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Determinants and Strategies of Patenting Activities: Some Evidence from Belgian Manufacturing Companies

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Summary
This paper examines the impact of R&D activities and other technological determinants on the number of patents applied by 379 Belgian manufacturing firms in 1994-95. The study extends previous work on the R&D-patent relationship by distinguishing different types of R&D activities and sources of financing. Another question addressed is the extent to which foreign R&D subsidiaries localised in Belgium transfer the knowledge developed in the local economy to their home country. On the whole, foreign subsidiaries seem to have a lesser propensity to patent, R&D activities exhibit slightly decreasing returns to scale with respect to patenting and important differences are observed in the estimated impacts of these activities according to their type and source of financing.

JEL codes: F23, O31, O32, O34
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Michele CINCERA
Université Libre de Bruxelles
mcincera@ulb.ac.be
D.U.L.B.E.A. & C.E.P.R.

1. Introduction[1]

The high dependency of the Belgian innovation system on foreign multinationals could be an important reason for its lower propensity to patent. Indeed, on the one hand, there is the hypothesis that Belgian subsidiaries are specialised in the adaptation to the European market of products and processes developed, in the first place, in foreign headquarters of multinationals. On the other hand, head offices could be hoarding a significant part of their R&D output, the foreign firms taking advantage of the local availability of a highly qualified workforce and knowledge base. The impact of R&D activities and other determinants of the innovative process on the number of patents applications is quantified thanks to a sample of firms in the Belgian manufacturing sector during the mid 90s. The econometric framework rests on a zero-inflated generalised event count (ZI-GEC) model. The logit part of this model estimates specific covariates that explain the decision to patent or to never engage in such activities. The GEC part, which is a generalization of the basic Poisson model, explains the positive patent outcomes and the zero arising because of the failures of innovation activities. The study extends previous work on the R&D-patent relationship by distinguishing different types of R&D activities and sources of financing. Another question addressed is the extent to which foreign R&D subsidiaries localised in Belgium transfer the knowledge developed in the local economy to their home country. On the whole, foreign subsidiaries seem to have a lesser propensity to patent, R&D activities exhibit slightly decreasing returns to scale with respect to patenting and important differences are observed in the estimated impacts of these activities according to their type and source of financing.

The plan of the paper is as follow. Section 2 discusses the main determinants of patenting and the strategies followed by firms. Recent trends in patenting activities of Belgian manufacturing companies are then illustrated and the strong place occupied by MNE's in these activities is emphasised. Section 3 presents the data set, the patent-R&D extended knowledge production function and several econometric models for count data. The main empirical findings are reported in section 4. The main conclusions of this study are drawn in section 5.

2. Determinants of patents and MNE's technological activities

2.1. S&T activities and firms' patenting strategies

The imperfect appropriability of the returns of innovative activities has been acknowledged since a long time. This appropriability problem arises from the non-rival and partially excludable property of the knowledge good. Non rivalry means that the use of an innovation by an economic agent does not preclude others from using it, while partial excludability implies that the owner of an innovation can not impede other to benefit from it free of charge. This public characteristic of the knowledge good is a source of market failure in the sense that firms will invest less in R&D than the socially optimal level[2]. There are several ways to compensate for the imperfect functioning of such markets[3].

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[2] Indisibilities and uncertainties associated with R&D activities are two other sources (Arrow, 1962).

Public technology procurement, R&D subsidies or tax breaks increase the expected returns by lowering the costs of these activities. R&D collaborations facilitate the exploitation of scale economies in R&D and the internalisation of the externalities generated by these activities. More directly, the intellectual property right system with patents, trademarks or copyrights restricts to competitors the exploitation that can be made from the knowledge created. Patents for instance are granted as a temporary monopoly right for the innovator while at the same time disclosing technical information in the public domain. However, despite several measures taken to strengthen the enforcement of patent rights[4], their effectiveness vary considerably across industry sectors, the nature of the technology, e.g. new products versus new processes or tacit versus codified technologies which affect the speed of technological diffusion or the ability of rivals to invent around a patent[5].

While the limitations of patents in protecting and exploiting the output of R&D activities lead firms to choose alternative appropriability strategies such as secrecy, lead time and learning curve advantages, the importance of patents as a means to exploit new technologies has increased, as have the resources companies devote to IP protection (Granstrand, 1999). As noted by the author, the literature in economic and management on patent strategies is generally very thin, the discussion often focusing on when (in the R&D sequence), where (choice of countries) why and how to patent. Based on the concept of a technology space, the product life cycle and the technology life cycle, the author develops a new way of classifying and characterising patents and patent strategies.

Table 1. Summary of patenting strategies

Strategy	Definition
Flooding/blanketing	Efforts made to turn an area into a jungle or a minefield of patents by "mining" every step in a manufacturing process with patents, more or less systematically. This pre-emptive strategy prevents rivals from patenting related inventions.
Strategic patenting	A single patent with a large blocking power which have deterringly high or insurmountable invent-around costs.
Fencing/surrounding	Important central patent fenced or surrounded by other patents, which are individually less important but collectively block the effective commercial use of the central patent, even after its expiration.
Patent networking	Building of a patent portfolio in which patents of various kinds and configurations are consciously used to strengthen overall protection and bargaining power.
Sporadic versus continuous	In the sporadic case, just a few patents at key steps in the R&D process are taken out. In the second case, a conscious effort is made to build up a rich patent portfolio, and patents are applied in a continuous manner in the R&D sequence.

