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# The geography of innovation in the Luxembourg metropolitan region: an intra-regional approach<sup>1</sup>

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## **Abstract**

The main objective of the paper is to analyse the local determinants of innovation in the Luxembourg metropolitan region. We are particularly interested in the impact of the local milieu and characteristics of firms. Our paper addresses two specific research questions. Firstly, we examine the extent to which geographic space is a determinant of innovation for five intra-regional units based on an aggregation of municipalities. Secondly, we investigate whether innovation is dependent on accessibility to the mean centre. In both cases, we examine innovation propensity and innovation output using microdata from the Community Innovation Survey (CIS 2006) carried out in Luxembourg. The paper shows that space matters both in terms of spatial units and accessibility within the intra-regional context of Luxembourg. It provides, in particular, first evidence of a close link between the effects on innovation at the intra-regional level of firms' profiles and agglomeration externalities. Both favour innovation for firms from Luxembourg-City and, to a lesser extent, from the Suburban Area.

*Keywords:* intra-regional innovation; firms' profile; location factors; local polynomial regression; Luxembourg metropolitan region.

*JEL classification codes:* O31, O38, C14, R11, R12

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## 1. Introduction

It has been widely recognised in academic literature that geographic space, in addition to characteristics specific to a particular firm or industry, is a key determinant of innovation and technological change (Audretsch and Feldman 2004, Fagerberg 2005). The empirical evidence suggests, for example, that being located in an agglomeration rich in knowledge resources is more conducive to the growth of a firm than being located in a less well-endowed region (Audretsch and Dohse 2007), because of positive externalities and spatial selection.

Location provides different types of externalities, such as knowledge spillovers, labour pooling, and backward-forward linkages, which enhance innovation opportunities (Krugman 1991, Johansson and Lööf 2008). The sum of these externalities is defined by Shefer and Frenkel (1998) as the 'local innovation milieu'. In addition, spatial selection has an important role to play, firstly because firms may consider the effectiveness of potential spillovers when deciding on a location (Audretsch and Feldman 1996), and secondly because local competition may encourage innovation by forcing firms to innovate or fail (Porter 1990). Firms in large urban regions are therefore expected to have higher rates of innovation, to adopt innovations more rapidly (Glaeser 1999, Feldman and Audretsch 1999) and to be more productive than firms located elsewhere.

Such externalities and spatial selection have been extensively studied at the international and inter-regional levels, both between urban regions within a country (Andersson and Lööf 2009, Antonietti and Cainelli 2009, Czarninski and Hottenrott 2009, Lejpras and Stephan 2009, Broekel and Brenner 2010), and between urban regions in a selection of EU countries (Sternberg and Arndt 2001, Simmie 2003, Gössling and Rutten 2007, Copus, Skuras and Tseggenidi 2008, Heidenreich 2009). Spatial selection has also been recently reconsidered through theoretical approaches (Baldwin and Okubo 2006, Melitz and Ottaviano 2008).

However, little attention has been paid to the intra-regional level, especially with regard to metropolitan regions. Notwithstanding the important contributions of Frenkel (2001), Oort (2002), Smith, Broberg and Overgaard (2002), and Teirlinck and Spithoven (2008), who have conducted research on the relation between urban cores and their peripheries, and Kaufmann (2007), Arauzo-Carod and Viladecans-Marsal (2009) who have conducted research on the Vienna and Spain regions using a metropolitan approach, this level of analysis appears to have been rather neglected in Europe. This is surprising considering the important role of metropolitan regions in the European economy, as well as their relative internal spatial heterogeneity (Krätke 2007).

This paper is an attempt to fill this gap by analysing the local determinants of innovation at the intra-regional scale in the Luxembourg metropolitan region. We are particularly interested in the impact of the location of firms within local milieu and the characteristics of firms or sectors on innovation activities and innovation impact at the intra-regional level. Two measures of innovation activities will be examined through two different spatial variables.

Firstly, we examine whether the propensity to innovate and innovation output depend on the regions where firms are located at intra-regional level. Our hypothesis is that firms located in Luxembourg-City tend to be more innovative than firms located in the periurban areas because they benefit from agglomeration economies, face higher competition, need to compensate for agglomeration diseconomies (notably high land rents), and have adequate characteristics to innovate. The composition of Luxembourg-City and other parts of the

regional system are not random. With the exception of Combes et al.'s (2009) study on productivity advantages, previous literature does not clearly separate between location effects and the effects of firms' characteristics. We expect there to be a cumulative effect from both.

Secondly, we investigate whether the propensity to innovate and innovation output of firms also depend on their accessibility to the centre of gravity (or mean centre). Studies of functional regions, i.e. integrated labour market areas organised by intra-regional commuting, usually assume that location characteristics should affect all firms in a given functional unit in the same way. By looking at accessibility at the level of the firm, we would like to challenge this perspective and provide an original view of the Luxembourg regional innovation system. Such approach is rare in the literature, Anderson, Quigley and Wilhelmson (2004), Rosenthal and Strange (2005) and Arzaghi and Henderson (2008) being the exceptions.

This paper is organised as follows. In the next section, we examine the scholarly debate on the geography of innovation, focusing particularly on local external economies and on spatial attractiveness in relation to the location of innovative firms. In section 3, we set out our methodology and discuss the characteristics of Luxembourg. Section 4 provides some stylised facts about the Luxembourg functional regions organised around Luxembourg-City. Section 5 presents the results, focusing on the propensity of firms to innovate and, innovation output in relation to, in a first instance, the different functional regions and, in a second instance, to the accessibility of the centre of gravity. In the last section, we conclude with a summary of the key findings.

## **2. Literature**

The determinants of a firm's innovation behaviour are usually described both as consisting of both internal and external factors (Sternberg and Arndt 2001, Audretsch and Feldman 2004). The growing complexity of knowledge has made it increasingly difficult for firms in a dynamic environment to capitalise internally on all types of knowledge (Lane, Koka and Pathak 2006). Firms are therefore encouraged to specialise (Powell, Koput and Smith-Doerr 1996) and to focus on the acquisition of external knowledge. Different options are available to firms seeking to capitalise on external knowledge: focusing on knowledge spillovers, developing cooperative agreements and acquiring knowledge. Economic geography focuses on these sources of external economies by dividing them into three different types: location factors linked to the general characteristics of the region, which all affect the intra-regional performance of firms; local technology and innovation policies, which may give an incentive to firms to innovate; and the overall firm environment at the extra-regional level, which influences firms' development.

