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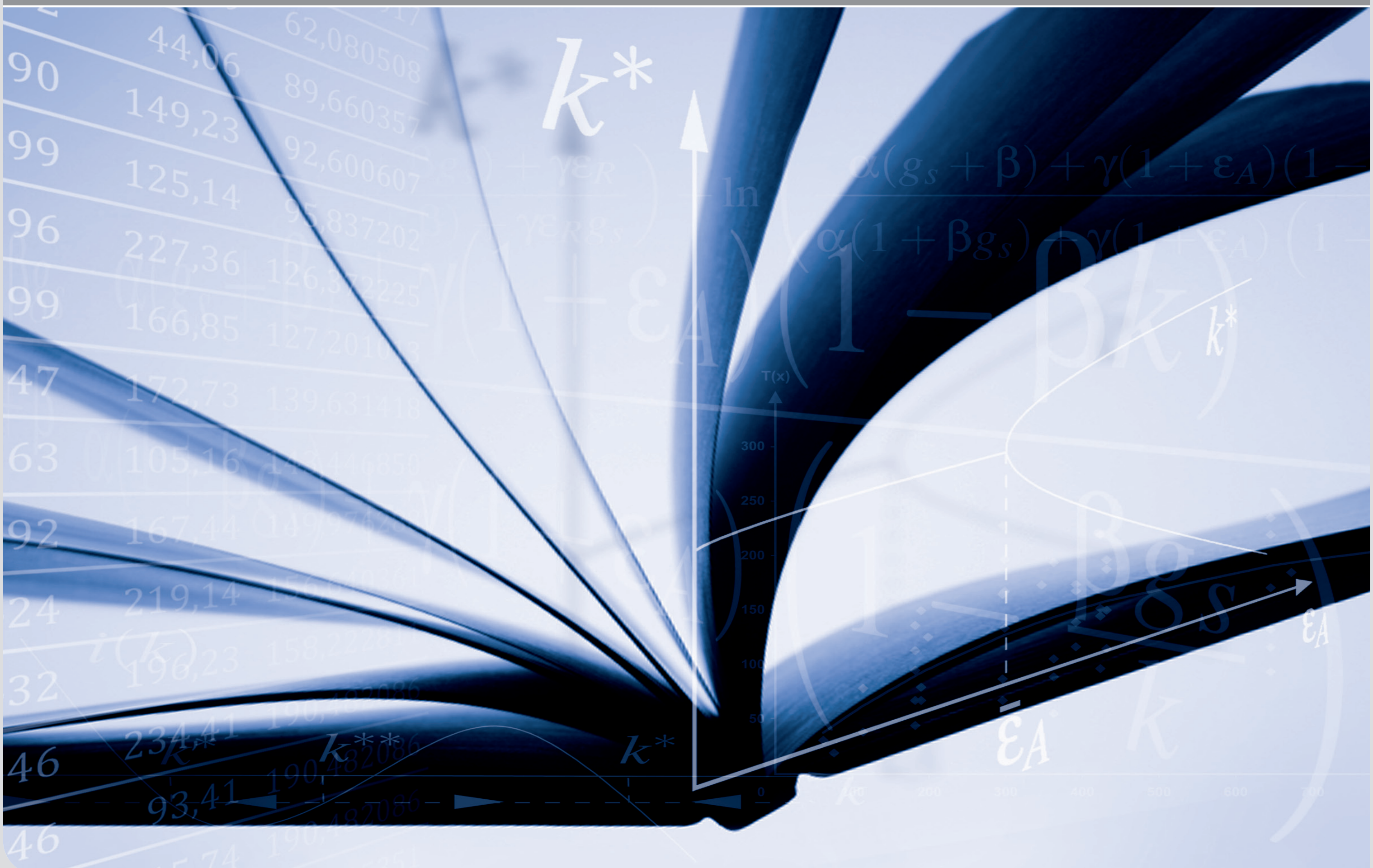

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Firm Growth and the Spatial Impact of Geolocated External Factors – Empirical Evidence for German Manufacturing Firms

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Abstract

In this paper the relationship between firm growth and external knowledge sources, such as related firms and universities, is studied. The spatial characteristics of these relationships are examined by geolocating firms into a more realistic relational space using travel time distances and using flexible distance decay function specifications. This approach properly accounts for growth relevant knowledge spillovers and allows for estimating their spatial range and functional form. Applying quantile regression techniques on a large sample of German manufacturing firms, we show that the impact of external factors substantially differ along firms' size, type of knowledge source and growth level.

Keywords: Firm growth, external factors, universities, agglomeration, space, spatial range, distance decay functions, knowledge spillovers, high growth firms, quantile regression

JEL-Classification: C31, D92, L25, R11

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1 Introduction

The economic literature contains a bulk of theories and empirical approaches dealing with firm growth and growth related factors. The empirical part has mainly focused on the detection of firm-specific factors and, to a lesser extent, general industrial, regional as well as national factors contributing to the growth of firms. The related theories address the research topic from very different perspectives ranging from neoclassical theories of optimal size, characterized by exogenous growth (Coase 1937), to evolutionary concepts, in which innovation-based growth is highlighted (Metcalfe 1993). With respect to the current literature, theories like endogenous growth theory and sociological concepts become apparent. Following the work of, *inter alia*, Romer (1990) on endogenous growth, knowledge can be considered as the most important driving force of economic growth. Being only partly a private good, the diffusion of knowledge throughout the economy might sustainably accelerate a firm's growth dynamic. However, knowledge diffuses neither perfectly nor instantaneously. On the one hand, a firm's adaption of external knowledge is restricted by its absorptive capacity (Cohen/Levinthal 1990) and by a sufficient complementarity to its own knowledge base (Nooteboom 2000). On the other hand, knowledge spillovers show a strong geographical dimension (Audretsch/Feldman 2004). Building upon early ideas regarding the diffusion of innovation (Hägerstrand 1952), the literature univocally accepts that knowledge cannot be transported frictionless across space. Consequently, geographical distance does matter.

Another, rather sociological view focuses on the relevance of resources to firms' economic performance (Hannan/Freeman 1977). Already Penrose (1959) states that firm growth occurs as a consequence of available excess resources. This resource-based view agrees with the endogenous growth theories upon the essential distinction between two growth factors: the firm-specific internal factors as well as the availability and usability of external resources. Besides the general socio-economic environment, in which firms are mostly regionally embedded, these growth relevant external factors in particular encompass concrete and thus geo-localizable knowledge-generating micro entities like universities and other firms.

However, economic theories and approaches do not put too much emphasis on the spatial impact of these external factors, although knowledge spillovers have been shown to have a geographical dimension.[5] The respective studies suffer from a missing or superficial conceptualization of space. We propose to substitute the inappropriate abstraction that is implicit in the concept of regions by using point coordinates of all relevant actors. By doing so, we assume that the location of firms in a concrete space relational to the external factors does matter. In light of this, we explain firm growth from an explicitly spatial perspective. More precisely, our research contributes to the economic literature mainly in two aspects. First, we explicitly integrate different external knowledge sources in the analysis of the determinants of firm growth. Secondly, we place growth relevant knowledge spillover processes in concrete space. Instead of imposing artificial and arbitrary regional delimitations and constructing imprecise measures of the regional available knowledge, we look at the exact geographical point locations of firms and their economic distance to different external sources of potential knowledge dissemination. This allows us to estimate the distance-weighted contribution of geolocated external factors on the growth of firms and to identify the spatial range and functional form of their impact.

In the following chapter 2 we start by discussing the theoretical framework of firm growth before we review and discuss some spatial issues related to external growth factors. Chapter 3 analyses the stochastic properties of a sample on German manufacturing firms and describes the construction of the variables, whereas chapter 4 presents the model and introduces into quantile regression as an adequate estimation technique. In chapter 5 the empirical results are discussed. Chapter 6 concludes.

[5] In this research we define "knowledge spillovers" as the process by which the investments in knowledge creation by one party produce external benefits to other parties (Jaffe et al. 1990). Spatial knowledge spillovers result from geographically limited knowledge diffusion, which can happen either intentional or unintentional (Döring/Schnellenbach 2006). For empirical reasons we do neither apply Griliches' distinction in pure (technological) knowledge spillovers and pecuniary spillovers (Breschi et al. 2005) nor differentiate between the manifold mechanisms through which knowledge diffuse.

2 Theoretical framework and hypotheses

2.1 Firm growth and its growth related external factors

In general, firm growth and related factors have been repeatedly studied in the economic literature and highlight a main issue of economics: market participants are competing with each other. This competition is the dynamic source of placing market participants at the right place to enable their creative skills and growth activities. In the long run, the firm's economic success depends on its competitiveness (Grebel et al. 2003). Thereby, for many business activities the most important factor is the existence and the emergence of new knowledge. The work of Witt (e.g., 2000) has improved our fundamental understanding of the role of knowledge and cognitive capabilities as central sources of structural change, technical progress and growth. To say it in the words of Witt (2011: 160): "All productive human activity implies an expression of knowledge that has previously been acquired by, and is held and processed in, the minds of the involved human agents". Witt (2003) summarizes the following knowledge-oriented factors that might be decisive in enhancing firm growth: (1) knowledge about the right choice of location, (2) knowledge about dynamic processes and interactions, (3) knowledge about natural growth limits and (4) knowledge about the dynamics of self-organization. The first three points highlight the key points which we address in the study at hand. First, knowledge about the right choice of location has been repeatedly studied in the previous literature. Already Weber (1909) aims at identifying the positive effects of agglomeration economies on firm localization. Secondly, knowledge spillovers often play a pivotal role in the growth process of firms (e.g., Witt 1997). To be part of a creative and sustainable knowledge network various dependencies such as to universities or to other firms might be possible. Thirdly, firms' activities, trajectories and interactions are not entirely unlimited and unbounded. Thus, their competitive capacity may be restricted within natural bounds, determined, for instance, by their size (Witt 1985).