Source: based on Granstrand (1999).

Table 1 details these different patent strategies. Of course, patenting behaviours are not only linked to the costs of patenting but also to the firms research strategies, the appropriability conditions of their returns as well as the determinants of these activities, in particular the type of research, e.g. whether it is basic or more applied, tacit or codified, product versus process R&D, the sources of financing of these activities, e.g. firms own funds versus private, public or foreign funds, the size of

[3] See Geroski (1995) for a discussion.
[4] For instance, in 1982, the Court of Appeals for the Federal Circuit was established to strengthen and make patent protection more uniform.
[5] See Levin et al. (1987) for a study of appropriability conditions differences across industries.

the firms and its technological diversification, the degree of internationalisation of the firm, the firm's market share or the opportunity to rivals to enter the market.

2.2. Innovation strategies of MNE's

As regards the degree of internationalisation of R&D, technology production has usually been centralised in the host country of MNE's. The reduction of the costs of communications and control, economies of scale in R&D and a better coordination between central and peripheral research labs have often been mentioned in the literature to explain this situation (Terpstra, 1985)[6]. However, during the past decade, multinational involvement in overseas R&D has increased significantly. Companies all over the world are investing more and more in overseas R&D as a tool to increase their competitive advantages and to exploit their resources in order to create better products. MNE's have accelerated the pace of their direct investments in overseas R&D, and have established or acquired multiple R&D laboratories abroad and are increasingly integrating these laboratories into global R&D network[7,8]. According to Granstrand et al. (1992), the many reasons for this growing decentralisation and internationalisation of R&D activities can be classified into three main groups of factors: demand-side, supply-side and environmental factors. The demand-side factors include a greater adaptation of products and technologies to local markets, a higher proximity to customers, an increase of competitiveness through the transfer of technology and the pressures of subsidiaries to enhance their status within a corporation. Among the main supply-side factors, the monitoring of the development of technology abroad and the hiring of a foreign and barely mobile highly skilled labour can be mentioned. Finally, the environmental factors concern the legislation on intellectual property, the provision of R&D incentives by the domestic government, e.g. tax advantages and subsidies for R&D, as well as governmental pressures to improve the subsidiary's capabilities beyond the simple assembly of proven products to innovative activities.

Belderbos (2001) too identifies two different motives for activities of overseas R&D. The first motive, which consists in the exploitation of the firm's technology abroad, means that companies adapt their products and processes to suit local markets and manufacturing processes and to fulfil local standards or manufacturing conditions. The second motive is the sourcing of foreign technology, which explains the founding of basic R&D for world market. In this case, firms access distinctive expertise in the local science base and hire skilled foreign engineers and researchers[9]. New

[6] As pointed out by Cantwell and Santagelo (1999), non-codified technological activities that necessitate highly tacit capabilities require a higher proximity.

[7] Angel and Savage (1996) and Belderbos (2001) among others, analyse the determinants of the localisation of Japanese R&D labs abroad ; Cantwell and Harding (1998) measure the R&D internationalisation of German firms ; Dunning and Narula (1995) and Florida (1997) examine the R&D activities of foreign firms in the USA and Pearce and Papanastasiou (1999) in the UK.

[8] Research joint ventures, firm's acquisitions and the establishment of greenfield units are the three main ways to entry a foreign market.

[9] The notions of Home Base Augmenting (HBA) and Home Base Exploiting (HBE) are often used to characterise these motives. For Kuemmerle (1999), HBA sites are more likely to be located near universities or public research and technology organisations. HBA units have increasingly been used as part of the multinational's strategy to build up and exploit S&T know-how located beyond the boundaries of the group while the activities of HBE sites are more aimed at transferring the knowledge developed within the group. Moreover, it appears that the experience gained during the establishment of a HBE makes it easier to create HBA after some years. This

established subsidiaries generally focus on the design and the development of products to local markets on the basis of the mother company's existing technologies, while R&D activities of acquired subsidiaries are more concerned with applied research and scanning of local technologies.

2.3. The high internationalisation and concentration of the Belgian technological base

Multinational firms largely dominate the Belgian innovation system. The share of subsidiaries of large foreign firms in national innovative activities of 54% is by far the largest among the industrialised countries (Patel and Pavitt, 1991). In the 1980s, this share was about 40% and this suggests that there have been since a long time strong linkage between MNE's and the national science and technology base in Belgium. Thus, because of its relative size and the ensuing need for a high degree of specialisation, the internationalisation of the Belgian technology base is indisputable. As stressed by Veugelers and Cassiman (1999) among others, external knowledge is an important determinant for the innovation process of firms. Increasingly, this knowledge is likely to originate from outside of their national borders, especially in a small size economy characterised by a high openness of its S&T system. Many studies have quantified the magnitude and direction of technology diffusion through different channels across industry sectors and nations and its impact on innovation and economic performance[10]. In a survey, Blomström and Kokko (1998) examine the effects of knowledge spillovers generated by MNE's. These effects influence domestic firms in the MNE own industry as well as firm in other sectors. The authors conclude to a positive impact of these effects, which vary systematically between countries and industries and increase with the local capability and competition[11]. On the other hand the effects on the home country of MNE's are more difficult to identify. There have been only a few studies examining the impact of international spillovers in the Belgian economy. Veugelers and Vanden Houte (1990), in an analysis of Belgian data on domestic R&D, find that the higher the presence of multinationals in an industry, the weaker will be the innovative efforts of domestic firms in that same industry. The study of Fecher (1990) reports a positive impact of domestic R&D spillovers on Belgian firms' productivity performance while no effect of international spillovers is found. More recently, Veugelers and Cassiman (1999), find that MNE's are more likely to transfer technology to the Belgian economy. However the main conclusion of the study is that it is not so much the international character of the firms, but rather their access to the international technology market that is important for generating external knowledge transfers to the local economy.