Previous studies have also emphasised the role of firms' environments in stimulating innovation activity (e.g. Audretsch and Feldman 1996, Autant-Bernard 2001) by suggesting interactions between environmental factors and firms' internal factors. Indeed, in line with the notion of absorptive capacities introduced by Cohen and Levinthal (1989, 1990) and further developed by Cockburn and Henderson (1998), spillover effects may be more readily assimilated if a plant has sufficient in-house capabilities. Firms are likely to exploit these opportunities in the selection of their location, in an example of a spatial attractiveness process. In addition, those who do not take advantage from these opportunities may have to move or may fail, being disadvantaged locally in competitive terms. This section focuses firstly on intraregional external economies and secondly on spatial attractiveness and spatial selection.

## *2.1. Local external economies*

Urban regions provide a favourable environment in terms of external factors, especially for highly innovative firms. In the US, for example, Audretsch and Feldman (1996) found innovative activity to cluster to an even greater extent than other activities. They also found that this propensity to cluster geographically tends to increase for industries where new economic knowledge plays a more important role. Patent citations are also highly localised (see Jaffe, Trajtenberg and Henderson 1993, Almedia and Kogut 1997). In addition, Audretsch and Feldman (2004) found that, in the US, the majority of new product innovations were located in cities.

The reasons why innovation tends to be mostly associated with urban regions and to diffuse faster within urban regions are well known (Gordon and McCann 2000): (1) urban regions limit transaction costs and provide better access to markets, resources and/or land rents; (2) urban regions provide a dense institutional context which favours the establishment of business relations and trust among economic actors; and finally (3) urban regions provide firms with Marshall agglomeration economies, such as a qualified pool of labour, knowledge spillovers and backward-forward linkages (Krugman 1991). The size and qualification of the labour market is indeed recognised as a key factor both for firms and for workers located in urban regions, which lowers their risk of labour shortage and unemployment. Agglomeration economies also arise from the possibility of learning from the experiences and innovation of other firms. Well-integrated firms have better access to non-codified information than isolated firms. Finally, agglomeration economies are also linked to the possibility of similar firms sharing suppliers. Interestingly, each of these externalities seems to have a different spatial range: more than 50 km for forward-backward linkages, less than 50 km for labour market pooling and less than 10 km for information spillovers, the externalities most sensitive to distance (Duranton and Overman 2006). Rosenthal and Strange (2005), analysing entrepreneurship in the New York metropolitan area, also found that if agglomeration effects exist they quickly decrease with distance (over five miles, in their case study) highlighting that close proximity matters. These mechanisms suggest, therefore, that the concentration of firms and workers in space favours productivity, because it improves the likelihood and effectiveness of interactions between social actors and hence the propensity to innovate.

The question of why proximity is important for innovative activities has received a great deal of attention over recent decades. Dosi (1988), for example, identifies the following five characteristics of the innovation process: uncertainty, the increasing role of scientific input, complexity, 'tacit knowledge' that can only be obtained by special learning processes, and the cumulative nature of innovation. Building on this, Feldman (1994a and 1994b) developed the theory that location mitigates the inherent uncertainty of innovative activity: proximity enhances the ability of firms to exchange ideas and be cognisant of important incipient knowledge, hence reducing uncertainty for firms that work in new fields. This reduces the costs of scientific discovery and commercialisation. Innovation activities depend on external opportunities including knowledge spillovers and location, and proximity is important for their exploitation. Spillovers are indeed spatially mediated (Audretsch and Feldman 1996). Some studies consider even that knowledge spillovers tend to be geographically bounded within the region where new economic knowledge was created (Agrawal 2002, Anselin, Varga and Acs 1997, Autant-Bernard 2001, Black 2005, Orlando 2000).

## *2.2 Spatial attractiveness and spatial selection of firms*

In addition, Feldman (1994a) suggests that innovative firms tend to be located in areas where resources resulting from previous innovation success are available, in what can be viewed as a path-dependent process. In this way, spatial attractiveness affects the location of innovative firms.

Firstly, firms may consider the effectiveness of potential spillovers when choosing a location, especially in industries where the generation of new economic knowledge is of relatively high importance. This line of argument has also drawn attention to the presence of universities as a locational factor (see Anselin, Varga and Acs 1997, Fischer and Varga 2003, Varga 2000, or Huffman and Quigley 2002). Audretsch, Lehmann and Warning (2003) link locational choice, as a strategic firm decision, to knowledge externalities in general and spillovers from universities in particular. They conclude that geographic proximity may be important to accessing the human capital embodied in university graduates, who may serve as a spillover mechanism. Duranton and Puga (2001) highlight in addition that spatial attractiveness may depend on firms' product lifecycles. Their study shows that diversified cities may serve as nurseries for firms, by providing a fertile experimentation environment favouring new products development, before these firms move to a more specialised cities with lower costs.

Secondly, spatial selection between firms also contributes to the location process of innovative activities. Porter (1990) argues, based on case evidence, that local competition encourages innovation by forcing firms to innovate or fail. Melitz and Ottaviano (2008) show also that larger markets attract more firms, which makes competition tougher, causing less productive firms to exit.

The fact that a number of theoretically-sound location factors help explain why firms are located in particular area on the basis of their involvement in innovation activities does not, nevertheless, mean that firms will automatically move to their ideal location. As Lejpras and Stephan (2010) show, firms are faced with the importance of sunk costs, which tend to reduce mobility. Finally, founder preferences or other factors, such as grants offered by the (local) government (see Devereux, Griffith and Simpson 2007), have a role to play. However, as highlighted by Audretsch and Dohse (2007) in their examination of firms' growth across regions, the non-randomness of firms has to be controlled in order to examine the specific effect of agglomeration economies. This leads us to specifically distinguish between firms' profiles, favouring innovation activities and agglomeration economies in our examination of intra-regional innovativeness. In the selection of these firms' characteristics we refer to the innovation literature, which highlights different factors such as firm size, economic sector, competition, internal skills and group membership enhancing innovation activity.