Basically, the factors contributing to firm growth can be distinguished into factors that are internal and factors that are external to the firm. Empirical studies in the economic literature have mainly focused on the former, such as its size, age or more recently R&D activities (for an overview see Coad 2007). For instance, previous research tends to emphasize that smaller firms experience higher growth rates than their larger counterparts. Underlying mechanisms, like the time scale on which firms operate or the likelihood of external learning, differ. In anticipation of the discussion on the relevance of external factors, it deserves a mention that particularly young and small firms can be expected to rely on external knowledge (Almeida et al. 2003). Firms' trading activities are another crucial internal factor. As a theoretical explanation, the learning-by-exporting hypothesis (Clerides et al. 1998) was brought forward and is confirmed by several empirical studies (e.g., Dosi et.al. 1990).[6] However, here we primarily want to focus on *external factors* and their impact on firm growth. Hence, the involvement in trading activities can be used as a selection criterion *a priori*: high- and medium-tech firms are characterized by higher export intensities (Raspe/van Oort 2008). And merely firms, for which knowledge is an important production factor, might actually benefit from external knowledge sources.

As discussed above, internal resources are not sufficient to achieve competitiveness and growth; for most firms a wide range of external factors is also relevant. The empirical literature (for a recent study see Barbosa/Eiriz 2011) reveals that region-specific characteristics engender differences in the way firms grow. Much attention was dedicated to the regional economic structure, which is assumed to represent the availability of resources and market opportunities (Storey 1994), or on general agglomeration advantages and disadvantages, which make up to a large part the New Economic Geography literature. Exclusively focusing on the firms' innovative performance, some studies systematically attempt to disentangle firm-specific internal factors from region-specific external factors, with the former turning out to predominate by far (e.g., Sternberg/Arndt 2001; Beugelsdijk 2007). However, these studies are characterised by a simplified conception of the regional environment surrounding a firm. In contrast, we focus on the presence and geolocation of entities that

[6] It is important to notice that a reversed causal relationship is likewise possible: increasing technological competences affect positively firms' competitiveness, and thus opens up new opportunities for trading (Boschma/Iammarino 2009).

can be considered as external knowledge sources. More precisely, we estimate the spatial impact of other related firms and universities on firm growth.

Regarding the co-location in proximity to other firms, already Marshall (1890) pointed to the fact that firms are more relatively efficient and hence performing better when located within or nearby an agglomeration. In respect to the economic geography literature, two sources of productivity enhancement are traditionally distinguished. Whilst positive effects of localization economies occur through specialization of related industries (e.g., Henderson et al. 1995), the positive effects of urbanization economies arise from agglomerating a variety of different industries (e.g., Glaeser et al. 1992). Even after many decades of intensive research, the literature on regional agglomeration remains rather indecisive about the real effect of specialization versus diversification at the regional level (Beaudry/Schiffauerova 2009). The indecisiveness can be mainly attributed to the high level of geographical aggregation that underlies these studies. Thus, it seems worthwhile to focus on the micro-processes of agglomeration effects. In accordance with the resource-based view of the firm, the most relevant agglomeration effect relies on both intended and unintended exchange and diffusion of knowledge across competing firms within an agglomeration. These diffusion processes might occur without any direct interaction through constant mutual monitoring (Malmberg/Maskell 2002) or as a result of direct interactions and learning processes in formal and particularly informal social networks (Singh 2005). Furthermore, the mobility of individuals (Breschi/Lissoni 2009; Eriksson/Lindgren 2009) and the exchange of intermediate goods (Döring/Schnellenbach 2006) cause specialized knowledge embodied in human and physical capital to circulate and accumulate across firms and increase their performance (Eriksson 2011). These theoretical considerations suggest that location within an agglomeration could influence firms' growth prospect.[7] Hence we get

> *Hypothesis 1: Firms benefit from being located in proximity to other firms, mainly due to an increased access to external knowledge. The degree of relatedness matters hereby.*

Audretsch and Dohse (2007), however, admit that only little is known about the impact of location at the micro level of firms. Most empirical studies on knowledge spillovers focus on the firms' innovation output, whereas only few studies examine their immediate impact on firm growth (notable exceptions are Audretsch/Dohse 2007, Eriksson 2011 or Raspe/van Oort 2008).

A similar reasoning holds true if the role of universities is considered. Again, studies on their impact on the innovative performance within firms (e.g., Jaffe 1989, Mansfield 1995) or dispersed across regions (e.g., Anselin et al. 1997; Ponds et al. 2010) dominate the empirical literature. Audretsch and Lehmann (2005) were the first who directly linked both firm-specific characteristics as well as access to knowledge from universities to firm growth. Subsequent work (e.g., Cassia et.al. 2009; Raspe/van Oort 2011) reveals significant relationships between firm growth and university presence. Generally speaking, universities' role is to perform education and research (Schlump/Brenner 2010). Both functions work as potential knowledge spillover channels, but they differ substantially in their underlying mechanisms. The former is related to the mobility of graduates, the latter to university-industry research collaborations. To state it simple, we get

> *Hypothesis 2: Firms benefit from being located in proximity to universities, mainly due to an increased access to external knowledge. Universities' specific functional roles matter hereby.*

However, universities are not equally important across industries. Especially firms from science based, knowledge intensive industries are expected to profit the most from the presence of universities (e.g., Klevorick et al. 1995). Likewise, the literature shows that the effectiveness of university-industry knowledge related linkages are influenced by the general regional environment (Varga/Parag 2000). For example, most rural communities have not been able to create the comprehensive and sophistic infrastructure necessary to meet the needs of foremost high-growth firms (e.g., Sherman et al. 2009), and graduates tend to prefer a diverse and open urban atmosphere (Florida 2005).

[7] Empirical studies focusing on the impact of agglomeration on firm performance are necessarily confronted by an endogeneity problem (Pinske/Slade 2010: 113). If firms with a high growth prospect tend to locate closer to external knowledge sources, due to other reasons than an increased access to that knowledge, the importance of spatial proximity for knowledge spillovers would be overestimated (Baldwin/Okubo 2006).

2.2 Spatial dimension of external growth factors

The theoretical discussion regarding the impact of firms' location in proximity to other firms and universities relies on a rather implicit assumption that knowledge spillovers are somehow bounded in space. It is argued that inherent properties of the nature of knowledge, like the degree of tacitness (Polanyi 1957) or complexity (Sorensen et al. 2006), increase the costs of transmitting knowledge over longer distances. Transferring complex, that means often unstructured, but economically valuable knowledge demands personal contacts. Because this kind of knowledge is mostly embedded in people, knowledge spillovers can be assumed to be a function of people's mobility and interactions (Andersson/Karlsson 2007: 131). Despite recent improvements in ICT (Sonn/Storper 2008), there are strong empirical findings that social interactions decrease with geographical distance (see Hoekman et al. 2010 for the collaboration between firms or von Proff/Dettmann 2010 for the collaboration between academia and industry). However, as Döring and Schnellenbach (2006) assess, empirical studies lack a consensus on the spatial range of knowledge spillovers. Distances as diverse as 10 km (Baldwin et al. 2008), 120 km (Anselin et al. 1997) or 300 km (Bottazzi/Peri 2003) are reported. Reasons for the discrepancies are mainly twofold. First, their measurement is based upon regional entities instead of firms. In line with Eriksson (2011) we argue that spatial aggregates like regions blur real economic relationships. Secondly, space suffers from an over-simplified conceptualization. Within the Euclidian plane, there is no way to account for the unequal infrastructural configuration and consequently for economic distances, which ultimately matter. Furthermore, the impact of distance is not properly represented. At best, a linear distance decay function is assumed (Lychagin et al. 2010). Most studies, however, are based upon arbitrarily chosen distance-circles which determine proximity in an absolute and dichotomist fashion.

Regarding the first point, Beugelsdijk (2007: 195) states that the "region as such is a spatial unit, not an actor". Only firms are directly susceptible to knowledge spillovers, and thus the proper level of analysis. Because imperfect competition and heterogeneous firms are defining characteristics of the economic landscape, regions as consistent aggregates are impossible to exist (Harris 2010; Pinske/Slade 2010: 111). As a consequence, regionalization, an ex-post abstraction of the continuous landscape, would imply a huge loss of information. Instead, it is reasonable to assume that each firm has its own specific hinterland. In our case, the extension of that area can be set equal to the range where a sharp decline in the impact of growth-relevant knowledge spillovers occurs (Andersson/Grasjö 2009). This means that we define the *region* from the firms' perspective. In doing so, we avoid the artificial distinction between intra- and inter-regional knowledge spillovers. This widespread distinction is problematic mainly for two reasons. First, the regional science literature ignores the former due to its explicit focus on inter-regional dependencies. But knowledge spillovers occur to a large part at a geographical scale much smaller than usually assumed as "regional" (Eriksson 2011; Raspe/van Oort 2008). Hence, their effect on the performance of economic entities is necessarily underestimated. Secondly, there is no reason why to assume that knowledge spillovers should abruptly take halt or change in their qualitative nature at predefined regional boundaries, which in most studies coincide with administrative territories.

