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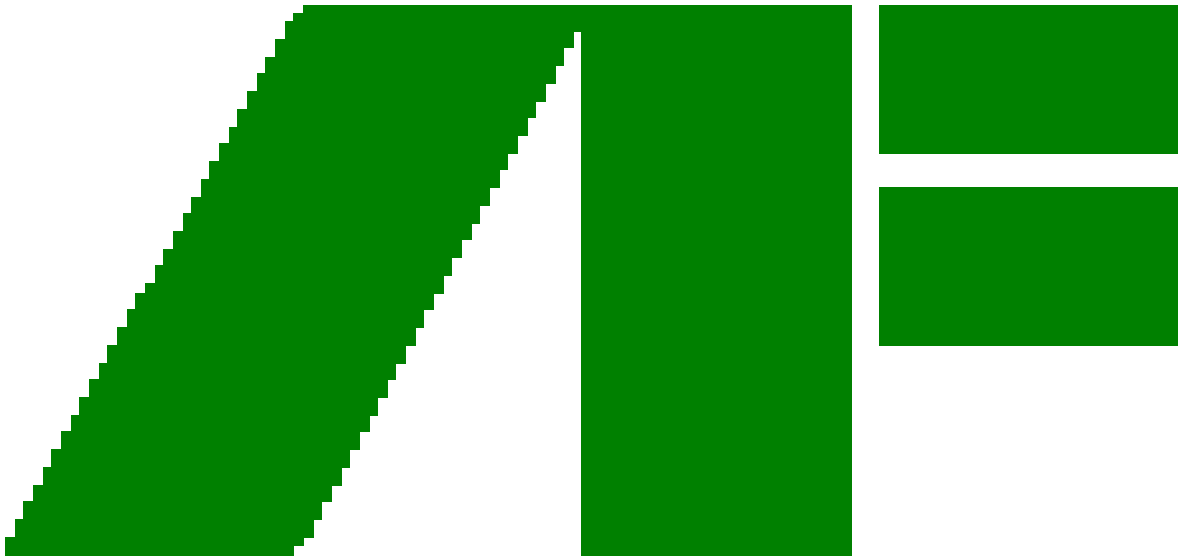
Evidence from Danish firms



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Regional influence on R&D behaviour

Evidence from Danish firms

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Abstract:

In this paper we analyse whether regional location matters for Danish firms' R&D performance. In accordance with Kleinknecht and Poots (1992) survey we test the urban hierarchy hypothesis, which states that firms in urban agglomerations are more likely to perform R&D than firms elsewhere. The micro dataset used in the analysis is obtained by merging Danish R&D statistics with account data. Our logit analysis on the probability of firms undertaking R&D investments partly suggests that regional location matters. Other non-regional factors such as size of firm, ownership (dependence) and industry are as well estimated to have a significant influence on the probability that a firm invests in R&D. However, comparing non-regional with regional factors, the non-regional factors seem to be of more importance.

Keywords: R&D, Innovation, Regions, Urban agglomerations

JEL Codes: O18, O31

1 Introduction

Throughout decades regional shifts in the structure of the industry have been observed. The theoretical concept intended to account for these is based on the life cycle of industrial development; the urban hierarchy hypothesis, which predicts that large urban agglomerations are advantageous environments for innovating firms because of the presence of a highly qualified labour force, information density and the physical proximity of business partners and knowledge centres such as universities or R&D laboratories of large firms.

In the early stage of their life cycles, product innovations are often associated with risks and uncertainties such as unforeseen technological problems, consumer reactions and/or actions by competitors that may change the evolutionary direction. Therefore, it is possible that access to knowledge is important for the emergence of innovations and the probability of their success or failure. As research centres are often located in the Metropolitan area or in larger cities it seems plausible that firms in these areas are more innovative given the advantages of agglomeration. On the other hand, in the later stages of the lifecycle where the technology matures and becomes more standardized, which cause the advantages of urban agglomeration to ease off. In addition, when they see a profitable business, entrants will enter the market and thereby squeeze the profit margins. This may cause the firm to transfer its production to rural areas where factor prices are lower. Thus, if the firm's location is of importance to its R&D activity, firms in urban agglomeration are both more likely to engage in R&D and do it more intensively than a similar firm located in rural areas.

The aim of this study is to present empirical evidence regarding the influence of regional location on the R&D behaviour of Danish firms. More precisely, merging micro data from the Danish R&D statistics with account data a logit model on the probability of firms undertaking R&D investments is set up as a function of firm, industry and regional variables. The paper is disposed as follows. In the next section the regional distribution of the business enterprise sector's R&D expenditures is presented. Beyond the regional mapping of the R&D activities the special regional classification to be used in the estimation later on in the paper is discussed. Subsequently, theoretical key arguments and earlier empirical findings on the determinants of R&D are discussed in section 3. In accordance with the main purpose of this paper, special attention is paid to the regional factors behind the R&D decisions of the firms. In section 4, the empirical model to be used in the analysis is set up and the importance of the included factors is discussed. Section 5 presents the data set

used for the analysis in section 6. Section 7 gives the results of simulations with the estimated model and finally section 8 concludes.

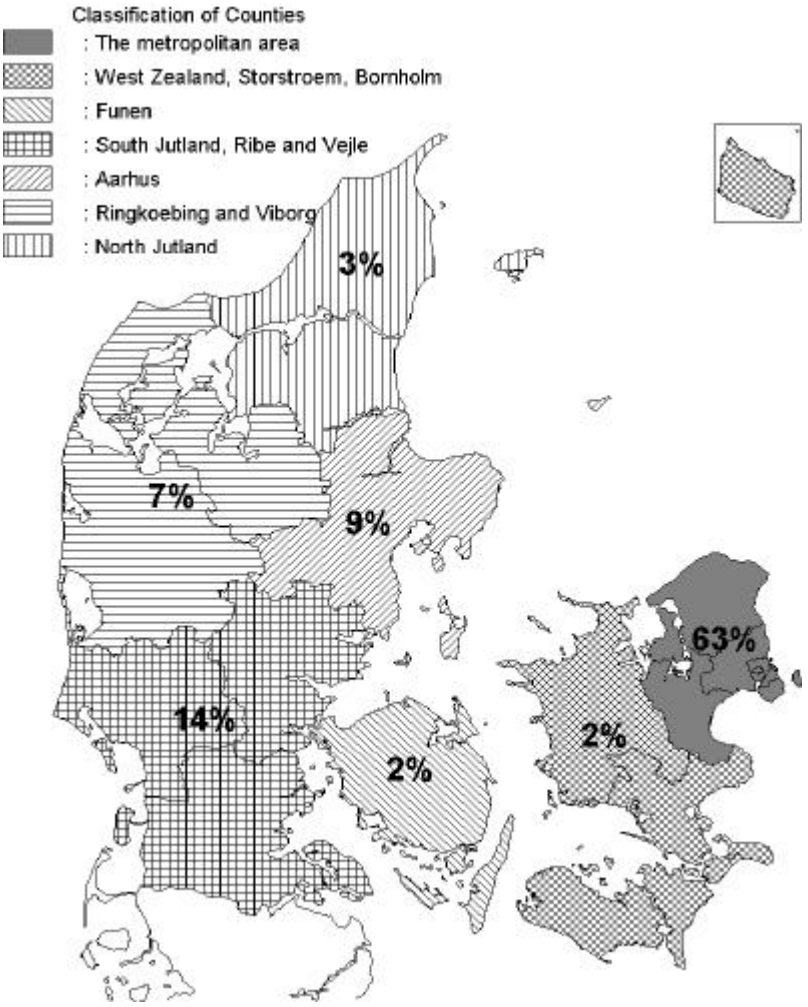
2 The Geography of Research and Development

In this section we draw a picture of the distribution of research and development (R&D) across the Danish counties and by regional characteristics. The data used derives from the official Danish R&D statistics and from public information on the economic performance of Danish firms, see below in section 5.