The incidence of these factors can be summarised as follows. Large firms typically have more resources for product innovation and are also led to innovate in terms of processes in order to decrease costs or to improve products. These incentives reflect large firms' commitment to multiple projects (Veugelers and Cassiman 1999). Innovation is also found to vary substantially across sectors (see Patel and Pavitt 1995). Technological opportunities (Nelson and Wolff 1997), appropriation conditions and demand (Arvanitis and Hollenstein 1994) which vary across sectors all favour innovation activities. In addition, internal skills favour in-house capabilities and absorptive capacities, i.e. the ability to acquire external knowledge, to assimilate it and to exploit it (Cohen and Levinthal 1989 and 1990). The increasing complexity of the knowledge needed to innovate implies that innovation depends increasingly

on external knowledge (Fagerberg 2005). Firms operating mainly in foreign markets face higher costs than those operating only within their national market, due to the additional cost of developing their distribution or supply networks. Therefore, they need to have specific advantages in order to deal with this situation. Innovations are likely to provide these needed advantages. Finally, group membership is expected to provide absorptive capacity and therefore opportunities to innovate. The main reason for the existence of multinationals is their ability to transfer and exploit knowledge more efficiently than the market (Hymer 1976).

### **3. Data and case study**

#### ***3.1 The community innovation survey (CIS)***

The microdata used are taken from the Community Innovation Survey (CIS2006) carried out in Luxembourg by CEPS/INSTEAD on behalf and under the methodological responsibility of Staterc. This survey provides information about types of innovation implemented, innovation success and firms' profiles. In this study we consider as "innovation firms" those who were involved in product or process innovation in 2004-2006, as defined by the guidelines of the OSLO-Manual (OECD and Eurostat 2005). We will also use, as in standard literature, the percentage of turnover from product innovation as a measure of innovation success. Different studies have already used this survey to examine firms' innovation success in the context of Luxembourg, without however considering the potential impact of firms' locations (e.g. Dautel 2008 and 2010).

The target population of this survey is firms with at least ten employees, belonging to the following sectors: the 'manufacturing sector', 'electricity, gas and water supply', 'wholesale trade', 'transport, storage and communication', 'financial intermediation', 'computer and related activities', 'research and development', 'architectural and engineering activities', and 'technical testing and analysis'. The final sample obtained for this survey, resulting from a high response rate (around 90%), covered around 40% of this target population.

As noted previously, firms' characteristics favouring innovation activities are expected not to be randomly distributed over space. This survey allows us to consider the following characteristics over space: firm size, economic sector, group membership, nature of the market (mainly international or not), reflecting the competition faced by the firm, and, finally, percentage of employees with higher education, reflecting internal skills.

#### ***3.2 Spatial variables***

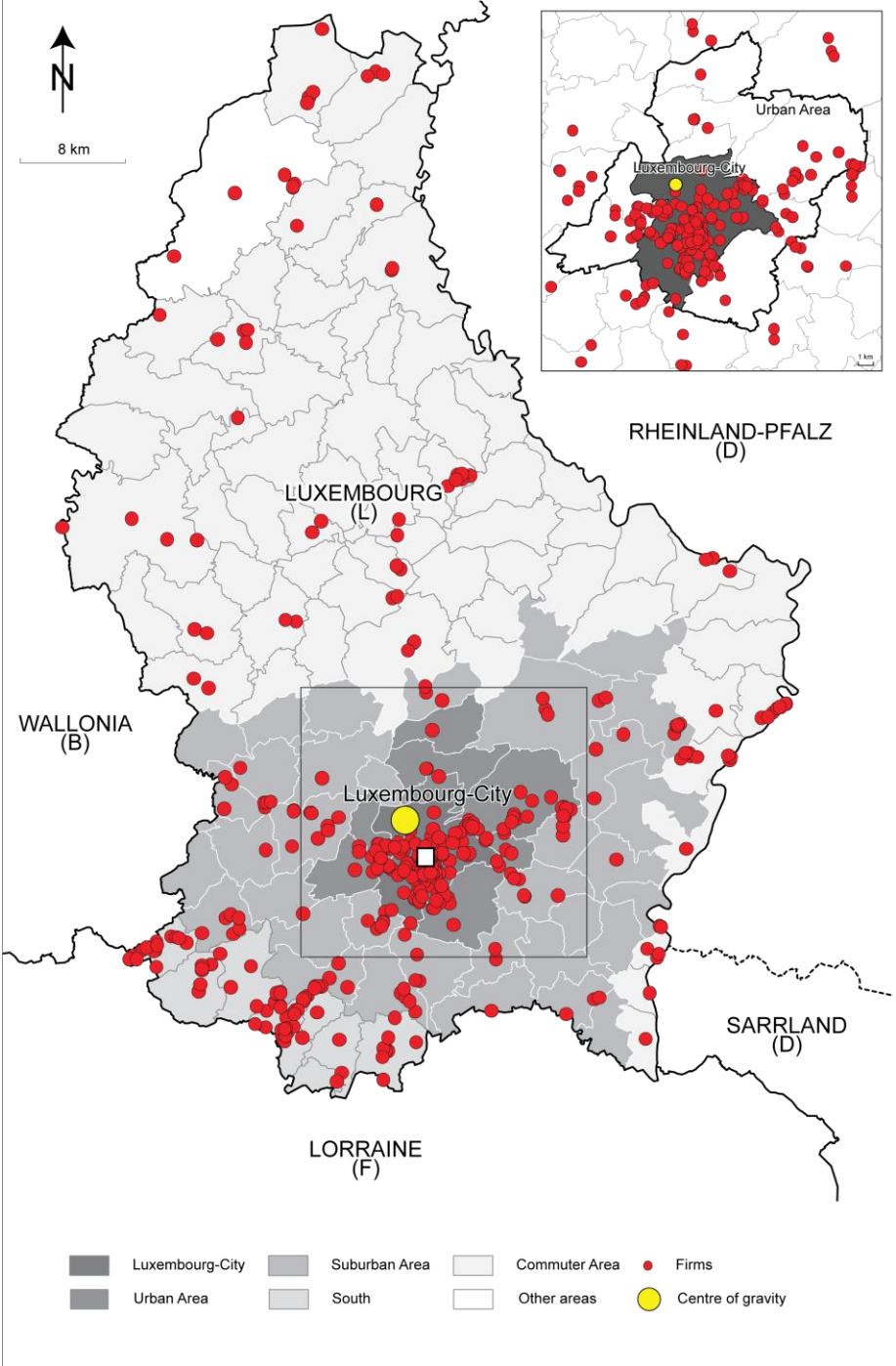
In order to investigate the geography of innovation in Luxembourg, we follow Cheshire and Gordon (1998) and Johansson, Klaesson and Olsson (2002) by defining a functional urban region as a set of municipalities between which there is intense labour market commuting. Despite a lack of comparative studies, we believe that these regions provide a coherent framework for analysing the development of innovative processes among firms because proximity externalities occur mainly within functional regions (Karlsson and Manduchi 2001).