Regarding the conception of space, we essentially assume a relational concept, in which every point in space – here the geolocated firms – depends on everything else around (Rodriguez-Pose 2011). Tobler's (1970) first law of geography states that the relatedness decreases with distance. If this assumption holds true for the impact of external knowledge sources on firm growth, the concrete location relational to these sources is important to understand the dynamics of firms (Andersson/Karlsson 2007: 132). However, it is virtually impossible to measure the real individual impact of each single external knowledge source on each firm, mainly due to the intangibility of the assumed knowledge flows (Koo 2005). Therefore, we calculate the potential of knowledge spillovers to occur, or more basically the potential of opportunities for interactions from a firms' perspective, in other words the accessibility of the firms' locations. Karlsson and Manduchi (2001) argue that the accessibility approach, based on early ideas of Weibull (1980), makes the general concept of geographical proximity operational in the first place. A high accessibility means a high potential for interaction, and because knowledge spillovers are mainly related to the mobility and interaction of people, "knowledge accessibility transforms into potential knowledge flows" (Andersson/Karlsson 2007: 133).

Interactions are time-consuming. Consequently, the firms' access to external knowledge not only depends on the location pattern of the knowledge generating entities, but also on the physical infrastructure (Andersson/Karlsson 2007). Whereas physical distance is still the frame, in which interactions occur (Rodriguez-Pose 2011), it is travel time that is directly related to the frequency of interactions (Andersson/Grasjö 2009). Furthermore, the negative time sensitivity of interactions and thus the intensity of knowledge spillovers are not linear in space, but vary between different geographical scales (Johansson et al. 2003; Andersson/Karlsson 2007). Following the literature on commuting behaviour, we argue that within a narrow local context of few minutes, the intensity of knowledge spillovers should not show any time sensitivity. At these distances, interactions can take place at short notice. However, after some threshold distance the frequency and contribution of growth relevant economic interactions are highly distance-sensitive and may decrease rapidly. This range defines the extension of the region from a firms' perspective. For long distances, the influence of geography ceases to matter once again, because interactions require general planning in advance. Essentially, we get

> *Hypothesis 3: Different types of external knowledge sources show different spatial ranges and functional forms in respect to their impact on firm growth. Furthermore, the range and form also varies along the firms' organizational characteristics such as their size.*

The S-shaped function of willingness to commute or interact, which above is deduced from behavioural assumptions, can be described mathematically by a downward log-logistic function of travel time *t* (see Vries et al. 2009 for technical details):

$$f(t) = 1/(1 + r^{-s} * \exp(s * \log(t))) = 1/(1 + (t/r)^{-s}) \quad (1)$$

with *r* and *s* representing two parameters that describe the shape of the curve. The curve starts rather flat with the value of 1, becomes steeper, and then gradually flattens again to approach 0. Parameter *r* determines the location of the curve's bending point, and parameter *s* its degree of steepness. If *s* becomes 1, the curve takes the shape of a negative exponential one. Using this flexible family of distance decay functions, we construct firm-specific measures of the average potential impact of other technologically related firms' activities (firm-specific agglomeration measures, as it is dubbed by Eriksson 2011) and of university activities. Therefore, the values of all single geolocated external knowledge sources are multiplied by a distance weight resulting from the best fitting distance decay function. Finally, their average value is taken. More precisely, we estimate the distance-weighted impact of universities and other firms on the firms' growth rates.[8] In doing so, we not only obtain information regarding the magnitude of that impact, but also regarding its spatial range and functional form.

3 Data and variables

3.1 Dependent variable: employment and turnover growth

A sample of German manufacturing firms was extracted from the Creditreform MARKUS database.[9] The growth rates $g_{i,t}$ are calculated by taking the differences of the natural logarithms of the size of firm *i* between two successive years *t*:

$$g_{i,t} = \ln(size_{i,t+1}) - \ln(size_{i,t})$$

[8] This modelling strategy was suggested by Andersson and Grasjö (2009) as an alternative to traditional spatial econometric models, because spatial externalities are directly modelled via spatially discounted explanatory variables. Performing an extensive Monte Carlo analysis, they confirmed that this approach captures substantive spatial dependence in the dependent variable and accounts for both local and global spillovers.

[9] The sample was extracted from the Creditreform MARKUS DVD on 11/2010 including all firms for which sales/turnover and employment information is available at least for the time period 2004 to 2009.

Since no universally best size indicator exists, we employ and compare two alternatives: turnover as well as employment number.[10] Due to data availability, growth rates are calculated for the years 2005, 2006 and 2007 and pooled together.[11] Furthermore, only firms which display either import or export activities are selected (see chapter 2.1). Since the growth of micro-firms is a rather erratic and lumpy process (Coad/Hölzl 2009), firms with less than ten employees are excluded from the analysis. Additionally, we omit very large firms with more than 1000 employees.

In chapter 2.1 we argue that the size of the firm determine its growth logic and necessity of external knowledge sources. Because these stylized facts preclude the possibility to pool together firms of different size groups, we perform our analysis on different subsamples. Therefore, we split the sample according to the European Commission (2003) into the three size bins small [10-50), medium [50-250) and large [250-1000) on basis of the average annual firm size. The compositions of all analysed subsamples are presented in Table 1.

Table 1 Number of firms within each analysed subsample

	Employment growth			**Turnover growth**		
size	small	medium	large	small	medium	large
2007	3365	3618	966	3640	3553	979
2006	3335	3560	965	3701	3647	994
2005	3168	3365	922	3620	3596	983
pool	**9868**	**10543**	**2853**	**10961**	**10796**	**2956**

An analysis of stochastic properties of the firms' growth rates yields valuable information about the underlying growth process. If Gibrat (1931) were right that firm growth follows a random walk process with growth events being independent of each other, the central limit theorem would predict that the resulting distribution of growth rates tends to normality at the limit. But recent empirical evidence tells a different story (for instance, see Bottazzi et al. 2002 for Italy or Bottazzi et al. 2011 for France). Rather than the bell-shape of a normal curve, an exponential tent-like shaped distribution is observed, with tails that are much fatter than the ones of a normal distribution. In other words, growth events at the extremes occur with a significantly higher probability. In search for a more general and flexible distributional model that describes the observed stochastic properties of the growth rates $g_{i,t}$, the Subbotin distribution family was introduced into economics by Bottazzi et al. (2002):

$$f(g_{i,t}; b, a, m) = \frac{1}{2 * a * b^{\frac{1}{b}} * \Gamma(1 + \frac{1}{b})} * \exp\left(-\frac{1}{b} * \left| \frac{g_{i,t} - m}{a} \right|^{b} \right)$$

with Γ(.) standing for the gamma function. Three parameters define the distribution: the location parameter *m*, which indicates the existence of a general trend in the data, the scale parameter *a*, which determines the spread or dispersion of the distribution, and the shape parameter *b*. Both the normal ($b = 2$) and Laplace ($b = 1$) distribution are particular cases of the Subbotin family of probability densities. To conclude, the Subbotin family allows for a continuous variation from non-normality to normality, with a smaller shape parameter *b* representing fatter tails. Table 2 depicts the estimated distributional parameters. A significant positive growth trend can be observed in all sub-samples, whereas firms tend to be subject to some convergence only in case of employment. For turnover growth, in contrast, a rather divergent growth pattern emerges. The variance in the growth rates of smaller firms is slightly, but not significantly higher.[12] The most relevant observation here, however, is

[10] The pros and cons of different size measures are discussed in the literature at length (see Coad 2007). Whereas growth in turnover is of special interest at the level of management, employment growth primarily should concern regional policy makers. Raspe and van Oort (2008) argue that the employment measure is most adequate from the resource-based view of the firm, because employees represent a firm's most important asset.

[11] The year of the financial crisis, 2008, was excluded from the sample because the stochastic properties of the growth rates exhibit a significant different behaviour and thus they qualify themselves for being a research topic on their own.

[12] A reduction of the growth rates' variance with an increase in firm size is also known as inverse variance size scaling (Stanley et al. 1996) and regarded as one of the stylized facts of firm growth. Testing for it in both the

that the underlying drivers in the growth process cannot be accounted for neither by the normal distribution nor by the Laplace distribution. Small values of *b* point to the fact that extreme growth events are not just mere outliers but a fundamental phenomenon of firm growth. This holds especially true for employment growth: since employees are discrete in nature, they change in numbers rather abruptly in a lumpy fashion (Bottazzi et al. 2007). The growth rates distribution consequently displays even fatter tails compared to turnover growth. In respect to this issue, the discussion on high-growth firms becomes apparent: most firms do not grow (or only slightly), whilst a small, however non-negligible part of firms experiences very rapid growth. These firms strongly contribute to the overall economic development and hence are of interest in their own right (Coad/Rao 2008).

Table 2 Estimated distributional parameters of the firms' growth rates

	Employment growth			Turnover growth		
size	small	medium	large	small	medium	large
b	0.603	0.474	0.348	0.830	0.688	0.592
std err	(.009)	(.007)	(.010)	(.006)	(.009)	(.014)
a	0.096	0.062	0.048	0.125	0.110	0.100
std err	(.001)	(.001)	(.002)	(.001)	(.001)	(.003)
m	0.033	0.012	0.002	2.5E-04	0.049	0.060
std err	(.000)	(.000)	(.000)	(.000)	(.001)	(.002)

3.3 Independent variables

a) Control variables

The firms' potential to benefit from geolocated external knowledge sources is specific to characteristics of the firms as well as of the corresponding regions (Beugelsdijk 2007; Eriksson 2011). Therefore, we control for relevant firm-specific properties and for the general regional environment. Building upon the literature on firm growth, we identified five important firm-specific control variables: the logarithm of its size (*SIZE*), its age (*AGE)*, its past year's growth rate (*G_t1*), its import quota (*IMP*) and export quota (*EXP*) as well as its sectoral affiliation to a knowledge intensive industry (*KI*).[13] The knowledge intensity dummy should proxy for internal research activities and its absorptive capacity (Koo 2005). All data stems from the Creditreform MARKUS database. Besides, two variables are chosen to control for the general regional environment. Urbanization economies *per se* can be measured by the population density (*POP*) of the corresponding labour market region, wherein a firm is located (Eriksson 2011).[14] The regional unemployment rate (*UR*) might reflect the vitality of the socio-economic structure. In the special case of Germany it foremost accounts for the persisting structural differences in the eastern and western part after the fall of the iron curtain. The data for these two variables is obtained from the German Federal Statistical Office (destatis).

b) Geolocated external growth factors

In this study we focus on two types of external knowledge sources: related firms and universities. To assess the impact of being located in proximity to related industrial firms, we measure the travel time distance from each firm to all other related firm activities. The issue of relatedness is tackled by a simple hierarchical approach: all other firms which belong to the same 2-, 3- or 4-digit industry are taken into account. In case of 3-digit industries, we excluded firms of the same 4-digit level in order to avoid double counting. An analogous adjustment is applied to the 2-digit industry, in which case the firms at the same 3-digit and 4-digit level are excluded. Applying the log-logistic distance decay

whole sample and in each size group separately, however, we do not receive any significant results. Re-scaling of the growth rates is therefore not necessary.

