THE LINK BETWEEN FIRMS' R&D BY TYPE OF ACTIVITY AND SOURCE OF FUNDING AND THE DECISION TO PATENT

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The link between firms' R&D by type of activity and source of funding and the decision to patent[*]

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Summary

This paper aims at assessing the impact of R&D activities on the number of patents applied by Belgian R&D manufacturing firms in the mid nineties. The paper extends previous work on the R&D-patent relationship by distinguishing different types as well as sources of financing of R&D activities. Another question addressed is the extent to which technological determinants differently affect the patenting of foreign R&D subsidiaries localised in Belgium as compared to domestic firms. Foreign subsidiaries appear to have a lesser propensity to patent in the host country, 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
KEY words: R&D, patents, MNEs, Belgian manufacturing firms, count data econometric models

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I. Introduction

This paper is an empirical study of the relationship between R&D activities and patent applications. This relationship is estimated by means of an extended knowledge production function (Griliches, 1979) on a representative sample of Belgian manufacturing firms active in R&D in 1994 and 1995. One novelty of this research is to consider different types of R&D activities and sources of financing of these intangible investments rather than total R&D expenditures as in previous studies examining the R&D-patent relationship[1]. For instance because of their more fundamental nature, the impact of basic and applied research may be different than the effect of research development on the output of the innovative process as measured by patent counts. Another interesting question is to look at the sources for the financing of research activities. Public funds for R&D may also have a different impact on patenting as compared to the firm's own funds. A second question addressed in this study is the extent to which foreign R&D subsidiaries localised in Belgium have different patenting propensities as compared to Belgian firms. Indeed, the high dependency of the Belgian innovation system on foreign multinational enterprises (MNEs) could be an important reason for its lower propensity to patent. On the one hand, foreign subsidiaries can be specialised in the adaptation to the local market of products and processes developed in the first place in the headquarters of MNEs. On the other hand, head offices could hoard a significant part of the R&D output of their subsidiaries, these firms taking advantage of the local availability of a highly qualified workforce and knowledge base. A third originality of this paper rests in the way the R&D-patent relationship is estimated. Firms may not apply for any patents not only because of the failures of their R&D activities but also for strategic reasons such as secrecy. In order to take into account these possibilities, an econometric zero-inflated generalised event count (ZI-GEC) is estimated following Lambert (1992) and Winkelmann and Zimmermann (1995). The discrete part of this compounded 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 zeroes arising because of the failures of innovation activities. On the whole the results indicate that foreign subsidiaries have a lesser propensity to patent in the host country, 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 firms' patenting activities. Recent trends in patenting activities of Belgian manufacturing companies are then illustrated and the strong place occupied by MNEs 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 are drawn in Section 5.

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[1] See for instance Hausman, Hall and Griliches (1984), Crépon and Duguet (1997a, 1997b), Cincera (1997) or Guo and Trivedi (2002).

II. Patents, R&D and MNEs R&D activities in Belgium

Determinants of patenting activities and S&T activities of MNEs

The imperfect appropriability of the outcomes 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 to the extent that firms will invest less in R&D than the socially optimal level[2]. The literature on public R&D discusses several ways to compensate for the imperfect functioning of such markets[3]. Public technology procurement, R&D subsidies or tax breaks for instance increase the expected returns by lowering the costs of these activities while 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] or to reduce the costs of filing a patent, their effectiveness varies considerably across industry sectors[5]. Patenting behaviours are not only linked to the costs of patenting but also to the appropriability conditions of the R&D output as well as the nature of these activities, in particular the type of research for example whether it is basic or more applied, tacit or codified, product or process oriented. These characteristics will affect the speed of technological diffusion or the ability of rivals to invent around a patented invention. The sources of financing of these activities, the size, the market share, the technological diversification, the degree of internationalisation of firms or the importance of entry barriers for potential competitors are other determinants that influence the costs of patenting. For instance large companies that benefit from public R&D support may be less financially constraint while worldwide firms may have to register their patents in several patent offices thus increasing the costs of these activities. Firms more exposed to potential competition may also have to apply for more patents.

As regards the degree of internationalisation of R&D, technology production has usually been centralised in the host country of MNEs. The reduction of the costs of communications and control, economies of scale in R&D and a better coordination between central and peripheral

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

[3] See Geroski (1995) for a discussion.