2.1 Expenditure on R&D in the Business Enterprise sector (BERD)

Denmark is administratively divided into sixteen counties that in this analysis have been grouped into seven for reasons of discretion. The distribution of BERD is shown in Figure 1

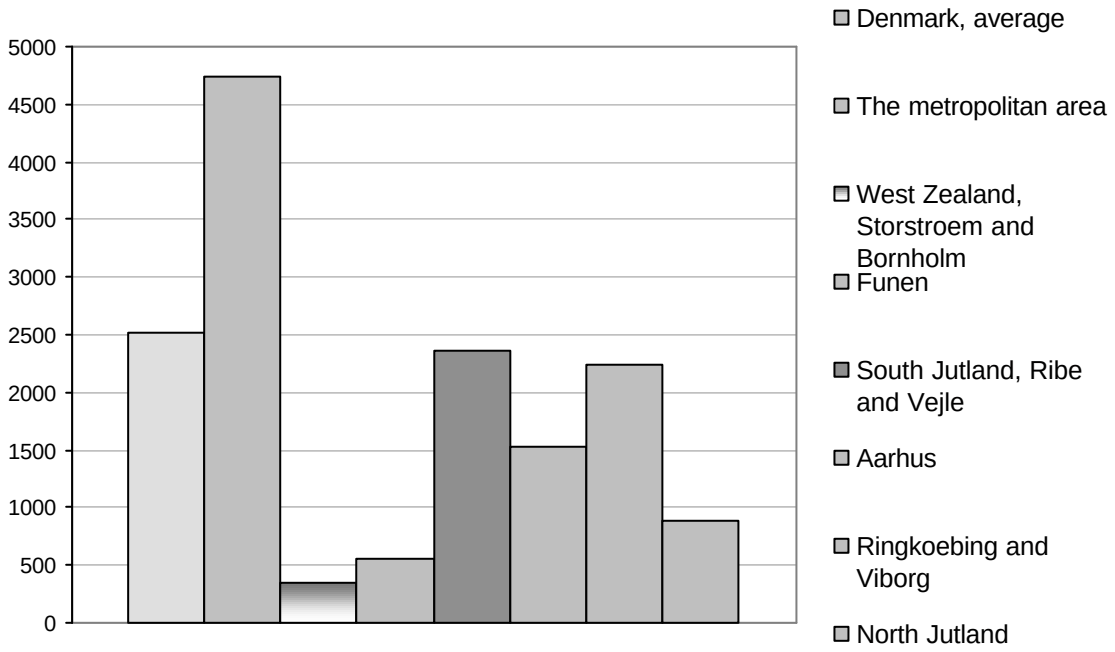
Figure 1: The classification of Danish counties into seven groups, 1997.



It is remarkable that by far the largest share of BERD (63%) is spent in the Metropolitan area while the region of the following counties: South Jutland, Ribe and Vejle as a merged area, accounts for the next largest part which amounts to only 14% of national R&D expenditures. Subsequently, the regions of Aarhus, of the counties of Ringkoebing and Viborg as a merged part, and of North Jutland spend 9%, 7% and 3% of the national R&D expenditures, respectively. The least R&D-spending regions are the regions of the amalgamated counties: West Zealand, Strorstroem and Bornholm, and the region of Funen both spending 2% of the national R&D expenditures on R&D.

The distribution of the R&D expenditures indicates that the R&D efforts are heavily concentrated in the Metropolitan area. However, as the population density also is pronounced in this area, it might be more informative to view each region's R&D-expenditures in the proportion to its population. Figure 2 shows per capita R&D expenditures both for Denmark on the whole and for each region.

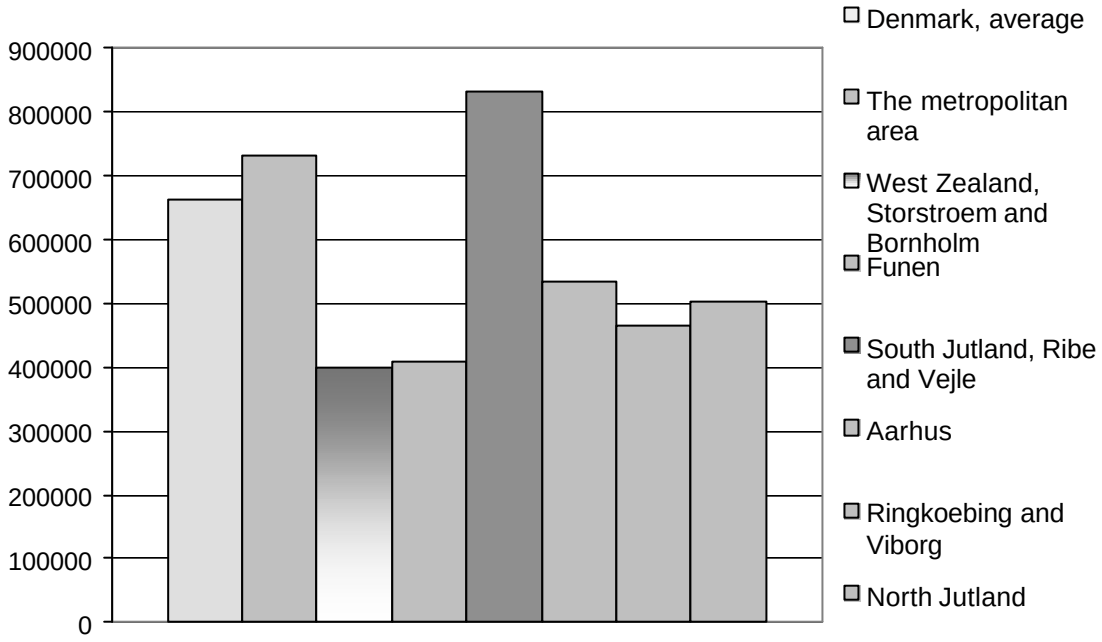
Figure 2: Per capita Business enterprise sector R&D expenditure (DKK), 1997.



Compared to the national level the Metropolitan area spends almost twice as much on R&D per capita and is also the only region with per capita R&D expenditures above the national level. The region of South Jutland and others and the region consisting of Ringkoebing and Viborg county have per capita R&D expenditures close to the national level while the region of Aarhus only spends what corresponds to 61% of the countrywide per capita R&D expenditure level. The region of West Zealand and others, the region of Funen and the region of North Jutland all spend relatively little on R&D per capita as their expenditures only correspond to 14%, 22% and 35% of

the countrywide level, respectively. Thus, the R&D expenditures of the Metropolitan area are both the highest in gross and per capita. Therefore, it might be interesting to see, whether the R&D expenditures per R&D man year show the same distributional pattern. It is understood that an R&D man year is a full-time employee's R&D performance in a year, denoted as full time equivalents FTE.

Figure 3: Business Sector R&D Expenditures per R&D employee, measured in DKK per full time equivalents (FTE), 1997.



The R&D expenditures per FTE's for the Metropolitan area only lie slightly above the average level, whereas the region of South Jutland and others is now the top scorer with R&D expenditures per FTE at about 25% above the average level. The regions of Aarhus, of Ringkoebing and Viborg and of North Jutland all have R&D expenditures per FTE that correspond to 70-80% of the average level. However, the R&D expenditures per FTE of the regions of West Zealand and others and of Funen are the relative lowest as they correspond to around 60% of the national level.

Thus, measured against FTE the R&D expenditures of all regions (incl. the Metropolitan area) besides the region of South Jutland and others and of Ringkoebing and Viborg are closer to the national level than in the case of per capita measurement. Albeit the Metropolitan area has the highest per capita R&D expenditure, the R&D expenditure measured against FTE is still above, however close to, the national level. The rest of the regions except the region of South Jutland and

others all have less than average R&D expenditures whichever measure is used. When measured against FTE the R&D expenditures are closer to the average level for all but the region of Ringkoebing and Viborg. The region of South Jutland and others shows R&D expenditures less than the average level when measured against the population but higher than the average when measured against FTEs. In addition, the region of South Jutland and others accounts for the highest R&D expenditures per FTE of all regions, indicating that the Metropolitan area and the region of South Jutland and others may engage more intensively in R&D than other regions in Denmark.

To measure the regional R&D-intensity only the firms within the region performing R&D are considered. The R&D-intensity can either be defined as 1) the sum of FTEs devoted to R&D for all firms as a percentage of the sum of all employees of firms performing R&D, see Kleinknecht and Poot (1992), or as 2) the sum of the R&D expenditure of all firms as a percentage of the sum of the turnover of firms performing R&D, see Dilling-Hansen et. al. (1998).