[13] The assignment is based on Legler and Frietsch (2006) with 3-digit industries as the highest level of disaggregation.

[14] Labour market regions are functionally delimited regions. Here we use the definition of Eckey et al. (2006) for Germany, which counts 150 regions in total.

function as defined in chapter 2.2 and finally taking the arithmetic mean, three firm-specific agglomeration variables result (*AGGL_2*, *AGGL_3* and *AGGL_4*, respectively). Relevant as knowledge resources are not only other firms' headquarters, but all places at which relevant other firms are active. Therefore, we use plant locations to represent other firms' activities. The Federal Employment Agency's (BA) establishment data, which consists of around 2 million entries per year, is used.

The impact of the location relational to universities can be assessed in a similar way. As a measure of their potential impact in general, the yearly available financial budget can be used (*UNIV_bud*). However, we also want to explicitly consider the different functional roles and knowledge transfer mechanisms of universities. Therefore, two relative measures are calculated in addition. The universities' relative strength in the education function is approximated by the number of graduates in comparison to that number which could have been expected from merely considering budget as a measure of their size (*UNIV_gra*). Analogously, the universities' relative strength in the research function can be approximated by the received third-party funds divided through the expected amount (*UNIV_res*) calculated again on basis of their budget. For interpretative reasons, the last two variables are normalized to the mean of zero. To receive the firm-specific location variables, these three measures are each weighted by the value of the distance decay function and the arithmetic mean is finally taken. Again, data is taken from destatis and encompass universities in a narrower sense as well as universities of appied science. Table 3 recapitulates the independent variables of this study, whereas descriptive statistics are reported in Table X1 (in the appendix).

Table 3 Overview of independent variables and data sources

Variable	Description	Data source
SIZE	(log) employment number or (log) turnover, respectively	Creditreform Markus
AGE	Years since founding date	Creditreform Markus
G_t1	past year's growth rate	Creditreform Markus
IMP	import quota	Creditreform Markus
EXP	export quota	Creditreform Markus
KI	sectoral affiliation to a knowledge intensive industry (dummy)	Creditreform Markus
POP	Population density of the firms' labour market region	destatis
UR	Unemployment rate of the firms' labour market region	destatis
AGGL_2	firm-specific agglomeration variable regarding other firms' locations (plants) of the same 2-digit industry	BA establishment data
AGGL_3	firm-specific agglomeration variable regarding other firms' locations (plants) of the same 3-digit industry	BA establishment data
AGGL_4	firm-specific agglomeration variable regarding other firms' locations (plants) of the same 4-digit industry	BA establishment data
UNIV_bud	firm-specific location variable regarding universities in general (budget)	destatis
UNIV_gra	firm-specific location variable regarding relative universities' strength in education function (graduates per budget)	destatis
UNIV_res	firm-specific location variable regarding relative universities' strength in research function (third-party funds per budget)	destatis

3.4 The calculation of economic distances

People do not interact economically as crow flies. It is a ubiquitous phenomenon that infrastructural endowment is uneven across space. Real bilateral travel times between the locations of each firm to the locations of all other firms' activities and to the locations of universities are of interest. The calculation of time distances is done by exploiting results from graph theory. Therefore, we model the road network[15] as a directed graph with travel time metric as edge weights. Knopp et al. (2007) introduced an algorithm to compute large-scale distance matrices without naively computing a quadratic number of distances. The small search spaces of a speedup technique to Dijkstras seminal

[15] Data on the German road network was taken from the OpenStreetMap project as of July 22nd, 2011 and consists of 8,226,112 nodes and 15,501,574 edges.

algorithm are precomputed and intersected to produce the matrix. This method only needs a linear number of shortest computations and therefore is several orders of magnitude faster than the naive algorithm. In addition, an algorithm of Geisberger et al. (2008) is used that exploits the natural hierarchy of road networks, called Contraction Hierarchies (CH). The method preprocesses a road network and produces a linear sized amount of auxiliary data that is used to speed up any subsequent queries. CH have the benefit of small search space, i.e. a query has to look at only a few hundred nodes in the graph. Combined with the previous algorithm we can compute distance matrices of 10,000 by 10,000 nodes within a matter of several seconds. In the first place this approach makes it possible to implement the idea of realistic economic distances at the micro level of economic entities like firms.

For geolocating the firms of the analysed samples, we use their exact address information. However, this information is not available for all other firms' plants that exist in Germany. Furthermore, in the case of universities it can be argued that a great part of them consists of spatially separated faculties, which are located mostly within the same municipality. Thus, we approximate the locations of both other firms' plants and universities by using the geocentroids of the corresponding municipalities. In doing so, a new issue arises. If one firm is located in the same municipality as another firm or university, it would be inappropriate to set the distance to zero or to use the distance to the municipalities' geocentroid. As a substitute, the existence of a general intra-municipality friction can be assumed. To obtain its value, we first drew a random sample of 1000 pairs of firms' address locations, each belonging to the same municipality, and then measured all bilateral distances. The mean of all intra-municipal travel times resulted to be 5.01 minutes.

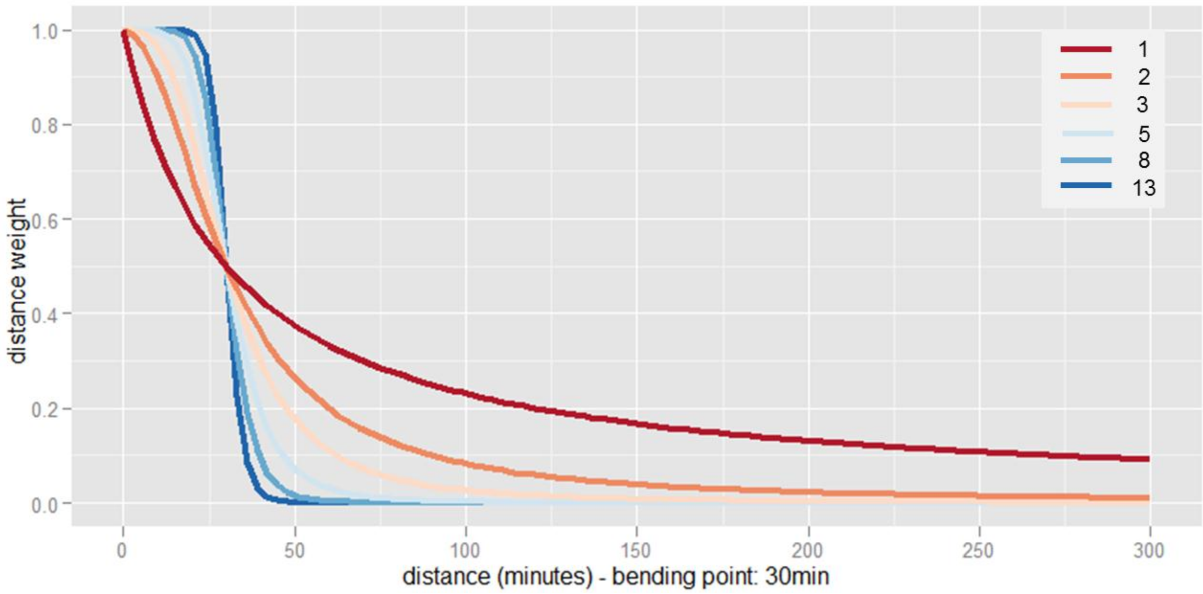
4 Model and Estimation

An identification of the best fitting model allows on the one hand to quantify the distance-weighted contribution of external factors to the growth of firms, on the other hand to reveal the exact spatial behaviour of growth relevant knowledge spillovers.

4.1 Specification of the models

The above deduced log-logistic distance decay function f(t) (see Equation (1)) determines the distance weights, which are used to construct the firm-specific measures of the average potential impact of other related firms and of university activities. The function is entirely defined by the bending point *b* and the steepness parameter *s*. Here, the former may take the values of 5, 10, 15, 30, 45, 60, 90, 120, 150, 200, 250, and 300 minutes, the latter the first six values of the Fibonacci row: 1, 2, 3, 5, 8 and 13. Figure 1 depicts an example with a fixed bending point at 30 minutes.