[4] For instance, in 1982, the Court of Appeals for the Federal Circuit was established in the US to strengthen and make patent protection more uniform. In the EU, the introduction by 2010 of a Community patent is expected to lower the costs of patenting.

[5] See Levin et al. (1987) for a study of differences in appropriability conditions across industries.

research labs are often mentioned in the literature to explain this situation (Terpstra, 1985)[6]. However, during the past decade, the involvement of MNEs 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 higher quality products[7]. MNEs 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 networks[8]. According to Granstrand et al. (1992), the 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) 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 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.

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[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 access 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 MNE'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.

The high internationalisation and concentration of the Belgian technological base

MNEs 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 linkages between MNEs 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 and a first question that is worth examining is what are the impacts of this high internationalisation of Science and Technology activities on the local economy. 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. Several 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 MNEs. These effects influence domestic firms in the MNE own industry as well as firms 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 the level of competition[11]. On the other hand the effects on the home country of MNEs 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 MNEs 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 1 sheds some light on the patenting activities of the top 50 Belgian firms over the last two decades. 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% respectively of the total number

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

[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".

of patents applied for by Belgian applicants between 1980 and 2000. In terms of US patents, these shares are even higher (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 suggesting that it is mainly the largest firms that patent outside the European market.

FIGURE 1

Cumulated distribution of the number of patent applications
of the top 50 Belgian firms (EPO and USPTO, 1980-2000)
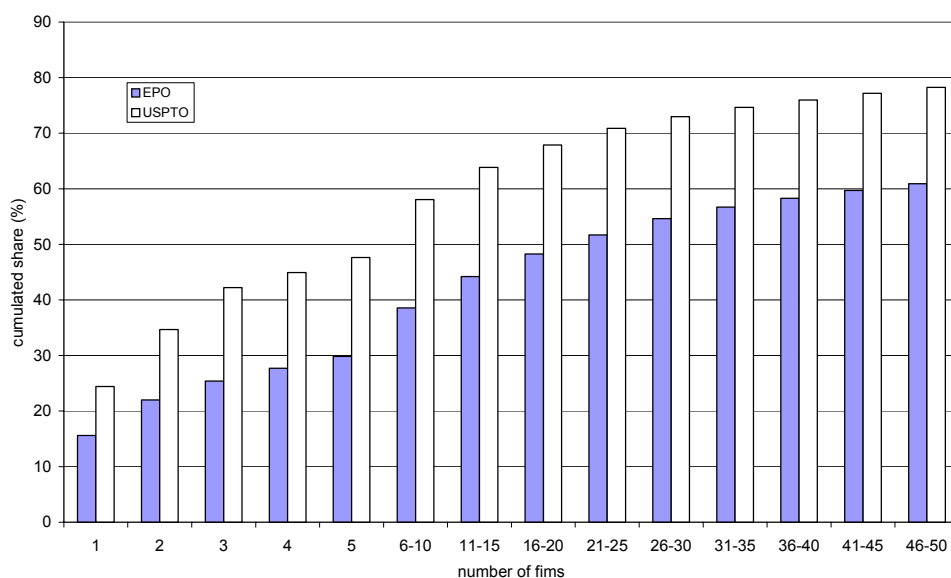
Sources: EPO and USPTO databases; own calculations.

TABLE 1

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

Table 1 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 MNEs. 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 towards foreign MNEs could be an important reason for its lower propensity to patent[12]. Subsidiaries can be specialised in the adaptation to the Belgian market of products and services developed and patented in the first place in the research labs of the multinational. These subsidiaries could also be involved in home based augmenting research activities, the local availability of a highly qualified workforce and knowledge base being the main reasons for their presence in the foreign country. In the first case, one can expect a lower propensity to patent for a given amount of R&D since the original invention is already protected. Then, in both cases the output of the R&D performed by the subsidiary can be directly patented by the multinational in its home country and not in Belgium[13]. Finally, the geographic distance between the MNE's home base and the domestic country can be another reason explaining a lower patenting propensity[14]. 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 influencing these activities.