Another feature of the Belgian technological landscape is the high concentration of innovation activities among a few large firms. Figure 2 sheds some light on the patenting activities of the top 50 Belgian firms. As can be observed, this activity is quite concentrated. Indeed, in terms of European patents, the two firms with the highest number of patent applications hold 15.6% and 6.4%,

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suggests that it is easier to establish a HBE unit compared to an HBA one and as a result the former are created before.

[10] See the recent survey of Cincera and van Pottelsberghe (2001) on international R&D spillovers and Mohnen (1996).

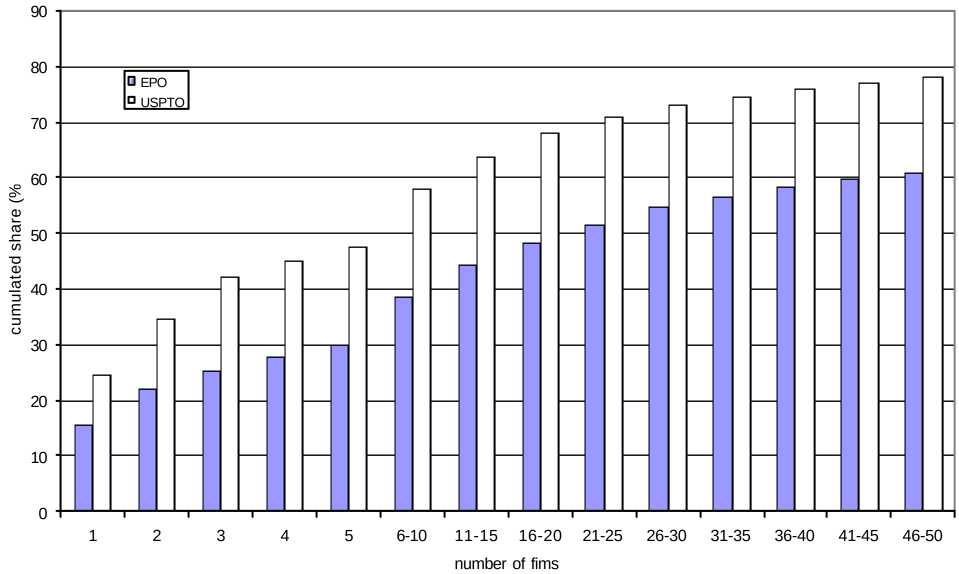
[11] In Jaffe's opinion (1986: p. 984), "from a purely technological point of view, R&D spillovers constitute an unambiguous positive externality. Unfortunately, we can only observe various economic manifestations of the firm's R&D success. For this reason, the positive technologically externality is potentially confounded with a negative effect of other's research due to competition".

respectively, of the total number of patents applied for by Belgian applicants between 1980 and 2000. In terms of US patents, these shares are even higher, being 24.4% and 10.3%, respectively. The cumulated share of US patents of the top 50 Belgian firms is about 78% against 61% for European patents. This shows that it is mainly the largest firms that patent outside the European market. Table 2 gives the list of the 20 largest companies in terms of patents. As can be seen, three companies (Agfa-Gevaert, Solvay and Janssen Pharmaceutica) concentrate 25.4% and 42.2% of the patent applications at the EPO and the USPTO, respectively. Globally, Belgian patent activity is highly dependent on a few companies. Another specificity of Belgian patenting activities is that a significant number of these companies are subsidiaries of foreign multinationals. This is particularly the case for Agfa-Gevaert, Janssen Pharmaceutica, and Alcatel-Bell, which account for more than 20% of all Belgian applications at the EPO.

The high dependency of the Belgian innovation system on foreign multinationals could be an important reason for its lower propensity to patent[12]. Indeed, on the one hand, there is the hypothesis that Belgian subsidiaries are specialised in the adaptation to the European market of products and processes developed, in the first place, in foreign headquarters of multinationals. On the other hand, head offices could be hoarding a significant part of their R&D output, the foreign firms taking advantage of the local availability of a highly qualified workforce and knowledge base. These points deserve further attention. In particular, the high concentration of technological activities among a few large companies and the important presence of foreign firms that could bring back to their home country an important part of their research output, asks for a closer examination of the outcomes of R&D as measured by patenting activities as well as the main determinants of such activities.

[12] As shown in Capron and Cincera (2000), the R&D productivity index as measured by the ratio of patents on R&D expenditures was 95 for Belgium in 1995 against 100 for the EU average.

Figure 2. Cumulated distribution of the number of patent applications of the top 50 Belgian firms (EPO and USPTO, 1980-2000)



Sources: EPO and USPTO databases; own calculations.