The geography of innovation is investigated in terms of two different spatial factors. First, we divide space into functional regions, which are organised around Luxembourg-City, as previously defined by Sohn and Walther (2008) according to morphological and functional criteria and recently used by Walther and Dautel (2010) to analyse intra-regional employment



growth. In this study, we use geographical divisions based on a monocentric vision of the nation state. Five intra-regional units based on an aggregation of municipalities (NUTS 5 level) allow us to study centre-periphery dynamics: (1) Luxembourg-City (2) The Luxembourg Urban Area, not including Luxembourg-City. (3) A Suburban Area in which the proportion of commuters working in the Agglomeration was higher than 40% of the active population in 2002. (4) A South Area in which the proportion of commuters working in the Agglomeration was lower than 40% of the active population in 2002, located in the country's former southern industrial basin. (5) A Commuter Area in which the proportion of commuters working in the Agglomeration was between 8.3 and 39.9% of the active population in 2002.

Map 1. Surveyed firms in the Luxembourg metropolitan area



Source: Authors.

This division of space allows us to take into account the different economic dynamics existing between the centre and periphery. The regions thus created remain, however, very rough. It is possible to refine the analysis by calculating the accessibility of each firm. Accessibility is defined as the distance of each firm to the centre of gravity of the spatial distribution of all firms.

Accessibility was calculated according to a two-step procedure. Using ArcView, a Geographical Information System software, we first identified the centre of gravity (also known as mean centre or geographic centre) of our set of firms. The centre of gravity is the average x and y coordinates of all firms in the Luxembourg metropolitan area. It is located north of the municipality of Luxembourg-City, in the district of Rollingergrund. This is an illustration of the global centrality of Luxembourg-City at the national level. The fact that this centre of gravity is located here, and not in one of the main business districts of the city, for example, is explained by the strong dispersion of firms in the municipal territory. Since economic activity in the country is so concentrated in the City and Urban Area of Luxembourg, the centre of gravity calculated in this study can be considered as an approximation of the theoretical most central location to economic activity, i.e. the point in space that firms can reach by covering the shortest distance.

Then we calculated the accessibility between the centre of gravity and every surveyed firm, expressed in an average number of minutes of travel. This value corresponds to the time needed to cover the distance between the two points by car, using the existing road network without disruption of traffic and observing the speed limits. It is an approximation of the dispersion of firms in space and allows us to make the assumption that there are specific benefits to being located at a close distance from that point. As the article will show, this does not necessarily mean that the density of firms is highest at this location.

### ***3.3 The Luxembourg metropolitan region***

Contrary to what might be expected, given the small size of the Luxembourg national territory (2586 km<sup>2</sup>), the spatial distribution of economic activities is highly heterogeneous. The following sections discuss the extent to which this spatial heterogeneity could affect innovation positively or negatively by focusing predominantly on the main functional regions of the country.

On the one hand, as shown by Walther and Dautel (2010), Luxembourg-City still is by a wide margin the main employment centre of the country, and most of the knowledge-intensive activities are primarily concentrated within the city despite lower employment growth there than in its surrounding regions. In 2008, more than 73% and 80% of employment linked to the knowledge economy was located in Luxembourg City and the Urban Area respectively (Walther 2011).

Luxembourg-City is also the only geographical unit undergoing specialisation of its economic activities, and the only one which is specialised in highly job-creating sectors such as financial knowledge-intensive services, and high-tech, market-intensive and other business services which tended to support the finance industry (Dautel and Walther 2009). The increasing concentration of such economic activities in the central and Kirchberg areas in Luxembourg-City has over time contributed to the development of a highly interconnected cluster where non-codified information is exchanged between firms, the national regulator and the political authorities (Pieretti, Bourgain and Courtin 2007, Walther and Schulz 2009,

Schulz and Walther 2010). Such concentration is very likely to favour agglomeration economies in Luxembourg-City.

On the other hand, the spectacular development of these activities, compared to the size of the city population – Luxembourg has 1.5 more jobs than residents – has generated strong competition between firms for access to the central city, resulting in a process of employment suburbanisation. As a consequence, the Luxembourg Urban Area has experienced strong employment growth since the 1990s and has developed as a prime location for manufacturing industries or less knowledge-intensive firms which could not compete with rising land and rent prices. Further from the capital, the South and Commuter Areas have experienced lower employment growth and have been increasingly integrated into the metropolitan economy over time, providing low-skilled services in the case of the former and a diversified mix of services and manufacturing activities in the case of the latter. Very recently, the number of high-technology and knowledge-intensive jobs grew significantly in the South Region which is explained by the establishment of back office financial services and, to a lesser extent, by the relocation of a public research centre previously located in the capital. This process could potentially offer new opportunities for firms willing to develop new products outside the capital city, but no clear evidence of such a pattern can yet be observed.

Such a structure, in which a central urban area reinforces its attractiveness, is consistent not only with previous studies conducted in large European metropolitan centres (such as London or Paris) but also with smaller specialised financial centres such as Zurich (Thierstein et al. 2008). It suggests that, even though the size of a urban region is usually regarded as a prominent factor in explaining the propensity of firms to innovate (Andersson and Karlsson 2004), smaller urban regions are also likely to develop competitive regional innovation systems, especially when these regions are highly specialised in high-tech or knowledge-intensive activities (Camagni and Capello 2004).

#### 4. Stylised facts on the Luxembourg functional regions

The propensity to innovate can be seen to vary greatly between the Luxembourg functional regions. As shown in Table 1, firms from Luxembourg-City, the Luxembourg Urban Area and the Suburban Area innovate more often than in the South and Commuter Areas. Those from Luxembourg-City (60%) tend to innovate twice as much as those in the South (31%) and Commuter Areas (25%). Large differences can also be seen between spatial units when considering innovation output, with the commuter area being the less favoured. These results highlight the impact of knowledge externalities, agglomeration economies and spatial selection on innovation commitment and innovation output.

*Table 1: Propensity to innovate and innovation output across functional regions*

	Luxembourg-City (%)	Luxembourg Urban Area (%)	Suburban Area (%)	South Area (%)	Commuter Area (%)
Propensity to innovate	60	47	52	31	25
Turnover from innovative products	4.9	3.9	5.6	3.9	2.0
No. of observations	182	74	134	86	86

Source: CIS 2006. Authors' calculations.

In order to examine the specific impact of learning, the next section examines firms' characteristics across functional regions. Firms' profiles, which differ across regions, are likely to explain most of these discrepancies.