III. DATA & COUNT DATA ECONOMETRIC MODELS

Data set construction and R&D extended production function

The constructed data set consists of a representative sample of 379 Belgian manufacturing firms over the period 1994-95[15]. 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 100 variables as regards innovation and economic activities among which the total number of patent applications in all patent offices around the world, different components of R&D activities or whether a firm is part of a foreign group or not[16]. Out of

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[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.

[13] Contrary to other countries like the USA or the UK (Bertin and Wyatt, 1988), the Belgian patent law do not request a first filing in Belgium if an invention has been created in the domestic territory.

[14] Maskus (1998) for instance, finds that the number of patents filed by US subsidiaries in host countries depends positively from the strength of intellectual property protection in these countries as well as from the distance to the USA.

[15] NACE sectors 15 to 36 as well as 74 (services to enterprises).

[16] Though some Belgian firms have R&D subsidiaries established abroad, the survey only concerns the firms (domestic and foreign subsidiaries) with R&D activities carried out in the Belgian territory.

1425 surveyed firms, 895 answered to the questionnaire and 456 reported positive R&D expenditures in 1995[17]. Several firms for which information was incomplete or unreliable have been deleted leading to a 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[18]. Table 2 lists these different components as well as the distribution of total R&D expenditures among them. It follows that the firms of the sample are mainly performing development and product research activities. R&D are principally financed with the firms' own funds and the share of subcontracted R&D is small. Table 3 gives some details as regards the composition of the sample as well as some descriptive statistics for the patent variable. Interestingly the foreign subsidiaries are characterized by a lesser propensity to patent as compared to domestic firms. As discussed before, besides the HBA and HBE hypothesis, the geographic proximity of the MNE can be another determinant that can affect the behaviour of repatriation of inventions[19].

The patent-R&D relationship is estimated in a first step by means of a probit model in order to directly 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, two sets of regional and R&D intensity dummies have also been included in the specification as well as three dummy variables that take the value one if the firm has acquired technologies developed outside, if there exist other activities linked to the increase of knowledge in the firm and if the firm does plan R&D activities in the two years to come. The estimated coefficients associated with some of these variables should reflect whether subsidiaries of foreign MNEs have a weaker propensity to patent and if the presence of this kind of firms decreases the innovative output of domestic firms. In a second step, the impact of R&D on patenting activities is estimated by means of an extended 'knowledge production function' (Griliches, 1979). This exercise extends previous work on the R&D-patent relationship by considering several components of R&D activities, for instance the 'R' and 'D' component, product- versus process-oriented R&D, intramural and subcontracted R&D, rather than total R&D expenditures. 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.

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[17] Cincera et al. (2003) use the same data set and the test statistic for the presence of sample selection bias due to the non respondents is not significant at the 1% level.
[18] 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 the OECD and EUROSTAT.
[19] It follows from the 91 subsidiaries in the sample that 27% of the MNEs to which they belong are established in the Netherlands, 19% in France, 10% in Germany and 5% in the UK. These countries are the main trade partners of Belgium and neighbor countries.

TABLE 2

Sample's distribution of total R&D expenditures
by type of activitiesand source of financing in 1995

Total R&D expenditures	100%	Intra-mural R&D		88%
Research	25%	Subcontracted R&D		12%
Development	75%	*Other firms*		*70%*
Personnel costs	58%	*Collective research centres*		*5%*
Investment	9%	*HEIs and RTOs*		*25%*
Organisation costs	33%	R&D financed with firm's own funds		88%
Product R&D	64%	R&D financed with external funds		12%
Process R&D	23%	*Other firms*		*55%*
Combination of product/process R&D	13%	*Public funds*		*40%*
		RTOs and HEIs		*5%*

Note: HEIs = Higher Education Institutions; RTOs = public Research and Technology Organisations
Source: Office for Scientific, Technical and Cultural Affairs, own calculations.

TABLE 3

Descriptive statistics of the sample

	# of firms	# of patents	Average patent propen-sity[a]		# of firms	# of patents	Average patent propen-sity
Industry[b]				Size			
High-tech	118	409	1.596	< 25 employees	119	23	1.082
Medium-tech	194	331	0.439	25-200 employees	141	102	0.735
Low-tech	67	36	1.330	> 200 employees	119	651	0.742
Region				Firms			
Brussels	54	314	3.244	Domestic firms	288	504	1.282
Flanders	234	386	0.576	Foreign subsidiaries	91	272	0.422
Wallonia	91	76	0.281	Total	379	776	0.748

Notes:
a) average patent propensity is defined as the number of patent applications per mio € R&D in 1995.
b) OECD's industrial classification based on R&D intensity. High-tech (resp. low tech): industries with average R&D intensity above 3% (resp. below 1%).
Source: Office for Scientific, Technical and Cultural Affairs, own calculations.