Table 1: The business enterprise R&D intensities in the seven groups of counties, 1997, Percent. [1)]

County	R&D expenditures/turnovers	R&D FTE's
The Metropolitan area	6,53%	9,17%
West Zealand, Storstroem and Bornholm	1,01%	3,18%
Funen	1,63%	3,40%
South Jutland, Ribe and Vejle	3,91%	5,41%
Aarhus county	1,04%	3,13%
Ringkoebing and Viborg	4,84%	11,34%
North Jutland	2,35%	5,20%
Denmark, avg.	4,04%	6,94%

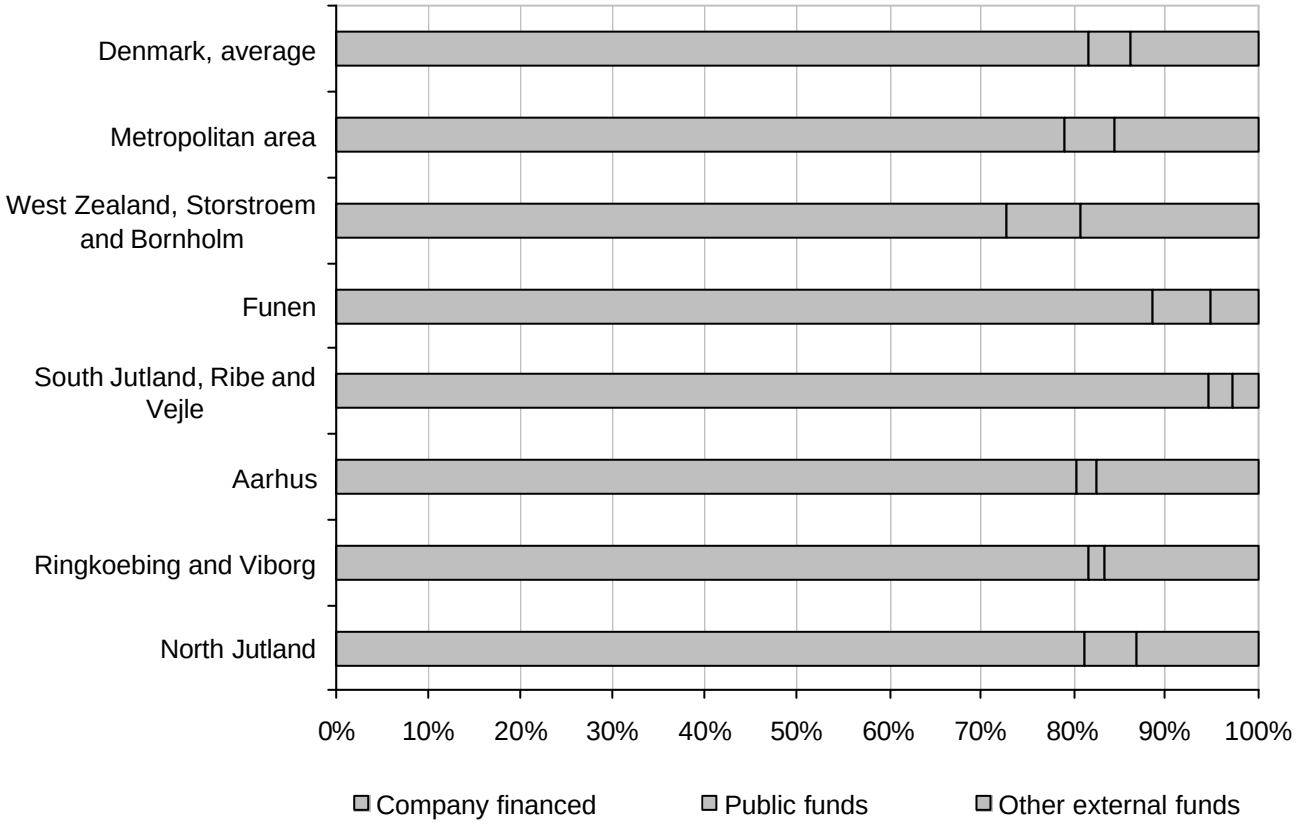
1) Only R&D-active firms are included in the table.

Both ways of calculating the R&D intensities show that the Metropolitan area and the region of Ringkoebing and Viborg are the most R&D intensive regions followed by the region of South Jutland and others and the region of North Jutland on a third and forth place, respectively. The regions of Funen and of Aarhus are the least R&D intensive regions. Depending on which measure is used either the Metropolitan area or the region of Ringkoebing and Viborg has the highest R&D intensity. If the R&D intensity is defined as 1), the Metropolitan area is the most R&D intensive region, whereas if defined as 2) the region of Ringkoebing and Viborg is the most R&D intensive

region. Noteworthy is that the expectation of especially high R&D intensity for the region of South Jutland and others is not quite fulfilled even though this region turns out to be the third most R&D intensive region. The forth and fifth most R&D intensive regions are the regions of North Jutland and of Funen, respectively, and the least R&D intensive regions are the regions of West Zealand and others and of Aarhus. This result does come as a surprise especially when it comes to the region of Aarhus since this region both has tertiary education and relative large businesses in which much R&D would be expected. However, note that the table includes R&D performing firms alone, irrespective of the overall probability that a firm perform R&D.

There seems to be ambiguous differences in the R&D efforts across the regions and in an attempt to explain what cause their occurrence, an examination of how the R&D expenditures are financed is carried out.

Figure 4: Internal and external funding of R&D, 1997. Percent



The firms in the region of West Zealand and others both receive the most support from the public and from external investors (the largest part of support coming from external investors) and as a result these firms finance their own R&D the least. In addition this region is also characterized by

relatively low R&D intensities, which may indicate that regional policies are aimed at the firms intending to encourage them to engage more in R&D. Nearly the opposite relation occurs for the region of South Jutland and others. Here the firms owing to relatively low external funding from both the public and external investors finance their own R&D the most. The firms in the region of Funen are also highly self-financing even though they in comparison with firms in other regions receive the second highest public support. The firms in the rest of the regions finance around 80% of their R&D expenditures themselves. External investors support them all more than the public though the firms in the Metropolitan area and the region of North Jutland receive relatively more support from the public than do the firms in the regions of Aarhus and of Ringkoebing and Viborg.

Altogether, the results of this classification of regions seem to indicate that the R&D leading regions are the Metropolitan area and the region of South Jutland, Ribe and Vejle since they have the highest R&D expenditures both per capita and per FTE and are relatively intense in their R&D efforts. The difference between these two leading regions is the self-financing share of R&D expenditures; the firms in the region of South Jutland and others are almost financing all of their R&D within the firms while the firms in the Metropolitan area receive a nice share of support. A reason for this difference may relate to the fields of R&D. In the Metropolitan area there are relatively more service firms and it is likely that they engage themselves in public available basic research, i.e. having easier access to knowledge spinning of from universities and other research institutes. Contrary to this, the region of South Jutland and others is characterised by relatively more manufacturing firms than service firms. Manufacturing firms are probably more engaged in product and process developments, and may in an attempt to improve competitiveness be secretive about their research and therefore chose to finance their R&D themselves. The R&D-intensities of Ringkoebing and Viborg are comparable in level with the ones of the lead. Yet, the spending on R&D is relatively less when measured against FTEs, which may indicate that in this region employees involved in R&D are more efficient or that their R&D projects span over shorter horizons. Contrarily, the rest of the regions have relative low R&D intensities and in addition spend relatively less on R&D compared to the lead.

2.2 R&D by characteristics of municipality

The presentation above can be criticised for dealing with counties, which are administrative units. Each county includes bundles of heterogeneous municipalities, e.g. a county normally includes one municipality with a large city functioning as a (urban) centre, a number of municipalities having centre close functions; other ‘urban’ municipalities, and a number of more rural-like municipalities.

In order to analyse the influence of the firm's location on its innovation activity in accordance to the urban hierarchy hypothesis mentioned in the introduction all municipalities must be categorized in classifications that account for their characteristics in relation to an urban area. In general, it is expected that firms located in urban areas most likely have a higher probability of investing in R&D than firms located in rural areas; the closer the location of the firm is to an urban area the more likely it is that the firm is engaged in R&D. The criteria used for classifying the municipalities are as follows, inspired from a number of studies coming from AKF (The Research Institute of Danish Counties and Municipalities, Copenhagen)

1. *The urban centre*: Municipalities having more than 40,000 jobs and a commuting intensity (in-commuters relative to out-commuters) above 2.