Figure 1 Log-logistic distance decay function with bending point at 30 minutes



Combining the two parameters, in total 72 possible distance weights result, whereas in addition different specifications are allowed for other firms versus universities. By choosing the model with the highest likelihood value, a quasi-continuous optimization of the distance decay function, which describes best the observed spatial impact of external knowledge sources, is performed. Basically, we estimate a simple linear model:

$$g_{i,t} = \sum_j \beta_j * x_{i,t,j} + \sum_k f(b_{agg}, s_{agg}, t_{i,k}) * AGGL_{i,t,k} + \sum_l f(b_{uni}, s_{uni}, t_{i,l}) * UNIV_{i,t,l} + \varepsilon_{i,t}$$

with β, b_{agg}, b_{uni}, s_{agg} and , s_{uni} representing the parameters to be estimated, $f(.)$ the above defined log-logistic distance decay function, $t_{i,k/l}$ the travel distance between the units i and k/l, x the various firm- and region-specific control variables, and $AGGL$ as well as $UNIV$ the distance weighted impact of other firms and universities, respectively. The error term is denoted by $\varepsilon_{i,t}$.

4.2 Quantile regression

Koenker (2005: 1) introduces the idea behind the quantile regression approach by citing the influential work of Mosteller and Tukey (1977): "What the regression curve does is give a grand summary for the averages of the distributions corresponding to the set of x's. […] regression often gives a rather incomplete picture. Just as the mean gives an incomplete picture of a single distribution, so the regression curve gives a corresponding incomplete picture for a set of distributions". Our intuition is that high growth firms, a dominant feature of firm growth, rely differently on internal as well as external factors. Focusing on the average firm may obscure these relationships (Coad/Rao 2008). Using quantile regression techniques, the specific conditional quantiles θ of extremely growing firms can be analysed explicitly (Chernozhukov 2005). That means, we identify those factors that stimulate highly expanding ($\theta_{0.90}$) and highly shrinking firms ($\theta_{0.10}$). Results are compared with the median firm ($\theta_{0.50}$). For the sake of completeness, we also estimate the model for $\theta_{0.25}$ and $\theta_{0.75}$.

Two further features make quantile regression techniques suitable to study the growth dynamics of firms (Buchinsky 1998). First, it is not sensitive to outliers on the dependent variable. This is especially relevant here, because the previous analysis of the stochastic properties highlights the high frequency of extreme growth events which would strongly influence OLS estimates. Secondly, no distributional assumption on the error term is made. Thus, quantile regression techniques are more appropriate to study heavy-tailed phenomena than regression techniques, which assume normal distributed errors (Coad/Hölzl 2009). Technical details are well described amongst others in Koenker and Bassett (1978), Koenker and Hallock (2001), and Buchinsky (1998).[16] Here we only want to point out that the coefficient estimates can be interpreted in the same way as OLS regression coefficients, more precisely as a partial derivate of the conditional quantile of the dependent variable $g_{i,t}$ with respect to particular independent variables $x_{i,t}$, $\delta Q_{\theta}(g_{i,t}|x_{i,t})/\delta x$ (Yasar et al. 2006). This derivative is nothing else than the impact of a one-unit change of an independent variable on the firms' growth rate at the θth quantile holding all other variables fixed (Koenker/Hallock 2001). However, it is important to note that the distance decay functions are optimized for each conditional quantile θ separately, which implies that differences in the estimates of the external factors along different θ cannot be readily interpreted.

5 Empirical Evidence and results

After briefly touching the most interesting findings in respect to the control variables, in the following subsections we discuss the results according to our hypotheses that have been set up in chapter 2 and present within each section only the relevant parts of the results. The complete regression results are reported in Tables X2 and X3 (in the appendix). Before starting the discussion, a general remark regarding the quantiles has to be made. Here, the estimates at $\theta_{0.25}$ and $\theta_{0.75}$ mostly show similar signs and p-values like either the estimates at $\theta_{0.50}$ or at $\theta_{0.10}$ / $\theta_{0.90}$, respectively. That means, only little additional insights can be obtained from their analysis. Therefore, we exclusively focus, unless otherwise stated, on highly growing ($\theta_{0.90}$), medium growing ($\theta_{0.50}$) and highly shrinking ($\theta_{0.10}$) firms.

5.1 Control variables

In line with current literature on firm growth, we observe a relationship of growth rates on firms' size, age and past year's growth rate. Negative coefficients for *SIZE*, which overwhelmingly appear, suggest that growth rates tend to decline with firm size, even viewed within narrower size classes. One deviation from this relationship is found: small firms that experience a strong decrease in employment (lower quantiles at $\theta_{0.10}$ and $\theta_{0.25}$) show a positive relationship, implying that especially small firms are hit by strong decreases in employment. Firms' *AGE*, which has only been rarely studied in the literature, is also negatively associated with firm growth, in particular for the upper quantiles of at $\theta_{0.75}$ and $\theta_{0.90}$. This means that if a firm gets older, its likelihood to experience extreme positive growth events is strongly reduced. Regarding serial autocorrelation, a negative sign for *G_t1* (past year's growth rate) is widely observed. This holds especially true for the upper and lower quantiles, suggesting that extreme growth events are a rather unique event in the firms' history. Interestingly, some positive serial autocorrelation is found for turnover growth. Whereas employment growth is lumpy by nature and other adjustment mechanisms seem to work after the employment number has changed once, a sustainable growth path is more probable regarding turnover. This is only one of many differences between the two alternative size measures, which obviously follow different growth logics. Therefore, we discuss each of them separately in what follows.

EXP, in general, shows a positive relationship with firm growth. This means that exporting activities are an essential element in increasing the potential of growth. This positive relationship is more frequently found for median and highly growing firms, especially in case of turnover growth, while it is never found for shrinking firms. High exports seem to offer growth economic opportunities, but are not helpful to avoid extreme negative growth events. Some negative, however not significant, coefficients even suggest the opposite. In contrast to export activities, *IMP* is less relevant to firm growth. Small firms, which rely to a higher degree on import activities from international markets, tend to be even more likely to experience a reduction of their employment number.

KI (dummy for the knowledge intensity of the corresponding industry) is a further decisive internal factor. Firms that belong to knowledge intensive industries, possess higher growth prospects. Estimates are larger for turnover compared to employment growth and in the former case consistently

[16] Standard errors are estimated using bootstrapping techniques. In line with Koenker and Hallock (2001), we only detected negligible small discrepancies between various available methods.

increase by moving up the quantiles. This indicates that firms belonging to knowledge intensive industries are more able to unfold a high turnover growth dynamic, but are not protected from strong downturns. Coefficients become even negative, however not significantly, at $\theta_{0.10}$. This result emphasizes the more volatile nature of the respective industries.

Besides the firm specific factors, we controlled for the general regional environment. *POP*, a general measure of urbanization effects, is accompanied in all significant cases by a negative sign, putting forward traditional New Economic Geography arguments that more densely populated areas are associated with higher capital input costs (labour and intermediate products) and thus may hamper firm growth. With exception of small firms, negative urbanization effects are more pronounced for the median growing firms at $\theta_{0.50}$: price competition becomes less relevant during phases of high growth and more densely populated areas tend to buffer extreme negative growth shocks. As expected, *UR* primarily seems to reflect structural differences between East and West Germany. Some tendency to catch up can be observed for East Germany's firms in terms of turnover. However, this convergence process does not occur in terms of the firms' employment number, which means that the unemployment rate in East Germany is a highly persisting phenomenon.

5.2 The impact of other related firms (*hypothesis 1*)

Hypothesis 1 proposes that firms benefit from being located in proximity to other related firms, however depending on the degree of relatedness. Regression results for the respective firms-specific agglomeration variables are reported in Table 4 for the different subsamples.

Table 4 Regression results for the impact of other firms

size	small [10, 50)			medium [50, 250)			large [250, 1000)		
quantile	**0.10**	**0.50**	**0.90**	**0.10**	**0.50**	**0.90**	**0.10**	**0.50**	**0.90**
sample	**Employment growth**								
AGGL_4	-0.017	-0.094	**0.038***	-0.325	-0.001	**1.289***	1.360	0.012	31.597
AGGL_3	0.002	0.012	0.005	7.562	-0.002	-0.159	-2.515	-0.011	-0.952
AGGL_2	0.006	0.003	-0.005	-5.680	**0.002***	0.027	**2.411***	0.003	-2.804
sample	**Turnover growth**								
AGGL_4	0.155	**0.055***	0.028	5.928	-2.098	0.034	**-1.095***	**-5.156***	**-11.598***
AGGL_3	**-0.216****	-0.017	0.005	-2.361	-1.186	-0.009	-0.513	4.290	5.705
AGGL_2	**0.043***	0.013	0.017	-4.269	**0.780****	**0.033*****	**0.146***	0.258	1.125

The most apparent observation is that the degree of relatedness strongly matters for the impact of agglomeration on firm growth. More precisely, *AGGL_4*, which represents the firm-specific agglomeration variable at the highest level of relatedness, only is positively correlated with employment growth at the highest quantile (for large firms at $\theta_{0.75}$). This clear pattern suggests that being located in proximity with other firms of the same 4-digit industry has in general no impact on employment growth, but that the highly growing firms are especially found among the firms that have many other firms from the same 4-digit industry nearby. High growth events seem to be more likely within agglomerations on the highest level of relatedness. Regarding turnover growth, firm size assumes a pivotal role. Whereas large firms are strongly hampered by such highly specialized agglomerations, their full potential unfolds on small firms at $\theta_{0.50}$ and $\theta_{0.75}$. Firms from the medium size class, in contrast, are not affected. Connecting the results for employment and turnover growth, we might conclude the following: Very fast increases in employment are only possible in a very specialised surrounding which is able to provide the necessary qualified labour. In principle, however, the small firms are those that benefit from a narrowly specialised surrounding, while such a surrounding is unattractive for large firms.

For *AGGL_3*, the intermediate level of relatedness, coefficients tend to be negative, however only in two cases significant (employment growth of medium sized firms at $\theta_{0.75}$ as well as turnover growth of small firms at $\theta_{0.10}$). In spite of or just because of a lacking relationship, this result is of special interest – it contradicts the widespread notion that *neither too much, nor too little specialization* would be most conducive for growth.