Table 2. The top 20 Belgian firms in terms of European and US patent applications, 1980-2000

Rank	EPO	C%	USPTO	C%
1	Agfa-Gevaert	15.6	Agfa-Gevaert	24.4
2	Solvay	22.0	Solvay	34.7
3	Janssen Pharmaceutica	25.4	Janssen Pharmaceutica	42.2
4	Fina Research	27.7	Bekaert	44.9
5	Bekaert	29.8	Fina Research	47.6
6	*Alcatel/Bell Telephone*	31.6	Picanol	50.1
7	IMEC	33.4	*Glaverbel*	52.4
8	*Ford New Holland*	35.2	Raychem	54.6
9	Picanol	37.0	*Staar*	56.4
10	Raychem	38.6	Centre de Recherches Metallurgiques	58.0
11	*Smithkline Biologicals*	40.0	UCB	59.7
12	Centre de Recherches Metallurgiques	41.3	IMEC	60.9
13	Innogenetics	42.3	*Plant Genetic Systems*	61.9
14	*Heraeus Electro-Nite International*	43.3	Michel Van de Wiele	62.9
15	*ACEC*	44.2	*Dow Corning*	63.8
16	Esselte	45.1	Esselte	64.7
17	UCB	45.9	*Metallurgie Hoboken-Overpelt*	65.6
18	*Sofitech*	46.7	*Fabrique National Herstal*	66.5
19	*Xeikon*	47.5	*Texaco Belgium*	67.2
20	Michel Van de Wiele	48.2	Innogenetics	67.9

Note: C% = cumulative share; the companies in italics are in only one of the top 20 rankings.
Sources: EPO and USPTO databases; own calculations

3. DATA

3.1. Data set construction

The constructed data set consists of a sample of 379 Belgian manufacturing firms over the period 1994-95. The data have been collected as part of the Belgian National R&D biannual survey organised jointly by the Federal Office for Scientific, Technical and Cultural Affairs and the Regional authorities in charge of S&T statistics. The questionnaire includes about 200 variables regarding innovation and economic activities. Out of 1425 surveyed firms, 895 answered to the questionnaire and 456 reported positive R&D expenditures in 1995[13]. Several firms for which information was incomplete or unreliable have been deleted leading to the working sample of 379 manufacturing firms. In terms of R&D expenses, these 379 firms are representative of 38.4% of Belgian total Business Expenditures on Research and Development in 1995[14].

Table 3. Descriptive statistics of the sample

	# of firms	average total R&D exp. 10^6 BEF	# of patents
By industry			
Food & beverage	19	18,8	6
Textile	12	13,0	0
Wood	8	18,8	1
Chemical products	50	156,3	189
Non metallic mineral products	13	70,1	296
Metals	10	158,9	26
Fabricated metallic products	23	66,9	23
Machinery	111	175,3	93
Other	28	15,3	29
R&D activities	89	66,5	92
Drugs	16	219,4	21
By region			
Brussels	54	72,3	314
Flanders	234	115,5	386
Wallonia	91	119,8	76
By size			
< 25 employees	119	7,2	23
25-200 employees	141	39,7	102
> 200 employees	119	297,2	651
Total	379	110,4	776

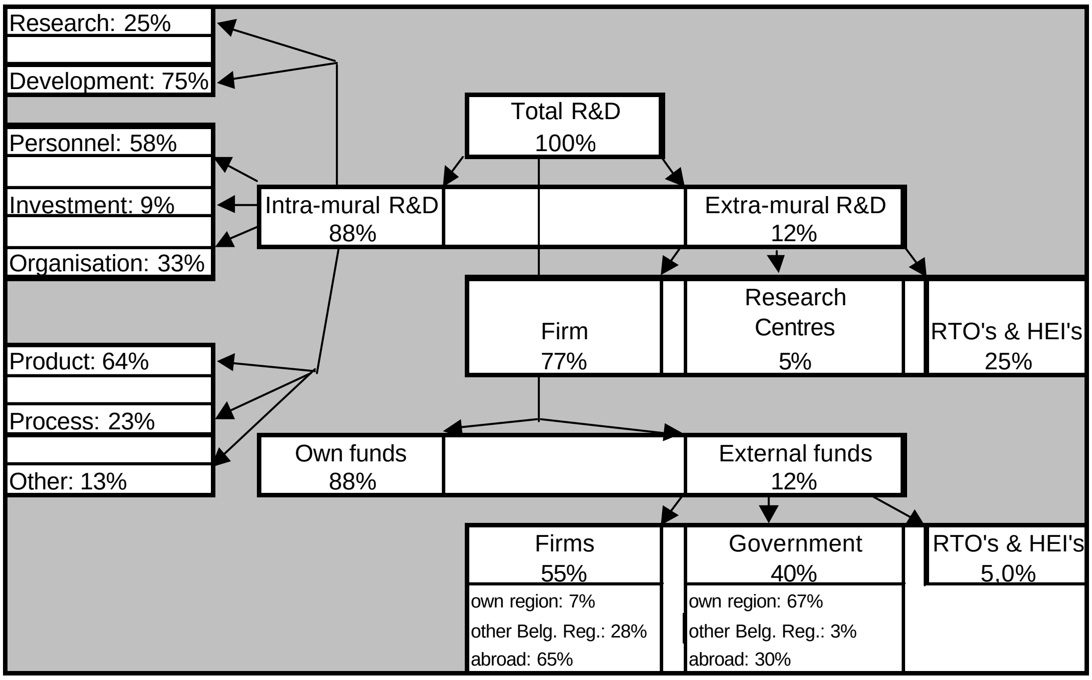
Source: Office for Scientific, Technical and Cultural Affairs, own calculations.

[13] Debackere and Fleurent (1995), have performed a limited non-response analysis and concluded that no systematic bias could be detected.