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[20]. Second, some firms may prefer alternative strategies to patents for protecting their new products and processes against imitation[21]. Finally, the output of the research activities carried out by the subsidiaries of foreign MNEs established in Belgium may be brought back to and patented in 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 in the host country.

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 λ_i. Parameters λ_i depend on a set of explanatory variables, which are in this case the determinants of the knowledge production function:

$$\lambda_i = \exp(x_i\beta) \tag{1}$$

where: x_i represents a set of k explanatory variables,

             β 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 β_k are elasticity. The Poisson distribution is given by:

$$P(Y_i = y_i) = \frac{\exp(-\lambda_i)\lambda_t^{y_i}}{y_i!} \tag{2}$$

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

$$l(y;\beta) = \sum_{i=1}^{N}\left[y_i x_i\beta - \exp(x_i\beta) - \ln(y_i!)\right] \tag{3}$$

This function is β 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:

$$E(y_i \mid x_i,\beta) = V(y_i \mid x_i,\beta) = \lambda_i \tag{4}$$

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[20] 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.

[21] 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, secrecy or learning curve advantages. See Cohen (1995) for instance for a discussion.

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 ε_i into the λ_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:

$$\widetilde{\lambda}_i = \exp(x_i\beta + \varepsilon_i) \tag{5}$$

The random terms ε_i take into account possible specification errors of $\widetilde{\lambda}_i$. 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 $\exp(\varepsilon_i)$:

$$P(Y_i = y_i) = \int_{-\infty}^{+\infty} \frac{\exp(-\exp(x_i\beta + \varepsilon_i))(\exp(x_i\beta + \varepsilon_i))^{y_i}}{y_i!} g(\varepsilon_i) d\varepsilon_i \tag{6}$$

where $g(\varepsilon_i)$ indicates the probability distribution of ε_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 $\exp(\varepsilon_i)$ follow a gamma distribution with parameters (λ_i, θ_i)[22] 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:

$$P(Y_i = y_i) = \frac{\Gamma(y_i + \theta_i)}{\Gamma(y_i + 1)\Gamma(\theta_i)} \left(\frac{\theta_i}{\lambda_i + \theta_i}\right)^{\theta_i} \left(\frac{\lambda_i}{\lambda_i + \theta_i}\right)^{y_i} \tag{7}$$

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

Cameron and Trivedi (1986) propose two parametrisations of the variance parameter ϕ_i :

$$\theta_i = \frac{\lambda_i}{\alpha}, \text{ and } \theta_i = \frac{1}{\alpha} \tag{8}$$

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 :

$$V(y_i) = (1+\alpha)E(y_i) \text{ for negbin I and } V(y_i) = E(y_i) + \alpha E(y_i)^2 \text{ for negbin II.}$$

Furthermore the Poisson model is nested in these negative binomial models, that is when parameter α 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:

$$f(Y \mid \lambda, \sigma^2, k) = C_i \times \begin{cases} \prod_{j=1}^{y_i}\left[\dfrac{\lambda_i + (\sigma^2 - 1)(j-1)\lambda_i^k}{(\sigma^2 - 1)\lambda_i^k j}\right], & \text{for } y_i = 1,2,... \\ 1 & \text{for } y_i = 0 \end{cases} \tag{9}$$

where

$$C_i = \begin{cases} \left((\sigma^2 - 1)\lambda_i^k + 1\right)^{\zeta_i} & \text{for } \alpha \geq 0 \\ \left((\sigma^2 - 1)\lambda_i^k + 1\right)^{\zeta_i} D_i^{-1} & \text{for } 0 < \alpha \leq 1; \lambda_i^k \leq \dfrac{1}{\alpha} \\ 0 & \text{otherwise} \end{cases}$$

$$\zeta_i = \frac{-\lambda_i^{k-1}}{\alpha}$$

$$D_i = \sum_{m=0}^{int^*(\zeta_i)} f_{binomial}(m \mid \lambda_i, \alpha, k)$$

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

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

$$V(y_i) = (\sigma^2 - 1)E(y_i)^{k+1} + E(y_i \mid x_i) \tag{10}$$

where σ^2 and k, which are independent of β, represent respectively the dispersion parameter and the non-linearity in the variance-mean relationship[23].