#### **4.1 Firms' profiles across functional regions**

Firms from Luxembourg-City have a very specific profile: they are highly specialised in financial activities (38.1% of them) and IT services (13.4%), operate predominantly in international markets (65.8%), and belong mainly to European groups (42.1%). The level of education of employees is also higher than in other functional regions. Finally, large firms are more numerous in Luxembourg-City than in the other functional units (Table 2).

*Table 2: Firms' profiles across functional regions*

	Luxembourg-City (%)	Luxembourg Urban (%)	Suburban Area (%)	South Area (%)	Commuter Area (%)
<b><i>Economic activity</i></b>					
High and medium high-tech	1.9	5.6	6.4	5.1	4.1
Medium low-tech	3.5	4.8	9.9	20.7	8.9
Low-tech	3.2	14.3	4.8	16.9	15.8
Gas and electricity	0.8	0.4	0.7	1.5	1.4
Wholesale and commission trade	15.3	15.7	20.0	21.5	29.8
Transport and communication	14.4	16.5	25.5	24.5	30.7
Financial intermediation	38.1	27.6	14.7	0.0	3.0
Computer activities	13.4	11.3	11.3	8.0	0.0
R&D – Engineering and consultancy – Technical testing and analysis	9.5	3.8	6.8	1.9	6.4
<b><i>Group membership</i></b>					
No	39.3	43.3	54.4	63.6	65.7
National group	13.4	6.9	17.9	15.8	17.0
European group	42.1	35.8	19.9	18.3	15.2
Non-European group	5.2	14.0	7.8	2.4	2.1
<b><i>Size</i></b>					
Small (10-49 employees)	69.4	72.4	73.3	74.1	80.7
Medium (50-249 employees)	23.1	21.9	20.9	22.0	18.1
Large (>249 employees)	7.5	5.8	5.8	3.9	1.2
<b><i>Market mainly foreign</i></b>					
No	34.2	30.9	35.9	58.4	39.3
Yes	65.8	69.1	64.1	41.6	60.7
<b><i>% of employees with higher education</i></b>					
	43.0	36.1	35.1	23.2	23.2
<b><i>No. of observations</i></b>					
	182	74	134	86	86

Source: CIS 2006. Authors' calculations.

Firms from the Urban and Suburban Areas are less specialised in financial activities (27.6% and 14.7%) than those in Luxembourg-City. They are more oriented than the latter towards

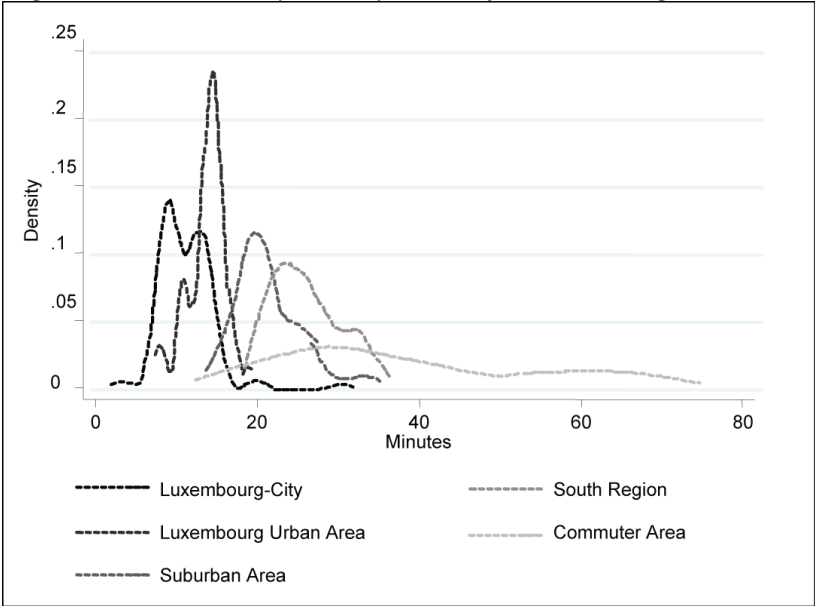
high and medium high-tech<sup>2</sup> (5.6% and 6.4%). Some of them are large (5.6%), but this is fewer than in Luxembourg-City. Most of them operate mainly in international markets (69.1% and 64.1%). Firms from the Suburban Area also often belong to European groups (35.8%). By contrast, firms from the South and Commuter Areas are unlikely to be large (3.9% and 1.2%) or belong to a group (36.4% and 34.3%). These firms often operate in transport (24.5% and 30.7%), wholesale trade (21.5% and 29.8%) or low-tech manufacturing.

Firms’ profiles appear therefore to differ substantially across functional units. These profiles favour the propensity to innovate in Luxembourg-City and, to a lesser extent, in the Urban and Suburban Areas. At the opposite end of the scale, the propensity to innovate is lower in the South and Commuter Areas. These results confirm previous studies which show that Luxembourg national territory is very heterogeneous despite its small size, with Luxembourg-City and Urban Area being the main location for knowledge-intensive and high-tech industries (Sohn and Walther 2008, Walther and Dautel 2010).

**4.2 Accessibility according to functional region**

As we analyse functional units and accessibility, it is highly important to examine to what extent these two variables are related. In order to examine this issue we consider, using a kernel density function, firms’ accessibility density by functional region. As expected, the accessibility density across functional regions (Figure 1) shows that Luxembourg-City has on the whole the best accessibility to the centre of gravity, followed by the Urban, Suburban and South Areas.

*Figure 1: Accessibility density across functional regions*



Source: CIS2006; Authors’ calculation.

The results also show that some of these densities are bimodal, especially for Luxembourg-City and the Commuter Area. Considering these, it appears that the second mode for Luxembourg-City (13 minutes) does not differ much from the mode for the Urban Area (14 minutes). It appears also that the first mode for the Commuter Area (29 minutes) does not

<sup>2</sup> The distinction between high and medium high-tech, medium low-tech, and low-tech is based on an OECD-Eurostat knowledge-based classification (see OECD 2006 and Eurostat 2006).

differ much from the mode for the South Area (23 minutes). The accessibility exam will therefore to some extent mix firms from different functional units. It must also be noted that most of the firms have adequate accessibility to the centre: 94% of them needed less than 40 minutes to access the centre.