[14] See Capron et al. (1999) for a description of the methodology implemented to check the consistency of these data as well as the procedure to extrapolate these data to the Belgian total figure published by OECD and EUROSTAT.

Table 3 gives some details as regards the composition of the sample as well as some descriptive statistics for the main variables retained in this study. Figure 2 gives the distribution of R&D expenses among several components of these activities.

Figure 2. Distribution of total R&D expenses by type of activities and source of financing



Source: Office for Scientific, Technical and Cultural Affairs, own calculations.

3.2. R&D extended production function and econometric models for count data

In a first step, a probit model is implemented in order to assess the main determinants for patenting. Among these determinants, we can mention the size of the firm, the permanent nature of its R&D activities, the percentage of multinational firms in a given industry sector and the fact that the firm is part of an international group. As additional determinants, a set of regional dummies have also been included in the specification as well as three dummies that take the value one if the firm has acquired technologies developed outside, if there exist other activities linked to the increase in knowledge in the firm and if the firm does plan R&D activities in the two years to come. Among others, the estimated coefficients associated with some of these variables should reflect whether multinational firms have a weaker propensity to patent and if the presence of this kind of firms decreases the innovative output of domestic firms. Finally, in order to present the previous analysis into an unified framework, some first results estimated by the zero inflated GEC model discussed below are presented.

In a second step, the impact of R&D activities on patenting activities is carried out by considering an extended 'knowledge production function' (Griliches, 1979). This exercise extends previous work on the R&D-patent relationship[15] by considering several components of R&D activities (i.e. its 'R' and its 'D' component, product- versus process-oriented R&D, and intramural

[15] See, among others, Hausman, Hall and Griliches (1984), Crépon and Duguet (1997a, 1997b) and Cincera (1997).

and subcontracted R&D) rather than total R&D expenditures of firms. The distinction between the origin of the financing, i.e. internal versus external funding, is also considered. As regards the external funding of R&D, information is available on whether the funds originate from public authorities, other business firms, or research and technology organisations (RTOs) and Higher Education Institutions (HEIs). A similar distinction for extramural R&D activities is made.

3.3. Econometric models for count data

In order to assess the impact of R&D activities and other technological determinants on firms' patenting, the discrete non-negative nature of patent counts has to be taken into account. For instance, because of difficulties and uncertainties inherent to R&D activities, firms do not always apply for patents and hence a zero value is a natural outcome of this variable. The first part of this section presents some basic models for count data that deal with the discrete non-negative nature of the patent dependent variable. The second part discusses zero-inflated count models. The motivations for considering this kind of modified count models are threefold. First, a large number of firms in the sample did not apply for any patent and the basic count data models may not be well suited to explain this large number of zero outcomes[16]. Second, some firms may prefer alternative strategies to patents for protecting their new products and processes against imitation[17]. Finally, the output of the research activities carried out by the subsidiaries of foreign multinationals established in Belgium may be brought back to the multinational home country. In the last two cases, the zero outcome results from a strategic decision of the firm not to apply for patents.

a) Basic count data models

The usual way to deal with the discrete non-negative nature of the patent dependent variable is to consider the simple Poisson regression model. Let y_i be this variable which represents the number of patent applications by firm i, where i = 1,...,N. The y_i are assumed to be independent and have Poisson distributions with parameters $?_i$. Parameters $?_i$ depend on a set of explanatory variables, which are in this case the determinants of the knowledge production function:

$$?_i ? \exp ? x_i ? ?$$

where: x_i represents a set of k explanatory variables,

? is the vector of associated coefficients to be estimated.

The dependent patent variable is related to this function through the conditional mean of the Poisson model. An advantage of such a specification is that when variables x_i are expressed in logarithms, parameters $?_k$ are elasticity. The Poisson distribution is given by:

[16] In this study, the share of firms with zero patents is 79%. Bound et al. (1984) report a share of 60% for US firms and Crépon and Duguet (1997b), a share of 73% for French firms.

[17] As discussed in section 2.2., lead time and secrecy are two examples.

$$P(Y_i\ ?\ y_i)\ ?\ \frac{\exp(?\,?_i)?_t^{y_i}}{y_i!}$$

The $ß_k$ are estimated by the maximum likelihood method and the log-likelihood is:

$$l(y;ß)\ ?\ \underset{i?1}{\overset{N}{?}}\ ?y_i x_i ß\ ?\ \exp?x_i ß?\ ?\ \ln?y_i!??$$

This function is ? globally concave, hence unicity of the global maximum is ensured. An important property of the Poisson model is the equality between its first two conditional moments:

$$E?y_i\,|\,x_i, ß?\ ?\ V?y_i\,|\,x_i, ß?\ ?\ ?_i$$

In most empirical studies, the equality of conditional mean and conditional variance of the dependent variable as implied by the Poisson model appears to be too restrictive. Very often, the conditional variance exceeds conditional mean, when estimating a cross-section model such as Poisson, which is known as 'overdispersion'. Two statistical sources can explain overdispersion: positive contagion and unobserved heterogeneity (Winkelmann and Zimmermann, 1995). For instance, when a firm has made a new important invention (drastic invention) which is patented, often this drastic invention is followed by small and continuous improvements and/or further developments, which can lead to subsequent patent applications. The failure to include individual specific effects is one explanation for unobserved heterogeneity. For instance, in the patent-R&D relationship the presence of firms unobserved effects like the uncertainty inherent to R&D activities, the ability of engineers to discover new products or the commercial risk of selling an invention, find expression in the fact that only a few successful firms are likely to apply for a large number of patents in a given time period while for a majority of firms the importance of patenting may be limited or even nil.

