049			
DVAL1	0.005	1.298			
DENMARK					
INTERCEPT	1.082	0.878			
PAT1	-0.220	-3.782	0.6043	2.065	0.0005
RD1	0.091	2.550		(-0.035)	(0.9819)
VAL1	0.001	1.108			
DRD	0.501	13.939			
DPAT1	-0.068	-1.225			
ITALY					
INTERCEPT	14.142	2.173	0.1138	1.909	0.3102
PAT1	-0.130	-3.252		(0.045)	(0.5775)
DRD	0.086	2.943			
DVAL1	0.001	1.377			
UNITED KINGDOM					
INTERCEPT	20.868	2.106	0.2006	1.948	0.0210
PAT1	-0.106	-3.135		(0.025)	(0.8847)
DRD	0.137	5.451			
NETHERLANDS					
INTERCEPT	5.818	1.579	0.1254	2.028	0.0009
PAT1	-0.094	-2.772		(-0.019)	(0.9763)
DRD	0.123	2.503			
DRD1	-0.056	-1.084			
DVAL1	0.005	2.784			

pat1 = number of patent applications lagged one year
rd1 =R&D lagged one year
drd = difference between current R&D and lagged R&D = rd - rd1
drd1 = rd1 - rd2
dpat1 = difference in the lagged number of patent applications = pat1 - pat2

Table 3 : ECMs for the R& D expenditure (as a linear function of patent applications and value added)

COUNTRY	Parameter estimates	t-values	Corrected R^2	Durbin-Watson h ($\hat{\rho}$)	Lagrange Multiplier (p-level)
GERMANY					
INTERCEPT	-65.495	-0.899	0.3388	1.896	0.0001
RD1	-0.088	-2.675		(0.052)	(0.9967)
VAL1	0.009	2.207			
DPAT	0.641	5.646			
DVAL	0.020	3.370			
DVAL1	-0.006	-1.096			
DENMARK					
INTERCEPT	0.779	0.414			
RD1	-0.208	-3.969	0.6109	2.064	2.5099
PAT1	0.321	3.603		(-0.034)	(0.1131)
VAL1	-0.002	-1.040			
DPAT	1.144	13.895			
DPAT1	0.157	1.873			
DVAL	-0.004	-1.406			
ITALY					
INTERCEPT	26.770	1.625	0.0869	2.004	0.0169
RD1	-0.102	-2.808		(-0.002)	(0.8967)
DPAT	0.580	2.852			
DRD1	0.082	1.027			
UNITED KINGDOM					
INTERCEPT	0.092	0.003	0.1987	1.940	0.0088
RD1	-0.116	-3.046		(0.029)	(0.9253)
PAT1	0.259	2.313			
DPAT	1.159	5.377			
NETHERLANDS					
INTERCEPT	-5.398	-0.777	0.1842	1.975	1.2307
RD1	-0.118	-3.481		(0.011)	(0.2673)
PAT1	0.132	1.904			
VAL1	0.002	1.059			
DPAT	0.368	2.706			
DVAL	0.119	3.818			

REFERENCES

- Acs, Z.J. and D.B. Audretsch (1989), Patents as a Measure of Innovative Activity, *Kyklos*, 42, 171-180.
- Archibugi, D. and M. Pianta (1992), The Technological Specialisation of Advanced Countries - A Report to the EC on International Science and Technology Activities (Kluwer, Boston).
- Arundel, A. et I. Kabla (1996), Patenting Strategies of European Firms: An Analysis of Survey Data, Paper presented at the 54th AEA Conference on 'Econometrics of Innovation - Patents' (Applied Econometrics Association, Luxembourg).
- d'Aspremont, C. and A. Jacquemin (1988), Cooperative and Noncooperative R&D in Duopoly with Spillovers, *The American Economic Review*, 78, 1133-1137.
- Baldwin, J. (1996), *The dynamics of competition in a North American Context* (Cambridge University Press, Cambridge).
- Bernstein, J.I. and M.I. Nadiri (1988), Interindustry R&D Spillovers, Rates of Return, and Production in High-Tech Industries, *The American Economic Review*, 78, 429-434.
- Bosworth, D. (1996), Opening the Black Box: Company Performance and the Valuation of Intellectual Property, Paper presented at the 54th AEA Conference on 'Econometrics of Innovation - Patents' (Applied Econometrics Association, Luxembourg).
- Bosworth, D.L., R.A. Wilson and A. Young (1993), Research and Development (Chapman Hall, London).
- Brod, Andrew and Ram Shivakumar (1997), Domestic versus International R&D Spillovers, *Economics Letters*, vol. 56, no. 2, pp. 229-233.
- Bussy, J.-C., C. Carpentier and I. Kabla (1996), The Utilisation by French Firms of the European Patent, *INSEE Studies in Economics and Statistics*, 1, 13-30.
- Capron, H. and M. Cincera (1996), Assessing the R&D Determinants of World-wide Manufacturing Firms, Paper presented at the 54th AEA Conference on 'Econometrics of Innovation - Patents' (Applied Econometrics Association, Luxembourg).
- Crépon, B. and E. Duguet (1996), Innovation: Measurement, Returns and Competition, *INSEE Studies in Economics and Statistics*, no. 1, 83-95.
- De Bondt, R. (1997), Spillovers and Innovative Activities, *International Journal of Industrial Organization*, 15, 1-28.
- Duguet, E. and N. Iung (1996), R&D Investment, Patent Life and Patent Value; An Econometric Analysis at the Firm Level, Paper presented at the 54th AEA Conference on 'Econometrics of Innovation - Patents' (Applied Econometrics Association, Luxembourg).
- Europese Commissie, 1996, Eerste actieplan voor innovatie in Europa (E.C., Luxemburg).
- Europese Unie, 1996, Groenboek over innovatie (E.U., Luxemburg).
- Eurostat (1996), *Research and Development: Annual Statistics*, Luxembourg.
- Evenson, Robert E. and Daniel Johnson (1997), Introduction: Invention Input-Output Analysis, *Economic Systems Research*, Special Issue on Invention Input-Output Analysis, vol. 9, no. 2, pp. 149-160.
- Geroski, P.A., J. Van Reenen and C.F. Walters (1996), Innovations, Patents and Cash Flow, Paper presented at the 54th AEA Conference on 'Econometrics of Innovation - Patents' (Applied Econometrics Association, Luxembourg).
- Griliches, Z. (1979), Issues in Assessing the Contribution of Research and Development to Productivity Growth, *Bell Journal of Economics*, vol. 10, no. 1, pp. 92-116.