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[23] Cameron and Trivedi (1986) present a similar variance function.

This more general full parametric specification allows for overdispersion (as well as underdispersion[24]). Furthermore, it encompasses 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*.

Zero-inflated count models

In order to investigate the excess zeros patent outcome discussed before, 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[25]. This so-called ZIP model allows for 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 probit part of the ZIP model estimates specific covariates that explain the decision to patent or to never engage in such activities. The Poisson part explains the positive patent outcomes and the zero arising because of the failures of innovation activities[26]. The same or different covariates can be estimated for each part of the ZIP model, whose distribution is given by:

$$\begin{cases} P(Yi = 0) = \varphi_i + (1 - \varphi_i)\exp(-\lambda_i) \\ P(Yi = y_i) = (1 - \varphi_i)\dfrac{\exp(-\lambda_i)\lambda_i^{y_i}}{y_i!} \qquad y_i = 1,2,... \end{cases} \qquad (11)$$

where: $\qquad \varphi_i = \dfrac{\exp(z_i\gamma)}{1 + \exp(z_i\gamma)}$

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 φ_i than the logistic distribution[27] and by replacing the Poisson model by more general event count data models. The econometric framework implemented in this paper rests on a zero-inflated

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[24] $(\sigma^2 - 1) > 0$ implies overdispersion and $0 < (\sigma^2 - 1) < 1, \lambda_i^k \leq \dfrac{-1}{(\sigma^2 - 1)}$ underdispersion.

[25] This model extends the hurdle Poisson model (Mullahy, 1986), which combines a binary probability model to determine whether the zero or non-zero outcome occurs with a truncated Poisson model for the positive outcomes.

[26] The ZIP model is not nested within the Poisson model, the restriction to get the Poisson model is $1 - \varphi_i = 0$, which is not a simple parametric restriction. Moreover, the ZIP model does not allow for a correlation, ρ, between the error terms in the Poisson and the decision models. Crépon and Duguet (1997b) estimate a heterogenous Probit-Poisson model by the simulated maximum likelihood method which allows for a correlation between the errors terms. However, the authors do not find a significant correlation coefficient in their study. This result is not surprising since the decision by firms of an alternative strategy to patenting such as secrecy can be expected to be independent upon subsequent potential failures associated with the R&D process, which in both cases lead to a zero patent outcome. This method has not been investigated in this study and is let opened for future work.

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

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 from the failures of innovation activities.

IV. Empirical findings

Before discussing 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 σ^2 parameter of the GEC model in Table 4 indicates that the Poisson model has to be rejected. Moreover, the data are consistent with the hypothesis that σ^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[28]. Regression results for the ZI-GEC model are reported in Table 5. As additional results, estimates of a simple probit model are also reported in this table.

TABLE 4
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

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 and firms in high-tech sectors are also more likely to apply for patents. The coefficients associated with the regional dummies are significant, which indicates a higher activity of patenting in Flanders and Brussels as compared to Wallonia, the reference group. 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 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 is less likely to influence the patenting process[29]. The two most interesting results concern the firms that are part of a foreign group and the share of multinational firms in a given industry. The estimated

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[28] In practice, there are very few examples where the GEC model outperforms the negbin II.
[29] See for instance Cincera (1997) or Grandstrand (1999) for evidence that patents are taken out in the upstream stage of the innovation process.