In order to address these issues, one possible extension of the Poisson model is to include a firm unobserved specific effect $?_i$ into the $?_i$ parameters. This firm-specific effect which is assumed to be invariant over time can be treated as random or as fixed. In the case of random effects, the Poisson's parameters become:

$$\tilde{?}_i\ ?\ \exp?x_i ß\ ?\ e_i?$$

The random terms $?_i$ take into account possible specification errors of $\tilde{?}_i$. These misspecifications may result from the omission of non observable explanatory variables or from measurement errors of these variables. The precise form of the distribution of the compound Poisson model depends upon the specific choice of the probability distribution of exp($?_i$):

$$P?Y_i\ ?\ y_i?\ ?\ \underset{??}{\overset{??}{?}} \frac{\exp ??\ \exp?x_i ß\ ?\ ?_i???\exp?x_i ß\ ?\ ?_i??^{y_i}}{y_i!} g?e_i?de_i$$

where $g(?_i)$ indicates the probability distribution of $?_i$.

The computation of the compound Poisson's distribution may be a difficult task - at least from an analytic point of view - because of the integral arising in the equation. However, when it is assumed that exp(?i) follow a gamma distribution with parameters $?\,?_i, ?_i?$[18] and are independent and identically distributed, the computation of the last formula leads to the well known negative binomial model. The probability distribution of this model is given by:

$$P?Y_i ? y_i?? \frac{??y_i ? ?_i?}{??y_i ? 1??\,?_i?} ?\frac{?_i}{?_i ? ?_i}?^{?_i} ?\frac{?_i}{?_i ? ?_i}?^{y_i}$$

Cameron and Trivedi (1986) propose two parametrisations of the variance parameter $?_i$:

$$?i ? \frac{?_i}{?}, \text{ and } ?_i ? \frac{1}{?}$$

which lead to the so-called negbin I and negbin II models respectively. The variance-mean relationships implied by these two models allow for overdispersion :

$V?y_i?? ?1 ? ? ?E?y_i?$ for negbin I and $V?y_i?? E?y_i?? ?E?y_i?^2$ for negbin II.

Furthermore the Poisson model is nested in these negative binomial models, that is when parameter ? tends to 0, negbin I and II converge to the Poisson model. Winkelmann and Zimmermann (1991, 1995) developed an even more flexible conditional mean-variance relationship. The authors developed the General Event Count Model (GEC) which is based on a new parametrisation of the Katz family. This model is distributed with density:

$$f?Y | ?, ?^2, k?? C_i ? ?\begin{cases} ?_{j?1}^{y_i} ?\frac{?_i ? ??^2 ? 1??j ? 1??_i^k}{??^2 ? 1??_i^k j}?, & \text{for } y_i ? 1,2,... \\ 1 & \text{for } y_i ? 0 \end{cases}$$

where

$$C_i ? \begin{cases} ???^2 ? 1??_i^k ? 1?^{?_i} & \text{for } a ? 0 \\ ???^2 ? 1??_i^k ? 1?^{?_i} D_i^{?1} & \text{for } 0 ? ? ? 1; ?_i^k ? \frac{1}{?} \\ 0 & \text{otherwise} \end{cases}$$

$$?_i ? \frac{? ?_i^{k?1}}{?}$$

$$D_i ? \sum_{m?0}^{int^*??_i?} f_{binomial}?m | ?_i, ?, k?$$

[18] If the set of explanatory variables contains a constant term, this assumption is not too restrictive.

$$\text{int}^*(y) = \begin{cases} \text{int}(y) + 1 & \text{for int}(y) < y \\ \text{int}(y) & \text{for int}(y) = y \end{cases}$$

The variance-mean relationship of the GEC model is defined as:

$$V(y_i) = \left[1 + (\sigma^2 - 1)E(y_i)^{k-1}\right] E(y_i \mid x_i)$$

where σ^2 and k, which are independent of λ, represent respectively the dispersion parameter and the non-linearity in the variance-mean relationship.

This more general full parametric specification allows for overdispersion (as well as underdispersion[19]). Furthermore, it embraces the Poisson model (for $\sigma^2 = 1$), negbin I (for $\sigma^2 > 1$ and $k = 0$) and negbin II (for $\sigma^2 > 1$ and $k = 1$) as special cases. Using the estimated value of σ^2 and k, it is possible to discriminate between the Poisson and both negative binomial models or to reject them rather than to choose one of them *a priori*.

b) Zero-inflated count models

In order to investigate the excess zeros patent outcome discussed in the beginning of this section, one possibility is to estimate, besides the event count models, a probit or logit model to explain the decision to patent. A more general model is the zero inflated Poisson model of Lambert (1992) that mixes a logit decision model with a Poisson model. This so-called ZIP model deals with two sources of overdispersion. The first source is related to the excess of zeros and the second to the unobserved heterogeneity arising from the presence of firms specific unobserved effects. The logit part of the ZIP model estimates specific covariates that explain the decision to patent or to never engage in such activities. The Poisson part explain the positive patent outcomes and the zero arising because of the failures of innovation activities[20]. The same or different covariates can be estimated for each part of the ZIP model, whose distribution is given by:

$$\begin{cases} P(Yi = 0) = \psi_i + (1 - \psi_i)\exp(-\lambda_i) \\ P(Yi = y_i) = (1 - \psi_i)\dfrac{\exp(-\lambda_i)\lambda_i^{y_i}}{y_i!} & y_i = 1,2,... \end{cases}$$

where: $\psi_i = \dfrac{\exp(z\gamma)}{1 + \exp(z\gamma)}$

z_i represents a set of k' explanatory variables,

γ is the vector of associated coefficients to be estimated.