- Griliches, Z. (1990), Patent Statistics as Economic Indicators: A Survey, *Journal of Economic Literature*, XXVIII, 1661-1707.
- Griliches, Z. (1992), The Search for R&D Spillovers, *Scandinavian Journal of Economics*, 94, Supplementary Issue, S29-S47.
- Griliches, Z. (1995), R&D and Productivity: Econometric Results and Measurement Errors, Chapter 3 in P. Stoneman (ed.), Handbook of the Economics of Innovation and Technological Change (Blackwell, London).
- Grupp, H. (1996), Spillover Effects and the Science Base of Innovations Reconsidered: An Empirical Approach, *Journal of Evolutionary Economics*, 6, 175-197.
- Grupp, H., G. Licht, M. Beise and C. Hipp (1996), Individual Enterprise Matched Innovation and Patent Statistics in Germany: A Scoping Study of Diversification, Paper presented at the 54th AEA Conference on 'Econometrics of Innovation - Patents' (Applied Econometrics Association, Luxembourg).
- Jaffe, A.B. (1986), Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value, *The American Economic Review*, 76, 984-1001.
- Jaffe, A.B. (1996), Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program, Discussion Paper Advanced Technology Program (National Institute for Standards and Technology, Gaintherbury - New York).
- Kabla, I. (1996), The Patent as Indicator of Innovation, *INSEE Studies in Economics and Statistics*, no. 1, 57-70.
- Kamien, M.I., E. Muller and I. Zang (1992), Research Joint Ventures and R&D Cartels, *The American Economic Review*, 82, 1293-1306.
- Kortum, S. and J. Lerner (1999), What is behind the recent surge in patenting?, *Research Policy*, vol. 28, pp. 1-22.
- Laat, E. de (1997a), Essays on Patent Policy - The Multi-dimensionality of Patents and Asymmetric Information, Tinbergen Institute Research Series no. 137 (Thesis Publishers, Amsterdam).
- Laat, E.A.A. de (1997b), Patents or Prizes: Monopolistic R&D and Asymmetric Information, *International Journal of Industrial Organization*, 15, 369-390.
- Leuven, J.W.M. van (1996), Patent Statistics as Indicators for Innovation, Paper presented at the 54th AEA Conference on 'Econometrics of Innovation - Patents' (Applied Econometrics Association, Luxembourg).
- Narin, F., E. Noma and R. Perry (1987), Patents as indicators of corporate technological strength, *Research Policy*, vol. 16, pp. 143-155.
- OECD (1995), *National Accounts*, *Volume 1, 1960-1993*, Paris.
- OECD (1996), *Structural Analysis*, Paris.
- OECD (1997), *Research and Development Expenditure in Industry 1974-1995*, Paris.
- Patel, P. and K. Pavitt (1995), Patterns of Technological Activity: Their Measurement and Interpretation, in Stoneman, P. (Ed.), Handbook of the Economics of Innovation and Technological Change, (Blackwells, Oxford), 14-51.
- Pottelsberghe de la Potterie, Bruno van (1997), Issues in Assessing the Effect of Interindustry R&D Spillovers, *Economic Systems Research*, vol. 9, no. 4, pp. 331-356.
- Schankerman, M. (1979), Essays on the Economics of Technical Change: The Determinants, Rate of Return and Productivity Impact of R&D, Ph.D. Thesis (Harvard University, Cambridge).
- Spender, J.-C. and R.M. Grant, Knowledge and the Firm: Overview, *Strategic Management Journal*, vol. 17, Winter Special Issue, pp. 5-9.

- Suzumura, Kotaro (1992), Cooperative and Noncooperative R&D in an Oligopoly with Spillovers, *American Economic Review*, vol. 82, no. 5, pp. 1307-1320.
- Symeonideis, G. (1996), Innovation, Firm Size and Market Structure: Schumpeterian Hypotheses and Some New Themes, *Working Paper no. 161* (Economics Department-OECD, Paris).
- Tsetsekos, G. (1992), R&D Capital Expenditure, Patents and Stock Prices, Working Paper (Drexel University, Philadelphia).
- Utterback, J.M. (1994), Mastering the dynamics of innovation how companies can seize opportunities in the face of technological change (Harvard Business School, Boston).
- Vonortas, N.S. (1997), *Cooperation in Research and Development* (Kluwer Academic Publishers, Boston).