## 5. Empirical results

### 5.1. Econometric approach

In line with the aim of the article, we use the following model:

$$Y = f(X, \text{loc}, u)$$

where Y represents the propensity to innovate or innovation output, X the independent or control variables, 'loc' the functional regions or the accessibility measure and 'u' the unobserved effects or measurements errors. The functional regions are dummy variables and accessibility, calculated by the number of minutes to access the centre of gravity of all firms located in Luxembourg, is a discrete variable. The independent variables are firm sector, firm size, belonging to a group, main geographical market and percentage of employees with higher education. The two control variables refer to the establishment of the firm during the reference period and an increase in turnover of at least 10% due to a merger.

This model is estimated by two types of functions according to the dependent variable, i.e. probit for propensity to innovate and tobit for innovation output (including a logistic transformation of the dependent variable). Indeed, as some firms did not introduce new or improved products to the market, their innovation output are left-censored. We take this restriction into account by estimating tobit models<sup>3</sup> (see Greene 1997 or Gourieroux 2000).

Based on this model, we compute predicted probabilities (propensity to innovate) or linear predictions (innovation output) in order to estimate profile effects and agglomeration effects. These are computed according to 'average' enterprise characteristics, which are firms with the average characteristics of the overall economy (i); or firms with the average characteristics of a given functional region or a given accessibility (j). The effect of a given spatial unit or given accessibility is also considered (loc).

More precisely, our predicted probabilities or linear predictions are computed as follows:

- $Y_1^*$  corresponds to the expected propensity to innovate or the expected innovation output for a firm with the overall average characteristics.
- $Y_{1 \text{ loc}}^*$  is the expected result for a firm with the average characteristics of a given spatial unit or accessibility.
- $Y_{2 \text{ loc}}^*$  is the expected result for a firm with the average characteristics of a given spatial unit or accessibility and including the spatial unit or accessibility effect.

Based on these results, profile and agglomeration effects are estimated as follows:

$$(1) \text{Profile\_effect} = Y_{1 \text{ loc}}^* / Y_1^* \text{ with } Y_1^* = a.X_i ; Y_{1 \text{ loc}}^* = a.X_{\text{loc},j}$$

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<sup>3</sup> It has to be noticed that the presence of heteroscedasticity has to be rejected for the overall tobit model. LR  $\text{Chi}^2(9) = 3.58$ ;  $\text{Prob} > \text{Chi}^2 = 0.937$ .

$$(2) \text{ Agglo\_effect} = Y_{2 \text{ loc}}^* / Y_{1 \text{ loc}}^* \text{ with } Y_{2 \text{ loc}}^* = a_2 \cdot X_{\text{loc}, j} + b \cdot \text{loc}_j$$

The accessibility estimations require, however, additional specifications due to the small number of enterprises at some levels of accessibility. Firstly, we retain a ‘sliding bandwidth’ of five minutes for estimating  $Y^*$ . Secondly, we smooth (1) and (2) by regressing these measures on accessibility using a local polynomial regression (see Fan and Gijbels 1996). The local polynomial regression offers, in addition, a way to reduce the inconsistency resulting from the eventual presence of heteroscedasticity in the tobit model estimations. The influence of outliers is indeed downweighted in the estimation of a local polynomial regression. The estimates derived from these additional specifications are represented in Figures 3 and 5.

### 5.2 Propensity to innovate by functional region and accessibility

Controlling for size, sectors, corporate structure, market, human capital and additional factors, the propensity to innovate differs across functional units, as shown by Table 3. Firms located in the South and Commuter Areas, and to a lesser extent in the Urban Area, appear less likely to innovate than those in Luxembourg-City. Distance to the centre of gravity, which acts as a proxy for accessibility, also appears to decrease the propensity to innovate. These two results suggest, therefore, the presence of agglomeration effects. However, firms from the Suburban Area do not appear to differ significantly from those in Luxembourg-City.

Table 3: Probit estimates

Propensity to innovate	Functional regions			Accessibility		
	Coef.	P>z		Coef.	P>z	
Minutes	-	-		-0.014	0.01	***
Urban Area	-0.318	0.09	*	-	-	
Suburban Area	-0.094	0.561		-	-	
South Area	-0.611	0.002	***	-	-	
Commuter Area	-0.348	0.074	*	-	-	
High and medium high-tech	1.000	0	***	0.944	0.001	***
Medium low-tech	0.341	0.199		0.268	0.303	
Low-tech	0.353	0.211		0.305	0.276	
Wholesale and commission trade	0.193	0.444		0.175	0.484	
Transport and communication	-0.332	0.196		-0.319	0.212	
Financial intermediation	0.254	0.327		0.225	0.382	
Computer activities	-0.015	0.957		-0.062	0.817	
Size	0.257	0	***	0.253	0	***
Group membership	0.207	0.114		0.208	0.111	
International market	0.179	0.188		0.233	0.084	*
% of employees with higher education	0.861	0.001	***	0.858	0.001	***
Creation in 2004-2006	0.207	0.459		0.266	0.345	
Merger	0.640	0.057	*	0.673	0.052	*
constant	-1.428	0	***	-1.356	0	***
Pseudo R <sup>2</sup>	0.178			0.168		
No. of observations	562			562		

\*, \*\*, \*\*\*: statistically significant at the 0.1, 0.5, 0.01 level.

Source: CIS2006. Authors' calculations.

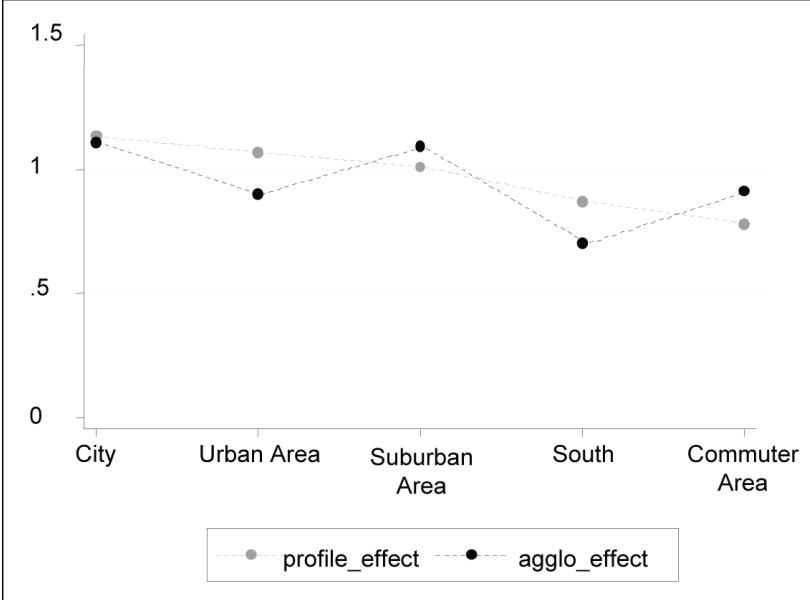
As expected, other aspects, which were found not to be randomly localised (see 4.1), also impact the propensity to innovate: firm size, belonging to a group, employees' level of education, and operating in high and medium high-tech industries increase the propensity to innovate in both regressions. In addition, the fact that a firm operates mainly in foreign markets increases its propensity to innovate in the second estimation. It is therefore expected that profile effects operate.