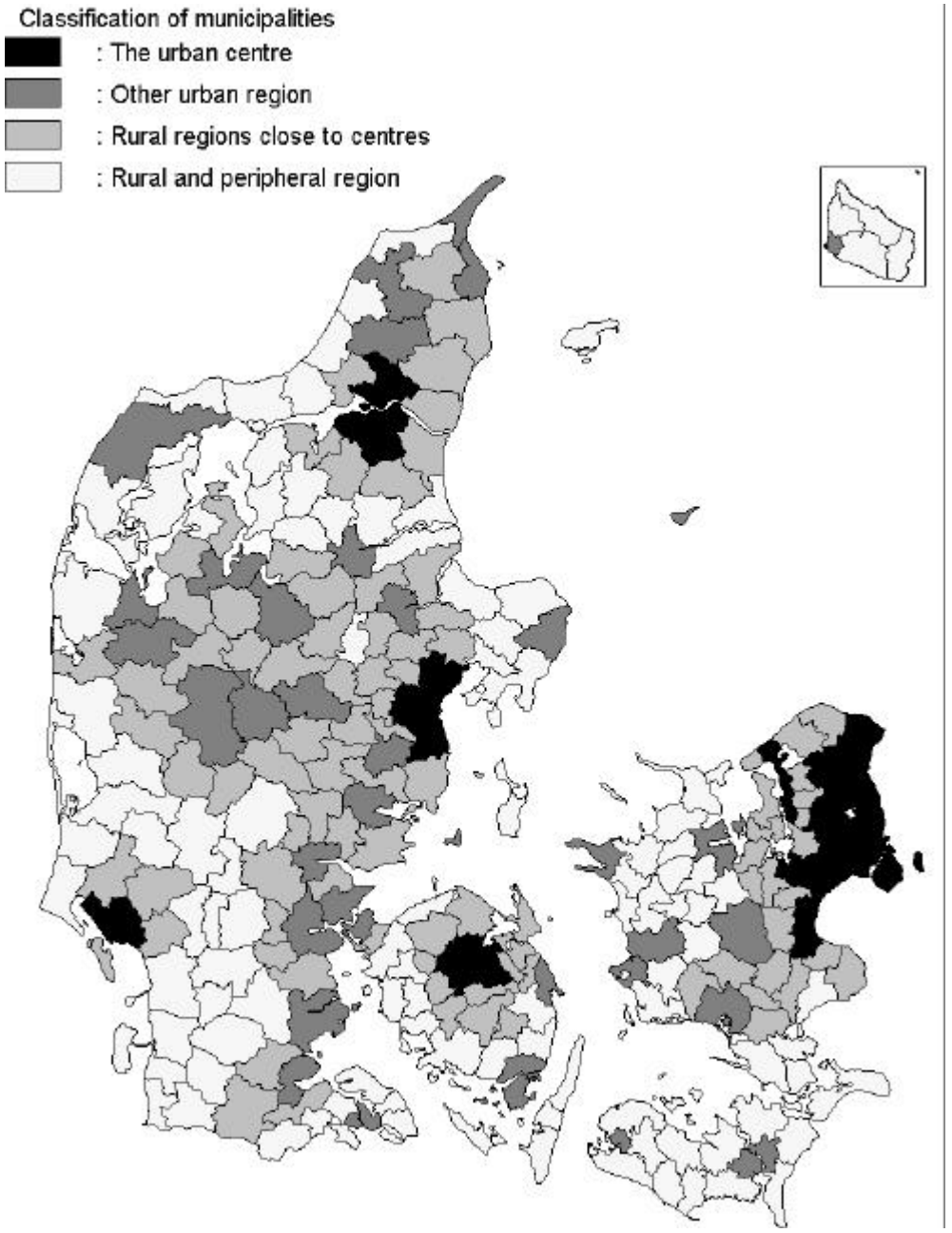
2. *Other urban region*: Municipalities with more than 10,000 jobs and located in the neighbourhood of an urban centre municipality though within 40 km from an urban centre (geographical midpoint).

3. *Rural regions close to centres*: Rural municipalities within a distance of less than 20 km. from an urban centre municipality or within a distance of 15 km. from a municipality in the classification: other urban region.

4. *Rural and peripheral region*: Other rural municipalities not included in 3.

Figure 5 illustrates the subdivision of municipalities into the above listed classification. If this classification is compared to the classification of the Danish counties into 7 it is easily seen that each county except for the Metropolitan area includes very different kinds of municipalities. This might imply that the results in the descriptive section 2.1 above may be reflected by the combination of municipalities in a county.

Figure 5: Danish Municipalities by characteristics



Note: Regions categorized according to information from AKF.

According to this classification the subdivision of the R&D expenditures of the business enterprise sector, BERD, is still very skewed, see table 2 below. Firms in 'the urban centre' region account for nearly 70 percent of the business enterprise sector R&D expenditures while in the 'other urban region' firms' BERD amount to 9.2 percent of the total R&D expenditures. Contrary to a priori expectations, in the 'rural and peripheral region' firms' share of R&D expenditures is above 13 percent of the total thereby making them superior to both the 'other urban region' and 'rural regions

close to centres'. The main explanation for the performance of the firms in the 'rural and peripheral region' is their large share of manufacturing firms with a large amount of R&D.

Table 2: The business enterprise sector R&D and the R&D intensity by region, 1997. Percent.

	BERD	R&D intensity
Urban centre	69.6	4.70
Other urban region	9.2	1.67
Rural regions close to centres	7.9	3.78
Rural and peripheral region	13.4	5.17
Denmark, total/average.	100.0	4.04

In accordance with the urban hierarchy hypothesis, see Malecki (1983) which suggest that the closer the firms' location are to 'the urban centre' region the more R&D-intensive the firms are, firms located in 'the urban centre' region have the highest BERD. These firms often take part in network and have easier access to knowledge from R&D-institutions, both factors encouraging the R&D effort. Surprisingly, firms located in the 'rural and peripheral region' have the highest R&D-intensity as well as the second highest share of BERD but as already mentioned the main reason for this is their high share of manufacturing firms with large amounts of R&D. There seem, however, to be some inconsistencies in relation to the urban hierarchy hypothesis for the R&D intensities since firms located in the 'rural and peripheral region' are most R&D intensive and therefore superior to firms elsewhere. And while firms located in 'urban centres' are superior to firms located in both the 'other urban region' and 'rural regions close to centres', in relation to the urban hierarchy hypothesis the firms in the ladder two regions come in the wrong order.

3 Theoretical arguments and earlier empirical evidence

As mentioned in the introduction the regional differences are often measured in accordance with the urban hierarchy hypothesis, which predicts urban areas to be advantageous environments for innovating firms.

In an analysis of the regional R&D activity in Holland, Kleinknecht and Poot (1992) estimate the probability of firms R&D performing and analyse the R&D-intensity in accordance to the above-mentioned hypothesis. On one hand, in order to find out which factors influence the probability of a

firm performing R&D and whether its location plays a role, they apply the logit model and on the other hand they use multiple regression to explain the regional differences in the R&D intensities.

3.1 The Determinants of the Performance of R&D

To be able to estimate whether the regional environment of a firm has an influence on its performance of R&D it is necessary to determine which factors, both regional and non-regional, that influence the R&D decision of the firm. Obvious candidates for non-regional determinants of the R&D behaviour of a firm appear in theory of Industrial Economics to be: the size of the firm, the market structure and competition (the growth of demand), financial solvency, export intensity, ownership characteristics (whether the firm is an independent firm or a part of a group of companies), the age of the firm, and whether the firm belongs to the manufacturing industry or the service industry.

One of the factors identified by the literature to have a significant influence on the undertaking of R&D is the *size of the firm*. By virtue of their size, larger firms are more capable of utilizing large-scale production, marketing and financing and are for that reason ideal units for R&D undertakers. In a number of previous studies the turnover of the firm has often been used as a measure of the firm's size. Another measure also applied often is the number of employees, since a capital-intensive firm may have high turnovers relative to its number of employees.

The relation between R&D performance and the *market structure* is based on the Schumpeterian hypotheses which predicts on one hand that large firms are relative more innovative than smaller firms and on the other hand that improving competitiveness is conducive to innovation[1].

Large firms are often operating in markets earning monopolistic rents and consequently may disregard potential innovative opportunities for the product or the production process if effective barriers of entry exist. Seeing a profit making business, entrants will try to enter the market and consequently increase the competition. If entry is successful, i.e. the incumbent firm has no long run cost advantages compared to the entrants, the incumbent firm experiences more and more competition which reduce the advantages from large-scale production and to reap the full short run profit it may choose to invest less in R&D. On the other hand, strong competition may encourage the firm to perform cost-reducing R&D.

[1] Schumpeter (1942)

Recent studies on different aspects of strategic competition have not shown a conclusive answer regarding the impact of competitiveness on R&D. The results usually depend on the assumed interaction between the firm and its competitors. Thus, in this perspective the inclusion of *competitiveness* as a determining factor for the performance of R&D could work either way. Consequently, the estimated influence on R&D could turn out insignificant.