In contrast, *AGGL_2* is positively correlated with firm growth. This holds especially true in respect to turnover growth and at the lower quantiles of highly shrinking firms. Consequently, being located in proximity to rather diverse and dissimilar, but yet related firms reduces the risk of experiencing extreme negative growth shocks. This phenomenon can be observed for large and small firms (for turnover growth of small firms only significant at $\theta_{0.25}$), but not for medium sized firms, for which the impact of a diverse agglomeration is significantly positive at $\theta_{0.10}$, and, in case of turnover growth, also at high growth quantiles.

To conclude, we partially confirm *hypothesis 1*: only certain firms, depending on the size class and growth level under consideration, might benefit from being located in proximity to other related firms. However, it seems to be the more broadly related activities (2-digit level) that firms benefit from. Narrowly specialised surroundings are only helpful for small firms, but reduce the growth of large firms.

5.3 The impact of universities (*hypothesis 2*)

Hypothesis 2 argues that firms benefit from being located in proximity to universities, however depending on universities' functional roles. Estimation results are reported in Table 5. At first glance, the impact of universities seems to be complex and at times contradictory. Therefore, one has to disentangle the effects and focus on their different functional roles, which basically consist of education and research.

Table 5 Regression results for the impact of universities

size	small [10, 50)			medium [50, 250)			large [250, 1000)		
quantile	**0.10**	**0.50**	**0.90**	**0.10**	**0.50**	**0.90**	**0.10**	**0.50**	**0.90**
sample	**Employment growth**								
UNIV_bud	4.5E-4	-2.3E-4	-0.001	**2.7E-4****	**2.9E-5****	**-0.001****	1.4E-4	**7.0E-5****	6.1E-5
UNIV_gra	0.002	0.001	**-0.018*****	-0.001	-2.4E-4	4.9E-4	-0.002	4.2E-5	-0.010
UNIV_res	0.162	-0.039	0.041	-0.065	0.001	**-0.243****	**0.154****	-0.014	0.644
sample	**Turnover growth**								
UNIV_bud	**-1.3E-4****	**-1.1E-4****	0.002	4.2E-6	-2.1E-5	-0.001	-9.7E-5	**-1.6E-4***	-1.4E-5
UNIV_gra	**0.004***	3.2E-4	-0.012	**0.007*****	**0.004*****	0.005	3.1E-4	**0.003***	**0.004*****
UNIV_res	0.098	0.040	-0.026	0.094	**0.072****	0.113	**0.378*****	**0.168*****	-0.030

As a general measure of the distance weighted impact of universities' activities serves their financial budget. In case of employment, *UNIV_bud* is strongly related with the growth of medium sized firms. If these firms are located nearby universities, extreme (positive and negative) growth events become less likely. We might conclude that universities offer medium sized firms options to deal with crises. At the same time, they do not help these firms to become fast-growing. Rather the opposite: medium-sized firms rarely increase their employment strongly if universities are around. For larger firms, a positive impact is found at $\theta_{0.50}$ and no impact is found for small firms. This is in line with the argument that medium and large firms require nearby universities for qualified labour, meaning for increasing their labour force. In case of turnover growth, we find similar, but no longer significant, effects for the medium-sized firms. However, for small and large firms the findings are very different. For these firms, the presence of universities is generally associated with a negative effect on turnover. We observe for small firms a higher vulnerability to extreme negative growth events, which might indicate that small firms, located in areas with a strong university infrastructure, are more innovative and, hence, fluctuate more in their turnover growth. Why larger firms are growing less if universities are nearby is rather unclear.

UNIV_grad provides information about the universities' relative strength in the education function. Let us first consider the median quantile. The results strongly vary with the two size measures. In general, we do not find any strong relationship between the education function and employment growth for the median quantile. In contrast, an over-proportional number of graduates is strongly related to turnover growth for medium sized and large firms. Hence, in line with suggestions in the literature, larger – or at least not small – firms benefit from nearby education of highly qualified labour. In the context of extreme growth events, we find a number of positive relationships at the lower quantiles of turnover growth (for small firms at $\theta_{0.10}$, for large firms at $\theta_{0.25}$, for medium sized firms at both $\theta_{0.10}$ and $\theta_{0.25}$), implying that university education makes nearby firms less vulnerable with respect to extreme negative turnover growth events. On the other end ($\theta_{0.90}$) we obtain mixed results, mainly depending on the firms' size. Being located in proximity to high university education activities, small firms seem less likely to experience strong (employment) growth, while large firms seem to be more likely to experience strong growth. This supports the above findings that especially large firms need a high number of nearby university graduates to be able to increase their labour force strongly.

The complementary measure of universities' relative strength in the research function, *UNIV_res*, reveals that research specialization can be regarded as an important success factor for turnover growth. Here the firms' size comes into play again. Although there is some indication (at $\theta_{0.75}$) that small firms rely on new scientific knowledge in order to succeed economically, research in nearby universities becomes utmost relevant for medium sized and large firms. This might suggests that only large firms systematically source and also have to absorptive capacity for external (scientific) knowledge in order to complement internal knowledge generation processes. In case of large firms, in addition significantly positive coefficients are observed at the lower quantiles ($\theta_{0.10}$ and $\theta_{0.25}$). This holds also in case of employment growth at $\theta_{0.10}$ and hence confirms again the risk reducing character of nearby universities. Finally, a single exception from the general positive impact is found for employment growth of medium sized firms: these firms are less likely to experience extreme decline if the universities around are research-intensive. An explanation for this finding requires more research on the topic. In short, *hypothesis 2* is partially confirmed provided that one considers the functional roles played by universities as well as the firms' characteristics.

5.4 Spatial range and functional form of impact (*hypothesis 3*)

Hypothesis 3 proposes that the spatial range and functional form of the impact of external factors on firm growth depend on the type of external knowledge source and the characteristics of the firms under consideration. Table 6 displays the estimated parameters for the best fitting distance decay function. Those parameters, where the corresponding variables are not significant at least on 5%, are consequently excluded from the analysis and placed into brackets.

Table 6 Estimated distance decay function parameters for all quantiles

size	small [10, 50)					medium [50, 250)					large [250, 1000)				
quantile	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**
sample	**Employment growth**														
r AGGL	(300)	150	(30)	(5)	300	(5)	(250)	300	15	30	5	(10)	(300)	300	(5)
s AGGL	(13)	13	(13)	(8)	13	(13)	(13)	1	13	13	2	(2)	(1)	13	(8)
r UNIV	(10)	(120)	(10)	250	10	300	300	300	45	15	45	(300)	300	(90)	(10)
s UNIV	(2)	(13)	(13)	13	1	1	1	1	13	2	13	(1)	1	(8)	(13)
sample	**Turnover growth**														
r AGGL	90	(150)	120	200	(200)	(5)	(15)	15	300	300	60	60	10	200	(10)
s AGGL	13	(13)	13	13	(13)	(13)	(3)	13	1	1	13	13	13	13	(13)
r UNIV	300	(300)	300	300	(5)	300	300	300	300	(10)	300	300	300	300	200
s UNIV	1	(1)	1	1	(13)	1	1	1	1	(13)	1	1	1	2	13

The steepness parameter *s* gives the shape of the distance decay function. The most clear result is that the two extreme parameter values, 1 and 13, occur most frequently. We find two standard cases of decay functions and only three cases that do not fit these standard categories. We ignore the exceptions and discuss the two standard cases:

1) The value 1 represents the exponential decay function and is in 17 out of 20 cases accompanied by the largest possible range, denoted by *r*, of 300 minutes. This combination implies an impact that is slowly and constantly decreasing with distance: a distance of 300 travel minutes implies half the impact than being located just next door. We find this decay function four times for small firms (40%

of the significant cases in this size class), ten times for medium-sized firms (67%) and six times for large firms (46%). This supports the view in the literature that smaller firms are less able to bridge distances. Furthermore, this decay function occurs 15 times in the context of university (71%) and only five times (29%) in the context of related firms. This confirms previous research insofar as research collaboration seems to occur over longer distances than other knowledge diffusion mechanisms like labour mobility or spin-offs (e.g., Ponds et al. 2010). Since in these cases economic distances do not matter much at all, it does not make any sense to specify regional boundaries, neither for empirical researchers nor for policy makers.

2) A parameter *s* of 13 suggests that there exists a clear threshold distance where the impact of external knowledge sources abruptly declines. We find 17 cases with *s=13*. This kind of decay function confirms the behavioural assumption that distance matters and actors differentiate strongly between the categories 'nearby' and 'distant', which implies an importance and clear definition of regional boundaries from the firms' perspective. However, the threshold distance covers the full spectrum of possible distances (see Table 7). The range of the nearby region depends on several aspects that will be discussed in the following.

However, first of all, this kind of decay function is dominantly found for the impact of other firms (13 out of 17 cases), while the decay functions are more heterogeneous in the case of universities (4 out of 21 cases). Hence, we obtain especially evidence for the fact that spillovers between firms have a certain range within which they work much better than beyond. Since the findings for universities are so few, we focus on the interaction between firms. For large firms we find all kinds of range parameters *r* between 10 and 300. Hence, as the literature suggests, large firms are able to interact also over larger distances. The ranges found for medium-sized firms, instead, are 15 and 30 minutes, implying that these firms have a smaller range in which they interact. Surprisingly, large ranges are also found for the small firms. This finding requires further research.