This model can be easily generalised by considering another parametrisation of ψ_i than the logistic distribution and by replacing the Poisson model by more general event count data models[21].

[19] $(\sigma^2 - 1) > 0$ implies overdispersion and $0 > (\sigma^2 - 1) \geq -\dfrac{1}{\lambda_i^k}$ underdispersion

[20] The ZIP model is not nested within the Poisson model, the restriction to get the Poisson model is $1 - \psi_i = 0$, which is not a simple parametric restriction. In order to discriminate between both models, Vuong (1989) test statistic for non nested models can be used.

[21] Greene (1994), for instance, considers a probit model mixed with a negative binomial model.

The econometric framework implemented in this paper rests on a zero-inflated generalised event count (ZI-GEC) model. The probit part of this model estimates specific covariates that explain the decision to patent or to never engage in such activities. The GEC part, which is a generalisation of the basic Poisson model, explains the positive patent outcomes and the zero arising because of the failures of innovation activities.

4. Empirical findings

Regression results for the probit model are summarised in Table 4. As additional results, the estimates of the ZI-GEC model are also reported in this table. As can be expected, firms with permanent R&D activities or with future R&D activities planed have a higher probability to engage in patenting activities. Another well established result is the fact that large firms are also more likely to apply for patents. The positive estimate associated with the variable 'Acquisition of outside developed technologies' indicates a complementary effect between these technological goods, own R&D and patenting. On the other hand, other innovative activities such as testing or marketing do not explain the decision whether to patent or not. This kind of activities takes place more in the downstream stage of the innovation process and hence does not influence the patent applications. The two most interesting results concern the firms that are part of a group and the share of multinational firms in a given industry. The latter suggests a positive impact on patenting. This result seems to contradict the findings obtained by Veugelers and Vanden Houte (1990) who found a negative effect. Yet, this negative outcome concerns the innovative effort of firms engaged in R&D activities and not the output of innovative activities as measured by patent applications. So, the positive result in Table 4 can be viewed more as a competitive effect between domestic firms and international ones or as a higher propensity of the latter to patent. Finally, no impact in terms of patenting is detected as regards the firms that belong to a foreign group. It is no clear whether this result is a consequence of the nature of R&D activities carried out by these firms or whether it is due to the transfer of the knowledge developed locally towards the home country of the foreign group. This point deserves further investigation.

Table 4. Probit and ZI-GEC models:

Determinants explaining the decision to patent (379 Belgian firms, 1995)

Model	Probit	ZI-GEC	
		Probit part	GEC part
Intercept	-2.3 (.707)*	-6.4 (.876)*	-9.3 (1.11)*
% of multinational subsidiaries in the industry	-.09 (.032)*	-.01 (.018)	
Firm is part of a foreign group	.03 (.206)	.03 (.357)	
Permanent R&D	.48 (.254)**	.80 (.471)	
Acquisition of outside developed technologies	.91 (.176)*	1.4 (.304)*	
Other (than R&D) innovative activities	.23 (.229)	.48 (.427)	
Future R&D planed (in the two years to come)	.59 (.266)*	1.1 (.473)*	
Total R&D expenditures			.85 (.112)*
Medium-tech industries	.58 (.297)*	.49 (.440)	.18 (.430)
High-tech industries	.63 (.228)*	1.4 (.451)*	.06 (.529)
Flanders region	.86 (.293)*	1.5 (.548)*	.08 (.571)
Walloon region	.74 (.328)*	1.3 (.609)*	.56 (.629)
Medium-size firms (20-200 employees)	.29 (.234)	.95 (.525)**	.69 (.416)
Large-size firms (more than 200 employees)	.80 (.243)*	1.0 (.404)*	.05 (.384)
K			.86 (1.17)*
S^2			5.7 (.876)*
Log-likelihood	-142	-458	

*Notes: heteroskedastic-consistent standard errors in parenthesis, *, resp. ** means statistically significant at the 5%, resp. 10% level*

Before to discuss the empirical findings regarding the links between patents and R&D activities, preliminary estimates of the different count data models described in the previous section are discussed. The estimated ? ^{2} parameter of the GEC model in Table 5 indicates that the Poisson model has to be rejected. Moreover, the data are consistent with the hypothesis that ? ^{2} is higher than one and that k is not different from one. These results lead to reject the negbin I model and vindicate the use of the negbin II count data model[22].

Table 5. Basic count data models: Estimated impacts of total R&D on patent applications (379 Belgian firms, 1995)

	Dependent variable: number of patents			
	Poisson	Negbin I	Negbin II	GEC
Intercept	-9.2 (1.4)*	-4.0 (.90)*	-8.8 (1.2)*	-8.9 (1.1)*
Total R&D expenses	.97 (.12)*	.45 (.07)*	.82 (.12)*	.88 (.10)*
S^2		26.6 (16)**	6.5 (1.3)*	5.6 (1.0)*
K				.95 (.13)*
Log-likelihood	-1539	-362	-336	-336

*Notes: heteroskedastic-consistent standard errors in parenthesis, *, resp. ** means statistically significant at the 5%, resp. 10% level*

The results of the patent R&D relationship are reported in Table 6. On the whole, total R&D activities exhibit slightly decreasing returns to scale with respect to patenting[23]. A similar analysis has been carried out by considering scientific publications instead of patent applications. In this case the returns of total R&D are lower. The higher risks and uncertainties of basic or fundamental research activities could account for this result.