Compared to investments in physical capital the payoffs of R&D investments are more risky and quite often have an expected payoff in the far future. External investors may be reluctant to undertake risky investments and the firm may therefore find it difficult to raise capital for its R&D. The self-financing possibilities of the firm are often measured by its *financial solvency* i.e. equity capital as a percentage of assets, which is an indicator of the liquidity constraint faced by the firm, see below.

Another hypothesis put forward by Schmookler (1966) states that the *market demand* has a significant effect on the performance of R&D. Firms are expected to invest in growing markets where an optimistic expectation of future sales possibilities may result in more R&D. Kleinknecht and Poot (1992) use the growth of the turnover to indicate Schmooklers "demand-pull" argument.

Hughes (1986) suggests that the relation between R&D and exports is positive, since the market for an exporting firm is relatively larger. Kleinknecht and Poot (1992) include in their logit model a dummy for the *export-intensity* (the exported share of the sale) that states whether the firm has exported more or less than 50% of its sales while Dixon and Seddigh (1996) compare the distribution of innovative firms with the distribution of non-innovative firms on intervals of export. Even though both these surveys find the relation significant, the export-intensity will not be included in the Danish survey because the data material does not provide adequate information.

Since the returns of R&D investments generally have far future perspectives and are riskier than other sorts of investments, a firms *ownership characteristics* may have an influence on how likely a firm is to invest in R&D and/or how R&D intensive the firm is. Evidently, Kleinknecht and Poot (1992) expect that independent firms are more reluctant to invest in R&D than firms belonging to a group of firms. However, no evidence suggested that firms belonging to a group of firms are more likely to invest in R&D though an earlier analysis had supported the expectation that these firms are more R&D-intensive than independent firms. Dixon and Seddighi (1996) evaluate whether the firms owned by foreigners are more likely to invest in R&D than firms owned by compatriots, but this ownership relation did not turn out to be significant.

The *age of the firm* is in Dixon and Seddighi's (1996) analysis expected to be of significance for the probability of the occurrence of firms undertaking R&D, but the expectation turned out wrong, as an almost equal share of firms older than ten years were and were not engaged in R&D.

Dixon and Seddighi's (1996) sample inquiry showed that most R&D intensive firms are in close contact with *knowledge centres* and likewise Kleinknecht and Poot (1992) show that R&D co-operations between firms have a positive influence on the R&D intensity.

Normally, the analysis of the R&D-intensity is carried out for the *manufacturing sector* and *service sector* separately. The reason for this grouping is the expectation of significant differences in their R&D activity.

Furthermore, Kleinknecht and Poot (1992) split up the group of firms in the manufacturing sector into a traditional sector and a "modern" sector. Belonging to the traditional sector are firms, which are relatively less likely to undertake R&D, have a low R&D-intensity and a bias towards process related (other than product) innovation. The firms belonging to the modern sector are conversely science-based and production intensive firms. A dummy on this grouping confirmed that firms belonging to the modern sector are more likely to engage in R&D than firms in the traditional sector. Correspondingly, Dixon and Seddighi (1996) find, that if a firm belongs to an industry with high technology possibilities (alike Kleinknecht and Poot´s modern sector) its R&D activity will be affected positively.

Kleinknecht and Poot (1992) include within their analysis dummies for public utility enterprises (gas, water and electricity supply), as well as for non-commercial services (including R&D laboratories). In addition they include dummies for firms, who bought advanced equipment for office or production automation, acquired licenses, and produced or bought software as these activities may be either a substitute or complementary for R&D.

3.2 Empirical evidence on the influence of regional location on the R&D decision

On Dutch data Kleinknecht and Poot (1992) find that the probability of a firm engaging in R&D is related positively to its size, export-intensity, technological opportunities, the production and acquisition of software and activities in the fields of biotechnology and new materials. The growth of sales and the purchase of licences only increase the probability of a firm performing R&D if it belongs to the manufacturing sector. On the contrary, firms that buy advanced machinery, have activities related to information technology or undertake substantial manpower training have an

increased probability of undertaking R&D only if they belong to the service sector. Likewise, Dixon and Seddighi's (1996) analysis on the R&D activity of manufacturing firms in northeast English indicate that the probability of a firm performing R&D is related positively to its turnover, export-intensity and technological opportunities.

The main purpose of Kleinknecht and Poots (1992) analysis is to estimate whether the regional location of a firm has an influence on its R&D activity and R&D-intensity. In their analysis The Nederlands is divided into three different types of regions: the urban centres, the rural districts and a periphery region between the two. Even though, alternative divisions of The Nederlands have been analysed they find no evidence that the firm's regional location is of significance for its R&D activity. Thus, Dutch evidence indicates that a firm deciding whether or not to undertake R&D, will make its decision independent of its regional location.

3.3 Empirical evidence on the influence of regional location on the R&D intensity

The above conclusion does not exclude the possibility that the regional location of the firm may influence how intensively a firm is engaged in R&D. Kleinknecht and Poots (1992) estimate the relation between R&D-intensity and regional location using a multiple regression analysis. Assuming the dependent variable, R&D-intensity, is affected by the same factors that at first hand are expected to influence the probability of undertaking R&D, the importance of regional location is estimated. In addition Kleinknecht and Poots (1992) include some dummies for the use of government innovation support facilities, which in an earlier analysis proved to have a positive impact on the R&D activity.

The findings of Kleinknecht and Poots (1992) analysis indicate that the R&D-intensity is dependent positively on the following factors: a firm's export intensity, if the firm is a manufacturing firm in the modern sector, is part of a group of firms, engages in R&D co-operations, receives a credit for technical development work or a subsidy for R&D work or for R&D work in specific technology fields. Only if the firm belongs to the service sector, is the R&D intensity affected positively by sales growth and if it belongs to non-commercial service sector. Contrary to expectation the R&D-intensity of a manufacturing firm is influenced negatively by its' size and received subsidies for manpower training.

As regards the influence of the regional location on the R&D intensity, the location only matters significantly for firms in the service sector. These firms are concentrated in larger cities and have

R&D intensities above average. Thus, the regional location may only matter for firms belonging to the service sector.

Kleinknecht and Poot emphasize that The Nederlands is a small country compared to Great Britain or the US and therefore a region in The Nederlands is much smaller relatively as the physical distances are considerably shorter. Malecki (1980) emphasizes that basic research should be concentrated in large agglomerations while process related research may be more decentralized following the location pattern of production plants. Kleinknecht and Poots analysis does not however distinguish between these two kinds of research but suggests that if Malecki's hypothesis is valid, firms in urban areas are expected to show R&D intensities above average.

3.4 Further investigations

Related aspects of importance of the firms' regional location on their R&D have been examined. Assuming that basic and applied research usually occur in a form of R&D department, whereas development work may more often be done in a less formal or organized way, Kleinknecht and Poot estimate whether firms in the urban areas are more likely to have formal R&D departments. This hypothesis could not be supported. The expectation that the mother company influences the R&D decision of a subsidiary firm located in a rural area also did not turn out to be significant. Whether the regional location is more important for smaller than for bigger firms could not be confirmed. A survey on whether a firm's R&D is related to either 1) product and service innovations; 2) process innovations or 3) R&D difficult to group, is dependent on it's regional location, showed that firms with high R&D intensity perform more product related research. Manufacturing firms with technological opportunities and firms whose R&D decisions depend on the mother company likewise engage more in product related R&D. Contrary to Kleinknecht and Poots earlier results the regional location is significant as firms located in urban areas engage less in process related R&D than firms in the periphery and even less compared to firms in rural areas. The relation does not however repeat itself for service firms as product and process innovation here has another meaning; a new service (or the new 'product') of a service firm often consists of a new procedure.

4 Empirical model

In this section the influence of various factors on the probability that a firm performs R&D are discussed and analysed. Assuming a logistic probability function the results of a logit model is used as the estimation form in the empirical analysis[2]. Thus, the probability that a firm is performing R&D can be written as

(1) $$L(w) = \frac{e^w}{1+e^w}$$

(2) $$w = x'b + e$$

where x is a column vector of explanatory variables, b is a column vector of the explanatory variables' parameters and finally e is the error term. Included in the final model are variables that are expected to affect the probability of a firm's R&D activity. These are listed below and discussed in the following

- Size of firm
- Market structure and competition
- Ownership characteristics (dependence)
- Age of firm
- Financial solvency
- Industry type (manufacturing vs. service industry)
- Location

Size of firm

As discussed in section 3.1, the size of the firm is expected to affect the probability of a firm performing R&D positively. Being more innovative, larger firms will compared to smaller firms have a larger probability of success. On the other hand, it should be mentioned that entrepreneurship may bring some smaller firms (younger firms, see below) to perform R&D. Accordingly a U-shaped functional form between the size of the firm and the probability of performing R&D might be possible.