coefficient associated with this last variable is in line with the results reported in Veugelers and Vanden Houte (1990). The authors also find that a high share of MNEs in a given industry has a negative effect, though it concerns the level of R&D effort rather than the output of these activities as measured by patent applications. This finding indicates the presence of competitive interactions between domestic firms and international ones but it could also be the result of a lesser propensity of the latter to patent. This hypothesis seems to be confirmed by the firms that belong to a foreign group whose impact on patenting is not significant. As discussed before this result can be explained by the nature of the R&D activities carried out by these firms or the decision for the subsidiaries geographically close to their home country to apply for a patent in their country as opposed to where the invention was created. The latter would suggest a transfer of the knowledge developed locally towards the home country of the foreign group. Firms engaged in home based R&D exploiting activities can be expected to carry out more important development activities as compared to the research ones. This seems to be the case for the firms in the sample since the median share of the research component with respect to total R&D expenditures is 12.2% on average for the foreign subsidiaries as compared to 17.8% for the domestic firms. Hence, the adaptation to the local market of new goods and services created in the home base could be a determinant why these firms have a lower propensity to patent in the local country. As regards the repatriation of inventions and the geographic proximity hypotheses, these questions could be further investigated having the patents applied by the MNEs as well as the residence country of the inventors.

TABLE 5
Determinants explaining the decision to patent - ZI-GEC model
(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 planned (in the 2 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)
Brussels region	.86 (.293)*	1.5 (.548)*	.08 (.571)
Flanders 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)*
S²			5.7 (.876)*
Log-likelihood	-142	-458	

Notes: other innovative activities consist in training and marketing activities or activities related to quality and standard; 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. When estimating the ZI-GEC model the estimates of the decision model turned out to be not significant, which can be

due to an overparametrisation problem. Therefore only the results of the GEC model are discussed. On the whole, total R&D activities exhibit slightly decreasing returns to scale with respect to patenting[30]. The results as regards the impact of R&D activities and their different components on patenting are also reported in Table 5. The estimated coefficients associated with these components appear 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.

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 costs included in the wages of researchers. The result for the last component highlights the importance of human capital in the inventive process. The low estimated elasticity associated with the share of R&D allocated to process oriented R&D confirms the fact that in many industries, secrecy to protect innovation processes is viewed as more effective as compared to patenting[31]. 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 result is not surprising since 75% of the R&D of the firms in the sample consist of development activities. As discussed in Section 2, the public funding of private R&D is mainly aimed to compensate for the imperfect appropriability of the R&D outcomes[32]. The results reported in Table 6 suggest no impact of publicly financed R&D on the output of these activities as measured by patent applications. On the one hand, given the existence of asymmetric information and moral hazard issues, government administrations may not always subsidise the most effective R&D projects with the highest economic returns[33]. On the other hand, such public aids are intended to support long-term fundamental research and as such it may take some time for the benefits to show up in the output of R&D activities.

The estimates associated with the share of intramural R&D financed by external funds from firms, government research labs, RTOs and HEIs, lead to a similar conclusion. Moreover, a 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 from RTOs and HEIs. This opposite finding with respect to the external funding of R&D in RTOs and HEIs can be explained by the fact that the decision to sub-contract R&D activities in such organisations comes from the firms themselves.

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[30] This result corroborates previous findings of related studies. See Cincera (1998), for a survey.
[31] See Cohen (1995) for a discussion.
[32] In the R&D survey, public financing is defined as direct subsidies and does not include indirect tax incentives.
[33] See Hall (2002) for a recent survey and a discussion of these questions.

TABLE 6

'Knowledge production functions': estimated impacts of R&D 'components' on patent applications – GEC model (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)*
S^2	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 incuded.

IV. CONCLUSION

This study has investigated the impact of R&D activities and other technological determinants on the outcomes of such activities as measured by patents applied by a representative sample of Belgian manufacturing companies over the mid nineties. The econometric results show slightly decreasing returns to scale of own R&D with respect to patenting. While, this result confirms the findings of previous studies examining the impact of total R&D on 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. The interpretation of this last result is twofold. On one hand, public subsidies to R&D may not be very effective since publicly funded R&D does not lead to successful patented inventions. In this case governments should not invest in research. On the other hand, public funded R&D is mainly concerned with long term basic research whose outcomes is more uncertain and takes a long time to show up in the output of R&D as measured by patent applications. This question could be investigated with long time series of

data. As additional results, 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 externalities and have an adverse influence on the innovative effort of domestic firms. Finally foreign subsidiaries do not appear to apply for patents in the host country. It is not clear at this stage whether this is due to the nature of research activities performed by these firms or if the output of these activities is repatriated in the home country of the multinational company. 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.

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