The results as regards the impact of R&D activities and their different components on patenting are also reported in Table 6. The estimated coefficients associated with these components appear

[22] In practice, there are very few examples where the GEC model fits better than the negbin II.
[23] This result corroborates previous findings of related studies. See Cincera (1998), for a survey.

much more differentiated. The distinction between in-house and sub-contracted R&D indicates that it is mainly the former activity that contributes to technological output as measured by patents. One argument to explain the lower 'productivity' of R&D carried out outside the firm is the occurrence of major transaction costs. As emphasised by Geroski (1995), given these costs, external research facilities will generally provide generic rather than specialised inputs into the R&D programmes of their clients. These generic inputs are less likely to lead to successful inventions and to patent applications.

Table 6. 'Knowledge production functions': estimated impacts of R&D 'components' on patent applications (379 Belgian firms, 1995)

Dependent variable: number of patents						
Intercept	-8.2 (.967)*	-5.3 (.664)*	-4.3 (.576)*	-7.3 (1.32)*	-5.5 (.849)*	-4.4 (.734)*
Intramural R&D	.66 (.098)*					
Research		.15 (.033)*				
Development		.26 (.065)*				
Product			.15 (.052)*			
Process			.02 (.041)			
Other			.09 (.038)*			
Personnel				.55 (.195)*		
Investment				-.02 (.085)		
Organisation				.05 (.046)		
Own funds					.29 (.104)*	.21 (.073)*
Extern. Funds					.121 (.042)*	
Firms						.08 (.029)*
Government						-.01 (.024)
RTOs and HEIs						-.30 (.094)*
Extramural R&D	.16 (.034)*	.20 (.034)*	.23 (.039)*	.17 (.037)*	.17 (.036)*	
Firms						.08 (.025)*
Collective research centres						-.03 (.031)
RTOs and HEIs						.13 (.020)*
K	.88 (.111)*	.86 (.111)*	.82 (.102)*	.87 (.105)*	.81 (.107)*	.80 (.096)*
S²	4.7 (.936)*	5.0 (.800)*	6.4 (1.08)*	4.8 (.884)*	5.7 (1.03)*	4.1 (0.78)*
Loglikelihood GEC model	-448	-450	-459	-449	-455	-441

Notes: *a) heteroskedastic-consistent standard errors in parenthesis, *, resp. ** means statistically significant at the 5%, resp. 10% level*
b) RTOs = Research and Technology Organisation, HEIs = Higher Education Institutions
c) Industry, regional and size dummies incl.

If we now turn to the composition of the R&D effort, the estimates suggest that the returns are higher for development activities, product-oriented research, and the share of R&D expenses that goes to the salaries of researchers. The result for the last component indicates the importance of human capital in the inventive process with respect to investments in R&D capital. The high estimated elasticity associated with the share of R&D allocated to product innovation confirms the higher propensity of Belgian firms to apply for product-oriented patents. The estimated elasticities associated with the 'R'esearch and 'D'evelopment components of R&D activities indicate that patenting tends to arise during the development of new products and processes stage of the invention process. This finding can be related to the important number of foreign subsidiaries with patenting activities in Belgium. These firms may well be more involved in the development of already patented products by the foreign mother company for local or national markets.

While some empirical evidence has been found for a leverage effect of publicly financed R&D on private R&D, there is in general no impact of the former variable on output performances of firms as measured by productivity growth[24] or patenting. The estimates associated with the share of intramural R&D financed by external funds, i.e. firms, government agencies, RTOs, and HEIs, lead to a similar conclusion. Moreover, significant negative elasticity is found for the RTOs and HEIs. The non-commercial orientation of the research financed by such organisations may account for this result. Finally, the higher returns of out-sourced R&D on own patenting come mainly from other business firms and to a lesser extent from RTOs and HEIs. This opposite finding with respect to the external funding can be explained by the fact that the decision to sub-contract R&D activities in such organisations comes from the firms themselves.

6. CONCLUSION

This study has investigated the impact of R&D activities and other technological determinants on the outcomes of such activities as measured by patent applied by Belgian manufacturing companies. The results indicate slightly decreasing returns to scale of R&D with respect to patenting. Important differences are observed in the estimated impacts of these activities according to their type and source of financing. In particular, a higher impact of intramural R&D financed by own fund and of product development activities are observed while no significant impact of public subsidies is found. Patent statistics suggest a high concentration and internationalisation of the Belgian innovation system. Furthermore, a higher share of foreign subsidiaries in an industry sector, tends to decrease the probability of local firms to patent. Hence, the technological activities of these firms could generate negative competitive externalites and have had an adverse influence on the innovative effort of domestic firms. Finally foreign subsidiaries do not appear to apply for patents. On the one hand, the outcomes of R&D activities generated by these firms may be brought back to the mother company and patented in the home country. On the other hand, the subsidiaries may be involved in Home Based Exploiting technological activities whose outcomes do not need protection by means of patents. This point deserves further investigation.

[24] See Capron (1992) and Hall (1996) for a review.

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