[2] See Amemiya (1981)

Market structure and competition

According to the above discussion product market concentration and competition are important factors in explaining the R&D behaviour of firms. In line with other studies the inverted U-hypothesis between product market concentration and R&D-effort is expected.

Another way to test the influence of the firm's competitive environment on the probability of R&D engagement is to include the profitability, i.e. profit over stockholder equity. According to Kamian & Schwartz (1982)[3] firms that operate in competitive markets with tough price competition experience low earnings, and may for this reason have an incentive to invest in R&D in order to pursue a product differentiating strategy. In that case, the impact of profitability on the probability that a firm performs R&D will be negative.[4]

Independent firm

In order to be competitive the independent firms must be innovative. Compared to firms belonging to a group of firms, an independent firm is forced to perform R&D on its own in order to produce new knowledge and implement the results in further innovation. In this perspective independent firms are less likely to receive information on new product and process research than firms belonging to a group of firms and to preserve competitiveness the independent firms must be more willing to invest in R&D – even though R&D investments are normally considered risky. This anticipation is contrary to the argument of Kleinknecht and Poots (1992) who because of the far future perspectives and risks of R&D investments expect independent firms to be more reluctant to invest in R&D than firms belonging to a group of firms.

Age of Firm

Younger and newly established firms generally have a larger potential for growth and as a consequence have a stronger incentive for investing in R&D, see e.g. Baldwin (1996). Conversely, firms of a certain age might have better organizational opportunities to gain from risky R&D investments. A U-like influence from firms' increasing age on the R&D probability is expected to account for the assumption that both the very young and old firms have the largest probability of performing R&D.

[3] See also Lunn & Martin (1986) and Dilling-Hansen et al (1998).

Financial solvency

Firms may in connection with the process of undertaking R&D investment face a liquidity constraint, as banks and other financial institutions might consider R&D investments too risky. Financial solvency is included in the analysis to account for these liquidity constraints. Thus, having a high degree of financial solvency the firm is expected to have better credit facilities, see Dilling-Hansen et al (1998) for earlier Danish evidence.

Industry type and location

In line with other studies the firms is divided into two groups, manufacturing firms and services. The expectation is that the former are more innovative than the ladder and consequently are the ones with the largest probability of performing R&D.

In conformity with the urban hierarchy hypothesis it is expected that 1) firms located in the large urban regions, i.e. the urban regions serving as centres, are more prone to invest in R&D than firms in other non-agglomerated urban regions; 2) firms located in the 'other urban region' are more prone to invest in R&D than firms in the 'rural regions close to centres'; and finally 3) firms located in rural regions close to centres are more prone to invest in R&D than firms in rural and peripheral areas, see Kleinknecht and Poot (1992). The regional classification of municipalities is shown in figure 5.

5 Data

The data to be used in the analysis is firm specific and derives from two different sources. First, general information on the economic performance of Danish firms is obtained from a private company (Købmandsstandens Oplysningsbureau), which on the other hand collects and organizes firm specific information from the authorities to whom all companies in Denmark have a legal obligation to report their economic performance.

Second, data on R&D is drawn from the official Danish R&D-statistic, which since 1995 has been collected by The Danish Institute for Studies in Research and Research Policy. The basic reporting unit is the legal firm, which can be identified in the account statistics mentioned above. Table 3

[4] This argument is in opposition to the liquidity constraint hypothesis that uses profitability as an indicator for liquidity. In that case, a positive relationship between R&D investments and the profitability of the firm is normally expected, see below.

shows summary statistics for the final data set covering year 1997 and is obtained by merging the two separate data sets.

Table 3: Summary Firm Statistics for the data set used in table 4.

Variables	Number of Observations	Mean	Standard dev.
Number of employees, 1997	1315	226.5	982.0
Firm Age (2000 minus birth year)	1315	22.8	30.7
Independent firms (1), else 0.	1315	0.60	-
Manufacturing firms (1), else 0.	1315	0.57	-
Profitability (profit/shareholders equity)	1313	0.04	0.16
Financial Solvency, 1997	1312	0.28	0.72
Assets, 1997 (Dkk. 1.000)	1313	1,184.9	17,677.2

The average size of the firm corresponds to 226 employees, indicating that larger firms are overly represented in the dataset. The standard deviation indicates that the sample includes some very large firms. Furthermore, the average age of firms included in the analysis is 22-23 years, 60 percent of the included firms are independent firms and nearly the same share belongs to the manufacturing sector.

6 Results

In this section the logit model is applied in order to give evidence of the influence from the above-mentioned factors on the probability of a firm performing R&D. In particular, the focus is directed towards the importance of the firm's regional location on the R&D probability.

Table 4 presents the result of various logit models on R&D performance of Danish firms. If the firm performs R&D the response variable is set to 1, otherwise it is set to zero.

The first three columns of table 4 report the estimation results of both the final model and more extensive models that include larger numbers of explanatory variables. The probability of a firm performing R&D increases significantly (in statistical sense) with firm's size, if the firm belongs to the manufacturing sector rather than the service sector and/or if it is an independent firm, i.e. not a member of a group of firms. The regional dummy variables, 'Urban Centres' serves as "numéraire", controlling for the 'other urban region' and the 'rural and peripheral region' are both

significant and negatively signed which is in accordance with the a priori suppositions, the urban hierarchy hypothesis; the closer the location of a firm is to large agglomerations ('the urban centre' region) the more likely it is to be engaged in R&D. However, the regional dummy controlling for the 'rural regions close to centres' is positive, though not significant, suggesting that firms in this regional location are most likely to perform R&D. This result is in conflict with the theoretical statement. Thus, contrary to e.g. the Dutch evidence, see Kleinknecht and Poot (1992), when the 'rural regions close to centres' are left out of account, the firm's regional location seems to matter for its R&D performing probability.

In addition, the influence of the firm's age on the probability of performing R&D turns out as expected (a U-like influence), with a maximum probability of performing R&D at the age of 22. However, though the estimated parameter is fairly stable it is not significant in any of the represented models.

Explanatory variables such as rent, financial solvency and the market concentration index are gradually eliminated from model 1 as the respective parameters turn out to be insignificant.

In the experimental phase sales growth and the juridical form of the firm (personnel ownership versus ownership with limited responsibility) were included in the model, yet none of the variables achieved a significant status. Furthermore, experiments with interaction terms between the regional dummy variables and the dummy variables for manufacturing and dependence neither gave meaningful or significant parameters. Accordingly, the estimations point towards an independent influence from the firm's location on its decision to invest in R&D.

Finally, it should be noted that the overall model fit is close to 69%, which means that in simulation experiments the model will correctly predict the probability of firms performing R&D in 69% of the cases.

Comparing the significant parameters across the models in table 3 it is easily seen that they are fairly stable and persistently significant. When all insignificant variables are removed from the model (except for age, which has a stable effect), the overall model fit is still around 68-69 percent. This indicate that the size of the firm, the regional dummies and the dummy-variables for independence and industry are important for the firms' decision of the firm on whether or not to engage in R&D.

In addition, the estimation forms in table 3 were repeated with the R&D-intensity[5] as the dependent variable using the standard Tobit procedure. By and large the estimation results were quite similar to the results in table 3 except for the fact that the location variables turned out to be insignificant. Accordingly, location does not seem to matter to the amount of R&D. This result is similar to the results found by Kleinknecht and Poot (1992).

[5] The R&D-intensity is defined as R&D expenditures as a percentage of turnovers.