But what about the size of both these effects across functional regions? The calculation of ratios described in the previous section, based on predicted probabilities or linear predictions, allows this to be done. The results show close links between profile and agglomeration effects. Agglomeration effects appear favouring innovation commitment in Luxembourg-City and the Suburban Area in comparison to the South and Commuter Areas (Figure 2). In addition, profile effects benefit firms from Luxembourg-City, the Luxembourg Urban Area and the Suburban Area in comparison to firms from the South and Commuter Areas.

This result is in line with previous findings for larger spatial units. Johansson and Lööf (2008), for example, have found that, after controlling for firm profile, location of the firm across Swedish regions impacts upon innovation propensity, favouring firms from the metropolitan Stockholm region. Their descriptive results also show that firms from the Stockholm region benefit from characteristics advantageous to innovation.

As noted above, such an approach assumes that location characteristics affect all firms in a given functional unit in the same way. In order to overcome this limitation, accessibility was examined.

Figure 2: Profile and agglomeration effects by functional region



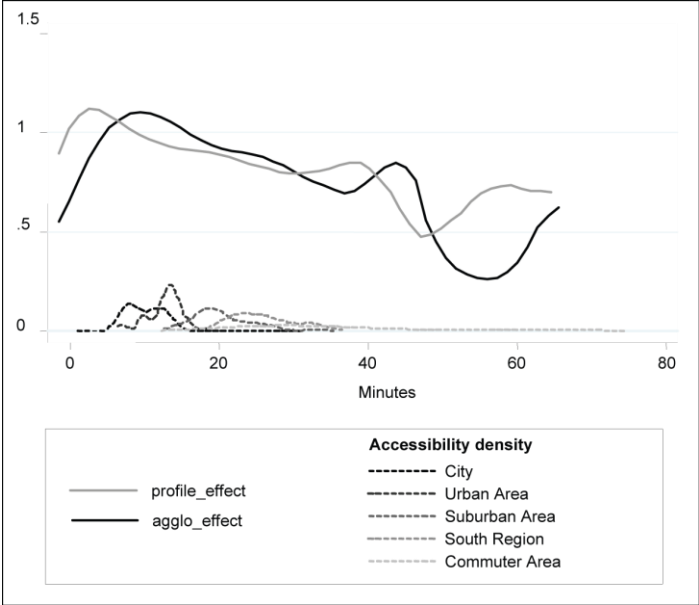
Source: CIS2006; Authors' calculation.

The accessibility results show lower profile effect for firms very close to the centre of gravity but still mainly operating in Luxembourg-City (Figure 3). In addition, higher profile effects, in comparison to nearby firms, are found for firms 40 minutes from the gravity centre, and lower effects for those 55 minutes away. In both of the latter cases, firms are mainly operating in the South and Commuter Areas. This suggests, therefore, some diversity within functional units regarding firms' profile effects. Some diversity is also found in terms of agglomeration



effects, especially between firms from Luxembourg City. Our results indicate that agglomeration effects increase with firm density in Luxembourg-City, and decrease with accessibility. Some variability is also found among the small number of firms with low accessibility. It must however be noted that this latter variability may be due to the small number of observations considered.

Figure 3: Profile and agglomeration effects according to accessibility



Source: CIS2006; Authors' calculation

5.3 Output of innovation activities according to functional region and accessibility.

Considered by functional unit, the estimates are of lower innovation output for firms in the South and Commuter Areas than for firms in Luxembourg-City (Table 4). Accessibility estimates show a negative impact of minutes on innovation output. Both results suggest that agglomeration effects are operating and that they decrease with distance.

Other variables impact positively innovation output: firm size, membership of a group, employees' level of education, operating mainly in international markets and belonging to high and medium high-tech or medium low tech industries. It is therefore expected that profile effects will be seen.

Table 4: Tobit estimates

% of turnover from new products	Functional regions			Accessibility		
	Coef.	P>t		Coef.	P>t	
Minutes	-	-		-0.025	0.09	
Urban Area	-0.595	0.218		-	-	
Suburban Area	-0.361	0.378		-	-	
South Area	-1.260	0.019	**	-	-	
Commuter Area	-0.858	0.105		-	-	
High and medium high-tech	2.024	0.005	***	2.010	0.005	***
Medium low-tech	1.333	0.07	*	1.165	0.111	
Low-tech	1.137	0.148		1.057	0.178	

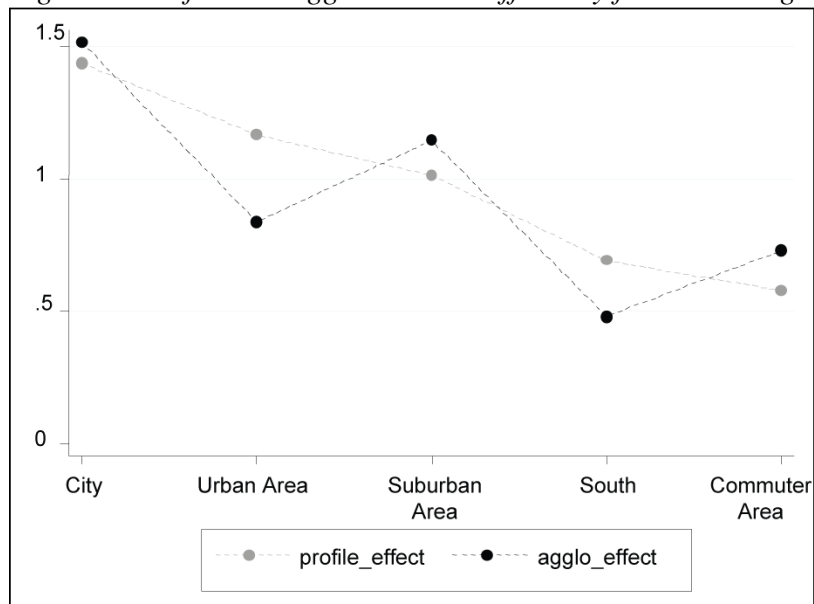
Transport and communication	0.877	0.218		0.822	0.249	
Financial intermediation	-0.409	0.573		-0.408	0.575	
Computer activities	0.951	0.15		0.944	0.154	
Transport and communication	0.337	0.645		0.281	0.701	
Size	0.325	0.015	**	0.339	0.011	**
Group membership	0.606	0.087	*	0.632	0.075	*
International market	0.974	0.008	***	1.056	0.004	***
% higher educated employees	1.720	0.006	***	1.786	0.005	***
Creation in 2004-2006	-0.717	0.37		-0.602	0.454	
Merger	-0.199	0.781		0.014	0.985	
constant	-8.801	0	***	-8.883	0	***
Log likelihood	-642.74			-644.06		
No. of observations (uncensored)	188			188		

\*, \*\*, \*\*\*: statistically significant at the 0.1, 0.5 and 0.01 level.