Table 7 Frequency of range parameter *r* in cases of an abruptly decreasing decay function (*s=13*)

Range r	**5**	**10**	**15**	**30**	**45**	**60**	**90**	**120**	**150**	**200**	**250**	**300**
Frequency	0	1	2	1	2	2	1	1	1	3	1	2

To conclude, *hypothesis 3* is confirmed insofar as the spatial range and functional form of knowledge spillovers depend on the kind of external knowledge source and characteristics of the receiving firms. Whereas in some cases spillovers remain constrained to a narrow local range of a few minutes (mostly in cases of the impact of other firms), in other cases they transcend traditional regional boundaries – in particular the impact of universities tend to be a supra-regional phenomenon. These results questions the capability of the concept of regions to account for knowledge spillover – regions, as usually delimited, are either defined too large or too small. At the same time, no universal valid specification for the distance decay function, which describes the spatial impacts of external knowledge sources on firm growth, is identified. This means that decay functions should not be specified *a priori*, but allowed to be determined endogenously by the data as it was done in the present approach.

6 Conclusion

Being a well-studied issue in economic geography and regional sciences, spatial knowledge spillovers have been largely neglected in literature on firm growth. With this research, we contributed on the one hand to the latter by analysing the impact of external knowledge sources like (technologically) related other firms as well as universities. On the other hand, we also contributed to the former by using a more realistic approach to assess the spatial range and functional form of growth relevant knowledge spillovers.

As main findings of our analysis it can be stated that both other related firms and universities are associated with firm growth. However, to assess their complex relationships, it is indispensable to distinguish between different degrees of relatedness and to disentangle the functional roles played by universities. Moreover, it is revealed that the impact of external knowledge sources depends fundamentally on firms' size and that it varies between median (or only slightly) growing, highly shrinking and highly expanding firms. More precisely, we found that a highly specialized agglomeration rather hampers growth of large firms, but boosts the growth of small firms. Being located in proximity to more diverse, but yet related firms is conducive for both small and large firms and especially reduces the risk of extreme negative growth shocks. Differences between the two alternative firm size measures, employment and turnover, become particularly visible with respect to the impact of universities. Universities' education activities make nearby firms less vulnerable to extreme negative turnover growth events. At the same time, graduates increase the growth potential for large firms in case of turnover, but not in case of employment. Furthermore, the empirical results suggest that firms require a certain size and thus absorptive capacity to be able to benefit from universities' research activities. Nearby research activities tend to have a strong risk reducing character regarding large firms. However, in this paper we not only focus on the magnitude of the impact of external factors, but also on its spatial range and functional form. In general, heterogeneous distance decay functions emerges with differences regarding the firms' size and the kind of external knowledge source. For instance, the impact of universities tend to extend to a wider range than the impact of other firms, which in some cases remains constrained to a narrow local range of few minutes. On the basis of both theoretical reasoning and empirical evidence we reject the use of spatial aggregates like regions to study spatial phenomena such as knowledge spillovers. Instead, we plead for directly looking at the geolocation of truly acting micro-entities and for a more realistic conception of space: it is the economic distance, which affects the entities' behaviour, however differently at different geographical scales.

For future research five major challenges are identified. First, additional external knowledge sources, like public research institutes, can be included. Secondly, although firms' age has shown to be strongly related to firm growth, the empirical literature mostly neglects or incorrectly substitutes it by size. We expect that impact of external knowledge sources also depends on the firms' age, however more work has to be done on identifying reasonable age groups. Thirdly, firms of different industries could be analysed separately, because there are strong reasons to assume that the spatial range and functional form of knowledge spillovers differ substantially across various industries (Bishop 2008). Fourthly, more sophisticated matrices should be used to assess true technological relatedness. Here we rely on a simple hierarchical approach, even though recent advances in the literature show that this might not be enough to fully tackle the technological dimension of relatedness. Foremost Eriksson (2011) argues that the degree of relatedness matters in respect to the spatial range of knowledge spillovers. Finally and due to the heavy-tailed nature of firm growth, it would complement our study to estimate a model based on the Subbotin distribution, which is able to account properly for the stochastic characteristics of the observed, but can so far not be combined with the idea to study various quantiles separately.

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Table X1 Descriptive statistics

		samples' mean and standard deviation						*Spearman correlation coefficient (average across samples)* [1]													
		Employment growth			**Turnover growth**																
		small	medium	large	small	medium	large	*(log) SIZE*	*AGE*	*G_t1*	*IMP*	*EXP*	*KI*	*POP*	*UR*	*AGGL_2*	*AGGL_3*	*AGGL_4*	*UNIV_bud*	*UNIV_gra*	*UNIV_res*
(log) SIZE	mean	3.078	4.555	5.978	8.005	9.562	11.212	-	0.09	-0.12	-0.03	0.13	0.01	0.02	-0.05	-0.07	-0.03	-0.04	0.03	0.02	0.02
	sd	0.524	0.545	0.517	0.807	0.816	0.744														
AGE	mean	28.487	35.646	41.047	28.652	35.398	40.702		-	-0.12	-0.06	0.00	-0.07	0.11	-0.18	0.00	0.03	0.07	0.04	0.08	0.08
	sd	22.595	25.230	27.330	22.963	25.271	27.320														
G_t1	mean	0.028	0.022	0.019	0.076	0.082	0.084			-	0.02	0.03	0.05	-0.04	-0.01	0.01	0.01	0.01	0.03	-0.02	-0.01
	sd	0.260	0.291	0.440	0.257	0.346	0.426														
IMP	mean	11.347	8.279	5.243	11.999	8.534	5.243				-	-0.07	-0.05	-0.01	-0.06	-0.01	-0.01	-0.01	-0.01	-0.01	0.00
	sd	24.753	20.695	15.291	25.269	20.850	14.887														
EXP	mean	28.274	35.558	45.996	28.109	35.481	45.915					-	0.23	0.06	-0.05	-0.04	-0.04	0.03	0.03	0.04	0.02
	sd	24.316	23.857	23.233	24.308	23.845	23.317														
KI	mean	0.404	0.409	0.480	0.395	0.403	0.485						-	0.07	-0.02	0.07	-0.12	0.02	0.03	0.00	-0.03
	sd	0.491	0.492	0.500	0.489	0.490	0.500														
POP	mean	405.188	367.134	352.966	412.589	369.775	356.555							-	0.03	0.19	0.15	0.26	0.24	0.05	0.13
	sd	348.450	319.757	289.470	354.253	321.565	288.678														
UR	mean	15.777	15.410	14.266	15.644	15.423	14.303								-	-0.03	-0.01	-0.02	-0.04	-0.31	-0.03
	sd	6.998	6.904	5.948	6.870	6.832	5.914														
AGGL_2	mean	0.004	0.003	0.078	0.121	0.096	0.077									-	0.20	0.34	0.07	0.01	0.02
	sd	0.008	0.006	0.131	0.187	0.152	0.128														
AGGL_3	mean	0.005	0.003	0.092	0.132	0.115	0.095										-	0.32	0.06	-0.01	0.05
	sd	0.014	0.009	0.176	0.312	0.248	0.186														
AGGL_4	mean	0.022	0.017	0.525	0.675	0.590	0.524											-	0.11	0.00	0.06
	sd	0.042	0.030	0.599	0.921	0.707	0.610														
UNIV_bud	mean	0.775	0.730	606.154	608.436	607.192	605.741												-	-0.23	0.26
	sd	3.895	3.741	54.351	47.955	52.906	55.106														
UNIV_gra	mean	0.000	0.025	-1.760	-2.069	-1.988	-1.727													-	0.16
	sd	0.762	0.773	2.809	2.809	2.810	2.813														
UNIV_res	mean	0.000	0.001	-0.055	-0.056	-0.057	-0.055														-
	sd	0.026	0.024	0.064	0.067	0.066	0.063														