Table 4: Logit models of the probability of firms conducting R&D Expenditures in 1997

	Model 1	Model 2	Model 3	Model 4
Intercept	-0.7731 (0.7229)	-0.7583 (0.7190)	-0.7742 (0.7054)	-0.7230 (0.7022)
Size (Log of employees)	0.2747*** (0.0493)	0.2750*** (0.0493)	0.2736*** (0.0488)	0.2710*** (0.0487)
Dummy for independent firm	0.3538*** (0.1318)	0.3531*** (0.1318)	0.3592*** (0.1312)	0.3601*** (0.1310)
Dummy for manufacturing sector	0.8026*** (0.1326)	0.8054*** (0.1318)	0.8336*** (0.1279)	0.8237*** (0.1274)
Age (Log of firms' age)	-0.7264 (0.4891)	-0.7265 (0.4892)	-0.6853 (0.4801)	-0.7126 (0.4775)
Age squared	0.1130 (0.0839)	0.1130 (0.0839)	0.1083 (0.0823)	0.1110 (0.0818)
Profit relative to shareholders equity	-0.2862 (0.4217)	-0.2900 (0.4210)	-0.4088 (0.3711)	
Financial Solvency	-0.0217 (0.0906)	-0.0222 (0.0906)		
Market Concentration (Herfindahl index)	0.4898 (0.8601)	0.3305 (0.2875)		
Market Concentration squared	-0.1911 (0.9717)			
Dummy for Other urban region	-0.2987** (0.1524)	-0.2977* (0.1523)	-0.3137** (0.1517)	-0.3180** (0.1514)
Dummy for Rural and peripheral region	-0.3790** (0.1875)	-0.3775** (0.1874)	-0.3786** (0.1859)	-0.3819** (0.1858)
Dummy for Rural region close to centres	0.1980 (0.1868)	0.2006 (0.1863)	0.1795 (0.1853)	0.1794 (0.1851)
Log likelihood	1652.869	1652.908	1668.135	1672.803
Concordance	68.7%	68.7%	68.6%	68.4%
Number of observations	1296	1296	1305	1307

Notes: Numbers in brackets are standard errors of the estimated parameters. * indicates that the estimated parameter differs significantly from zero at the 10% level of significance, ** at the 5% level and *** at the 1% level.

7 Simulations with the model

Using the model form shown in equation (1) and (2) and the estimated parameters in model 4 from table 3 the probability that a firm performs R&D can easily be calculated. Figures 6 and 7 show the results of a number of model simulations.

Figure 6: The simulated R&D probability of a 22 year old independent manufacturing firm as a function of firm's size and location.

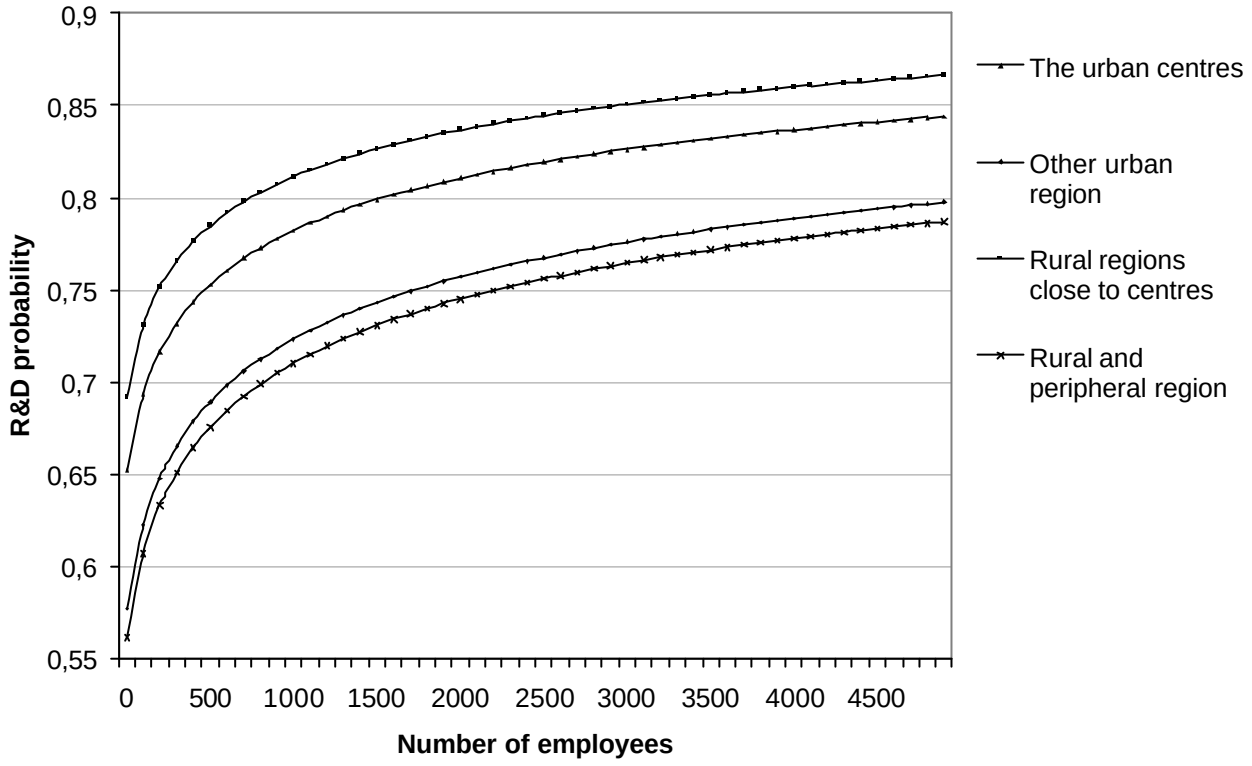


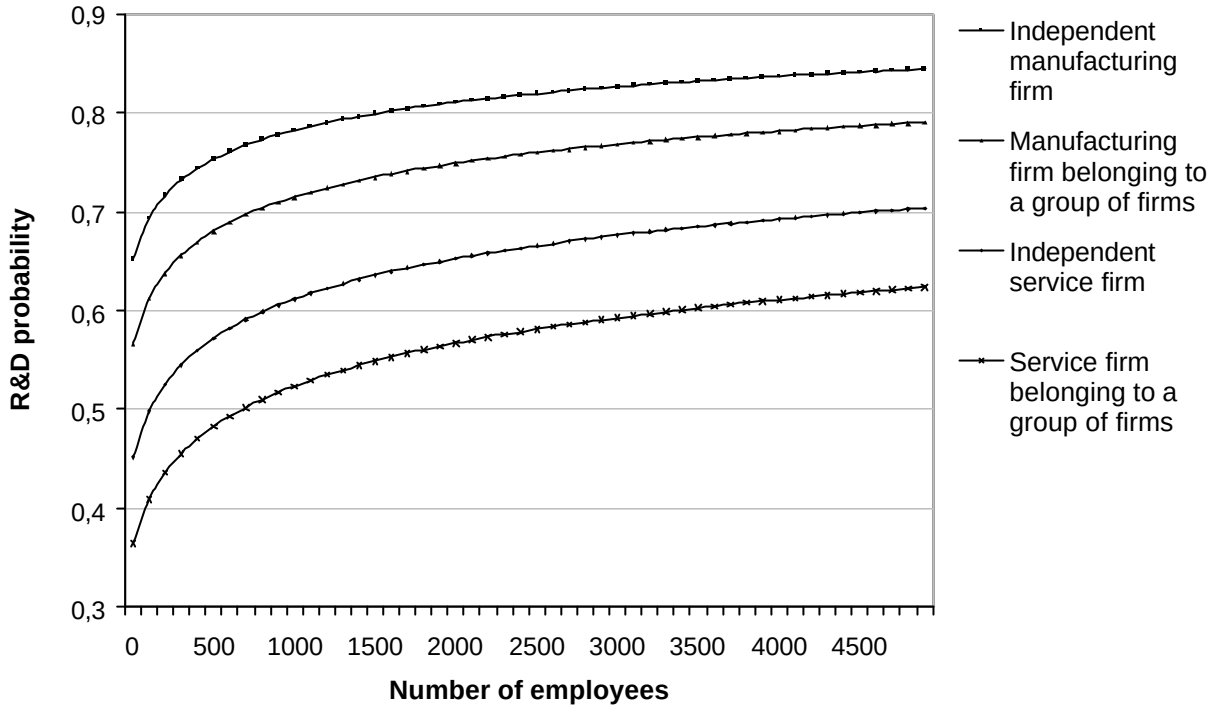
Figure 6 shows the probability that an independent 22 year old manufacturing firm will engage in R&D as a function of location and firm size. The probability of a firm performing R&D increases with the firm's size independent of the region in which the firm is located. In accordance with theory, firms at any size given located in 'the urban centre' region are more likely to perform R&D than firms located in the 'other urban region' and even more likely than firms located in the 'rural and peripheral region'. However contrary to theory, it seems to be the case for any given size of firm, firms located in the 'rural regions close to centres' are the most likely of performing R&D. Thus, this result may indicate that 'rural regions close to centres' are attractive areas for firms dealing with technologies that are at the ladder stage of their life cycles. However, the issue of influence from the regional location on product and process innovation will be dealt with in future work. A focus on the regional cases, which are consistent with theory, i.e. 'the urban centre' region,

‘other urban region’ and ‘rural and peripheral region’, reveals for any predetermined size that firms in ‘the urban centre’ region seem to be approximately six percent points more likely to perform R&D. This suggests that agglomeration advantages do exist.