Source: CIS2006. Authors' calculations.

The estimation of ratios described in 4.3 and presented in Figure 4 highlights the impact of profile and agglomeration effects on innovation output. Specifically, agglomeration effects tend to be lower in the Urban Area than in Luxembourg-City or the Suburban Area, and lower in the South than in the more remote Commuter Area. Profile effects decrease more linearly across functional units. Once more, our results suggest a close link between agglomeration and profile effects. However, agglomeration effects seem to be higher than profile effects in Luxembourg-City, the Suburban Area and the Commuter Area.

Figure 4: Profile and agglomeration effects by functional region

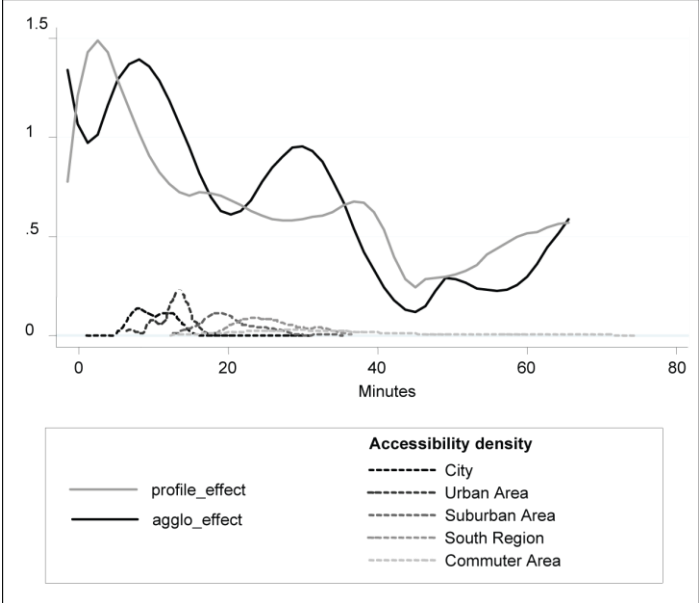


Source: CIS2006; Authors' calculation

The examination of accessibility shows higher variability of agglomeration effects when considering innovation output (Table 5). However, due to firms' density close to the centre of gravity, numerous firms benefit from high agglomeration effects. Profile effects appear to be high only for firms even closer to the centre.

In order to fine-tune these results, we have estimated them once again removing firms from given functional regions. The resultant findings show clearly that the second mode of agglomeration effects (at around 30 minutes to the centre of gravity) depends from the suburban area firms. This result suggests, therefore, that part of this area could offer more favourable conditions for innovation than other locations with identical accessibility to the centre.

Figure 5: Profile and agglomeration effects according to accessibility



Source: CIS2006; Authors' calculation

**6. Conclusion**

Our analysis of the geography of innovation within the Luxembourg metropolitan region suggests that innovation varies at the intra-regional level.

With regard to functional regions, firms from Luxembourg-City appear to innovate more often than those from other regions due to their own characteristics favouring innovation and the existence of positive externalities. Firms from the Suburban Area take also advantage of these effects, but to a lesser degree than firms from Luxembourg-City. At the opposite extreme, firms from the South and Commuter Areas are less likely to innovate, with both of these effects becoming negative. Our analysis of innovation output also highlights the presence of these effects, which are found to vary to an even greater extent. Both of these results provide first evidence of a close link between profile and agglomeration effects at the intra-regional level.

With regard to accessibility, our results provide further evidence of the variability of innovation at the intra-regional level, suggesting that profile and agglomeration effects may differ within the functional units. The accessibility results in relation to the propensity to innovate show, however, the organisation of innovation activities around one main centre, located in Luxembourg-City close to the centre of gravity of the spatial distribution of firms. This finding is less clear when innovation output is considered.

Our results suggest several directions for future empirical research on innovation within the Luxembourg metropolitan region. Firstly, this paper, which highlights the importance of

agglomeration effects in the innovation process, does not provide clear empirical evidence concerning their origins. Further analysis is therefore required of the spatial determinants of innovation. This is a complex issue, as these determinants are likely to differ according to location (Autant-Bernard 2001).

Secondly, our empirical evidence is, due to the availability of data, based on average firms, which does not allow us to take into account the fact that firms from a given location might belong to dissimilar clusters of activities. Since local spillovers are conditioned by technological proximity, firms are likely to benefit in different ways from local externalities. This is a particularly important issue in Luxembourg, as the country is currently creating a new science city, Belval, which is expected to combine in a single area most of the national research and higher education institutions with mostly low-tech or low knowledge-intensive incumbent firms. The expected relocation in Belval of some national R&D providers and the attraction of foreign firms, at least from bordering regions, should reinforce this issue.

Thirdly, as our models are static, our agglomeration effects are subject to endogeneity due to firms with unobserved attributes. This means that if e.g. firms with overachieving entrepreneurs would be disproportionately found in a specific area (Rosenthal and Strange 2003) such as Luxembourg-City, our agglomeration effects would be overestimated for this area. This issue has to be resolved through a more dynamic approach.

Fourthly, as indicated in previous studies (Walther and Dautel 2010), Luxembourg is undergoing a “metropolisation process” characterised by decreasing employment growth in Luxembourg-City and increasing growth within the close periphery. More research could be done to link these findings to those of this paper, in order to compare the geography of employment with the geography of innovation and give a more complete picture of the complex organisation of economic activities at the intra-regional level. Luxembourg-City favours firms’ innovation activity, while the Urban and Suburban Areas are the main recipients of employment growth. Further analysis is required to investigate this important topic.

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