Almost identical patterns for the regional R&D performing probability repeat themselves for all combinations of industry and independency; the manufacturing firm belonging to a group of firms, the independent service firm and the service firm belonging to a group of firms. Generally, firms located in ‘the urban centre’ region are more likely to be performing R&D than firms located in the ‘other urban region’ and even more than firms located in the ‘rural and peripheral region’. Still, in contrast with the urban hierarchy hypothesis, firms located in the ‘rural regions close to centres’ are the most probable of performing R&D.

Nevertheless, comparing the levels of the R&D performing probability for any predetermined size and location of the firm, independent manufacturing firms turn out to be the most likely to be engaged in R&D followed by manufacturing firms belonging to a group of firms, which in turn are more inclined to be performing R&D than independent service firms. The firms least likely to be performing R&D are service firms belonging to a group of firms. Figure 7 illustrates levels of the R&D performing probability for firms located in urban centres. Note that the figure is illustrative for all regions.

Figure 7: The simulated probability that a 22 year old firm located in 'the urban centre' region invests in R&D as a function of firm's size, industry and independence.



The figure illustrates that for any given size of firm the independent manufacturing firm is the most likely to perform R&D, whereas a service firm belonging to a group of firms has the smallest probability of being engaged in R&D. The difference is approximately 25 percent points.

The probability of a firm performing R&D increases significantly (in a statistical sense) with the firm's size; i.e. the larger the firm is the more probable it is to be engaged in R&D. This result is prevailing for independent firms as well as for firms belonging to a group of firms, no matter which industry, manufacturing or service, the firms belong to. However, for any give size of firm and within any region, an independent manufacturing firm is the most likely to be engaged in R&D followed by a manufacturing firm belonging to a group of firms and an independent service firm, the former being more likely than the ladder, and at last, a service firm belonging to a group of firms turns out to be the least probable of performing R&D. In addition, the regional location of the firm seems to be of less importance compared to industry and independence; the difference between the highest and the lowest R&D probability across industry and ownership is approximately twenty-five percent points while the difference across regional location only is approximately nine percent points.

When the probability of a firm performing R&D, defined in equation (1), is differentiated with respect to size, it indicates the impact of a one percent increase in the firm's size (number of employees) on the R&D probability. This is the marginal probability of the R&D performing firm and it is given by

(3) $$\frac{\partial L(w)}{\partial x_{size}} = \frac{e^{w}}{\left(1+e^{w}\right)^{2}} b_{size}$$

where x_{size} is an explanatory variable in x and b_{size} its parameter in b. Table 5 shows the marginal probability for independent manufacturing firms of different size.

Table 5: The marginal probability of firm's size for a 22-year-old independent manufacturing firm

Size of firm	Urban Centres	Other urban region	Rural regions close to centres	Rural and peripheral region
50	6.5	6.7	6.2	6.8
100	6.1	6.6	5.8	6.7
250	5.6	6.3	5.2	6.4
500	5.2	5.9	4.7	6.0
1000	4.7	5.5	4.2	5.6
2000	4.2	5.0	3.7	5.2
3000	3.9	4.7	3.5	4.9
4000	3.7	4.5	3.3	4.7
5000	3.6	4.4	3.1	4.5

As expected, which the shape of the R&D probability curves in figure 6 and 7 reveals (a positive relation between the R&D probability and size), it is evident that the marginal R&D probability is positive and decrease as the size of the firm grows. For example, a firm with a staff of 100 employees located in 'the urban centre' region can increase its probability of performing R&D by 6.1 percent if it employs 1 more person, while a firm also located in 'the urban centre' region with a staff of 1000 employees can only increase its probability of performing R&D with 4.7 percent by employing 10 more people. Thus, in any region, an increase in the number of employees by one percent has a decreasing effect on the R&D probability even though a bigger firm increases its staff by more.

Comparing the regions for any given size, by increasing their staff by one percent firms located in the 'rural and peripheral region' can affect their probability of performing R&D by more than firms in any other regions. The firms second most capable of affecting their R&D probability are located in the 'other urban region' followed by firms located in 'the urban centre' region, and the firms least capable are located in the 'rural regions close to centres'. Recalling that firms located in the 'rural regions close to centres' are the most likely to perform R&D, it does not seem surprising that they cannot affect the R&D probability much by increasing their number of employees.

If the results of this section are combined with the mixed results of the R&D intensities in relation to the urban hierarchy hypothesis, see table 2, it is evident, that firms located in urban centres achieve a high score on both measures. Even though firms located in the 'rural regions close to centres' are most likely to perform R&D they are not as intensively engaged in their R&D as firms located in 'the urban centre' region. They are, however contrary to the urban hierarchy hypothesis, more intensively engaged in their R&D than firms located in the 'other urban region' which in fact are the least R&D intensive firms with a relative low probability of being engaged in R&D. Most remarkable are firms located in the 'rural and peripheral region'; they have the lowest R&D probability but are at the same time the most R&D intensive firms.

8 Conclusion

The aim of this article has been to analyse the influence of the location of Danish firms on the R&D behaviour. In the descriptive part of the paper it was shown, that the Metropolitan area and the counties of South Jutland, Ribe and Vejle as a merged region are the leading regions in respect to R&D expenditures. The R&D level is high within the former on the account of the agglomeration of service firms and within the ladder on the account of the agglomeration of manufacturing firms.

Abstracting from the Danish counties, which include heterogeneous municipalities, the municipalities have been categorized to account for their characteristics in relation to the urban hierarchy hypothesis; the anticipation that firms' R&D activity depends negatively on the distance between the firms' location and 'the urban centre' region. Contrary to the Dutch evidence, see Kleinknecht and Poot (1992), when not taking into account the 'rural regions close to centres', the Danish evidence is in favour of this hypothesis. This result repeats itself for any combination of industry and ownership (independence or part of a group of firms).

The probability of a firm performing R&D increases significantly with the firm's size, if the firm belongs to the manufacturing sector rather than the service sector and if it is an independent firm, i.e. not a member of a group of firms. Evidently, manufacturing firms are more likely to perform R&D than service firms and to preserve competitiveness independent firms are more willing to invest in R&D than firms belonging to a group of firms. Furthermore, though the age of firm does not influence the R&D performing probability significantly (in statistical sense), it has fairly stable effect. However, explanatory variables such as rent, financial solvency, the market concentration index and sales growth were estimated to affect the R&D probability insignificantly.

In agreement with the urban hypothesis firms located in the 'urban centre' have been estimated to be more inclined to invest in FoU than firms located in the 'other urban region' and even more than firms located in the 'rural and peripheral region'. However, firms located in 'the 'rural regions close to centres'' have been estimated to be superior to firms elsewhere, which is in conflict with the urban hypothesis. The result may indicate that the 'rural regions close to centres' are attractive areas for firm that deals with technologies at the ladder stage of their lifecycle. The issue will be brought up in future research when the data required are fully available.

Irrespective of the ownership (independence vs. part of a group of firms) and regional affiliation manufacturing firms are always more likely to be engaged in R&D than service firms. Moreover, within industries, manufacturing or service, independent firms are always more likely to be engaged in R&D than service firms. To all appearances the regional location of the firm is of less importance to the R&D probability than industry and ownership.

With a one percent increase in their staff, firms located in the 'rural and peripheral region' are capable of affecting their R&D probability by more than any firm elsewhere. Subsequently and in succession are firms located in the 'other urban region' and 'urban centres'. Finely, firms located in the 'rural regions close to centres' are the least capable of affecting their R&D probability, but as these firms also are most likely to be engaged in R&D it is not surprising that they cannot affect their R&D probability to the same extent.

Firms located in 'urban centres' have second highest measure for both R&D probability and intensity. Firms most likely to perform R&D are located in the 'rural regions close to centres' and even though they, contrary to the urban hypothesis, are more intensively involved in their R&D than firms located in the 'other urban region', they are not as intensive as firms located in 'urban centres'. Firms located in the 'other urban region' are in fact the least R&D intensive firms and

they also have a relative low probability of being engaged in R&D. Finally, firms located in the 'rural and peripheral region' have the lowest R&D probability though they at the same time are the most R&D intensive firms.

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