[1] *Weighted average of Fisher's z-transformed correlation coefficients*

Table X2 Regression results on employment growth

	Employment growth														
size	**small [10, 50)**					**medium [50, 250)**					**large [250, 1000)**				
quantile	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**
SIZE	0.014**	0.045***	-0.052***	-0.071***	-0.179***	-0.051***	-0.013***	-0.014***	-0.049***	-0.120***	-0.059***	-0.026***	-0.022***	-0.054***	-0.124***
	(.009)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.004)	(.000)	(.000)	(.000)	(.000)
AGE	-1.6E-4	-3.4E-5**	-7.8E-5	-4.9E-4***	-0.001***	3.9E-5	-2.8E-5	-9.2E-5***	-4.9E-4***	-0.001***	7.0E-6	8.9E-5	-6.9E-6	-6.8E-5	-1.5E-4
	(.280)	(.002)	(.219)	(.000)	(.000)	(.740)	(.303)	(.000)	(.000)	(.000)	(.968)	(.095)	(.854)	(.423)	(.365)
G_t1	-0.056***	-0.003	-0.006	-0.038**	-0.190***	-0.039**	-0.008	-0.001	-0.012	-0.107***	-0.043	-0.018	-0.003	-0.030	-0.113**
	(.000)	(.108)	(.169)	(.001)	(.000)	(.002)	(.080)	(.623)	(.378)	(.000)	(.086)	(.051)	(.712)	(.067)	(.007)
IMP	-2.4E-4*	-1.0E-5	-9.2E-7	1.9E-5	-1.4E-4	-1.2E-4	-4.7E-5	1.9E-5	7.4E-5	7.0E-5	-0.001	-1.7E-4	1.4E-5	-1.6E-5	3.4E-4
	(.025)	(.382)	(.929)	(.740)	(.357)	(.481)	(.135)	(.446)	(.338)	(.657)	(.122)	(.261)	(.871)	(.942)	(.536)
EXP	1.6E-5	7.0E-6	2.0E-5	2.4E-4***	0.001***	2.0E-4	1.3E-5	4.0E-5	6.6E-5	1.4E-4	4.7E-5	1.1E-4	1.4E-4*	1.5E-4	1.2E-4
	(.874)	(.503)	(.107)	(.000)	(.000)	(.065)	(.694)	(.069)	(.254)	(.233)	(.842)	(.131)	(.015)	(.216)	(.594)
KI	0.013*	0.001	4.1E-4	0.005	-0.003	0.016**	0.005***	0.005***	0.010***	0.008	0.007	0.011***	0.011***	0.023***	0.032**
	(.010)	(.082)	(.421)	(.126)	(.728)	(.006)	(.000)	(.000)	(.001)	(.159)	(.516)	(.000)	(.000)	(.000)	(.002)
POP	5.2E-6	3.2E-8	-9.7E-7	-1.6E-5***	-3.0E-5*	-4.9E-6	-4.3E-7	-4.3E-6***	-1.7E-5**	-2.7E-5*	-4.3E-5	-2.2E-5**	-1.0E-5*	-1.4E-5	-2.1E-5
	(.409)	(.969)	(.354)	(.000)	(.011)	(.694)	(.841)	(.000)	(.001)	(.021)	(.101)	(.004)	(.010)	(.151)	(.215)
UR	-2.0E-4	-2.4E-5	1.5E-6	-2.8E-4	-0.001	-0.001	-1.1E-4	-1.9E-5	1.1E-4	0.001	-0.003**	-0.001	2.0E-5	-2.0E-4	1.2E-4
	(.604)	(.593)	(.975)	(.304)	(.382)	(.300)	(.458)	(.820)	(.664)	(.092)	(.002)	(.069)	(.941)	(.684)	(.890)
AGGL_4	-0.017	-2.2E-4	-0.094	-1.656	0.038*	-0.325	-0.006	-0.001	0.064	1.289*	1.360	0.825	0.012	0.028*	31.597
	(.190)	(.945)	(.500)	(.265)	(.042)	(.959)	(.210)	(.819)	(.957)	(.024)	(.807)	(.324)	(.267)	(.039)	(.178)
AGGL_3	0.002	-0.003	0.012	2.026	0.005	7.562	-0.003	-0.002	-1.979*	-0.159	-2.515	-0.753	-0.011	-0.012	-0.952
	(.826)	(.332)	(.764)	(.183)	(.722)	(.344)	(.380)	(.288)	(.015)	(.738)	(.568)	(.227)	(.083)	(.249)	(.967)
AGGL_2	0.006	0.002*	0.003	-0.720	-0.005	-5.680	0.002	0.002*	0.647	0.027	2.411*	0.282	0.003	0.001	-2.804
	(.150)	(.025)	(.841)	(.173)	(.281)	(.067)	(.069)	(.025)	(.082)	(.786)	(.041)	(.144)	(.082)	(.810)	(.463)
UNIV_bud	4.5E-4	-6.3E-6	-2.3E-4	5.3E-6	-0.001	2.7E-4**	6.5E-5**	2.9E-5**	-1.6E-4**	-0.001**	1.4E-4	5.4E-5	7.0E-5**	-1.1E-4	6.1E-5
	(.314)	(.140)	(.595)	(.718)	(.079)	(.004)	(.002)	(.005)	(.009)	(.007)	(.627)	(.259)	(.015)	(.111)	(.989)
UNIV_gra	0.002	-1.0E-4	0.001	-0.001***	-0.018***	-0.001	-0.001	-2.4E-4	-6.0E-4	4.9E-4	-0.002	-0.001	4.2E-5	-0.001	-0.010
	(.532)	(.078)	(.624)	(.000)	(.000)	(.656)	(.191)	(.224)	(.253)	(.863)	(.210)	(.187)	(.938)	(.053)	(.262)
UNIV_res	0.162	0.001	-0.039	0.015	0.041	-0.065	-0.015	0.001	-0.011	-0.243**	0.154**	0.020	-0.014	-0.024	0.644
	(.177)	(.284)	(.565)	(.099)	(.751)	(.179)	(.189)	(.883)	(.505)	(.008)	(.007)	(.427)	(.416)	(.127)	(.215)
Distance decay function parameter															
r AGGL	(300)	150	(30)	(5)	300	(5)	(250)	300	15	30	5	(10)	(300)	300	(5)
s AGGL	(13)	13	(13)	(8)	13	(13)	(13)	1	13	13	2	(2)	(1)	13	(8)
r UNIV	(10)	(120)	(10)	250	10	300	300	300	45	15	45	(300)	300	(90)	(10)
s UNIV	(2)	(13)	(13)	13	1	1	1	1	13	2	13	(1)	1	(8)	(13)

*p-values in parentheses (*** p<0.001, ** p<0.01, * p<0.05)*

Table X3 Regression results on turnover growth

	Turnover growth														
size	**small [10, 50)**					**medium [50, 250)**					**large [250, 1000)**				
quantile	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**
SIZE	**-0.015****	-0.001	-0.002	**-0.010*****	**-0.031*****	**-0.028*****	**-0.004*****	0.001	**-0.011*****	**-0.035*****	**-0.025****	-0.007	**-0.008***	**-0.012***	**-0.028***
	(.008)	(.123)	(.432)	(.000)	(.000)	(.000)	(.001)	(.499)	(.000)	(.000)	(.007)	(.091)	(.026)	(.042)	(.011)
AGE	-4.6E-5	-2.3E-5	**-4.9E-4*****	**-0.001****	**-0.002*****	2.2E-4	-3.7E-5	**-3.1E-4*****	**-0.001*****	**-0.001*****	1.7E-4	1.7E-5	-7.6E-5	**-3.8E-4*****	**-0.001****
	(.780)	(.319)	(.000)	(.000)	(.000)	(.112)	(.193)	(.000)	(.000)	(.000)	(.394)	(.848)	(.356)	(.000)	(.003)
G_t1	**-0.100*****	-0.005	**0.029***	0.018	-0.040	-0.024	0.008	**0.019****	0.002	**-0.050*****	-0.009	-0.001	-0.012	-0.027	-0.078
	(.000)	(.352)	(.013)	(.183)	(.082)	(.127)	(.069)	(.007)	(.868)	(.000)	(.821)	(.968)	(.422)	(.301)	(.362)
IMP	-2.1E-4	-2.3E-5	9.8E-5	**3.1E-4****	**0.001***	-2.2E-6	1.7E-5	**2.5E-4****	**2.8E-4****	1.6E-4	2.1E-5	-1.8E-4	-1.3E-4	-1.2E-4	-0.001
	(.104)	(.564)	(.115)	(.003)	(.027)	(.989)	(.669)	(.005)	(.002)	(.307)	(.955)	(.326)	(.278)	(.605)	(.123)
EXP	-2.0E-4	1.0E-6	2.9E-5	**3.8E-4*****	**0.001*****	-6.8E-5	-4.3E-5	-5.1E-5	**1.9E-4***	**4.2E-4***	-3.7E-4	-1.4E-4	**2.0E-4***	**3.5E-4***	**0.001****
	(.217)	(.926)	(.641)	(.000)	(.000)	(.667)	(.165)	(.461)	(.042)	(.011)	(.138)	(.303)	(.031)	(.038)	(.003)
KI	-0.004	0.001	**0.007***	**0.021*****	**0.051*****	-4.5E-4	0.003	**0.017*****	**0.027*****	**0.039*****	-0.011	0.007	**0.023*****	**0.030*****	**0.026***
	(.634)	(.190)	(.024)	(.000)	(.000)	(.955)	(.077)	(.000)	(.000)	(.000)	(.314)	(.177)	(.000)	(.000)	(.024)
POP	5.3E-6	-1.5E-6	**-1.2E-5****	**-2.8E-5*****	**-4.9E-5*****	-1.2E-5	**-4.9E-6***	**-2.4E-5*****	**-3.2E-5*****	-1.6E-5	-2.2E-5	**-2.5E-5***	**-2.9E-5****	**-5.0E-5*****	**-5.9E-5****
	(.632)	(.315)	(.004)	(.000)	(.000)	(.300)	(.044)	(.000)	(.000)	(.183)	(.381)	(.026)	(.004)	(.000)	(.007)
UR	**0.001***	2.1E-4	**0.001*****	**0.001****	**0.003*****	**0.002****	**0.001*****	**0.003*****	**0.004*****	**0.003*****	-2.2E-4	**0.002****	**0.004*****	**0.005*****	**0.008*****
	(.018)	(.113)	(.000)	(.010)	(.001)	(.006)	(.000)	(.000)	(.000)	(.000)	(.868)	(.001)	(.000)	(.000)	(.000)
AGGL_4	0.155	0.005	**0.055***	**0.059****	0.028	5.928	-0.480	-2.098	0.001	0.034	**-1.095***	-0.502	**-5.156***	0.015	**-11.598***
	(.079)	(.286)	(.043)	(.006)	(.424)	(.531)	(.103)	(.084)	(.963)	(.298)	(.044)	(.097)	(.045)	(.655)	(.025)
AGGL_3	**-0.216****	-0.008	-0.017	0.002	0.005	-2.361	-0.023	-1.186	-0.015	-0.009	-0.513	-0.149	4.290	-0.033	5.705
	(.002)	(.200)	(.459)	(.895)	(.862)	(.788)	(.911)	(.121)	(.255)	(.617)	(.134)	(.334)	(.129)	(.123)	(.229)
AGGL_2	**0.043***	0.002	0.013	0.008	0.017	-4.269	0.046	**0.780****	**0.022*****	**0.033*****	**0.146***	**0.091***	0.258	**0.017***	1.125
	(.046)	(.232)	(.119)	(.109)	(.069)	(.093)	(.479)	(.002)	(.000)	(.000)	(.026)	(.024)	(.796)	(.024)	(.522)
UNIV_bud	**-1.3E-4****	-3.9E-6	**-1.1E-4****	**-1.6E-4***	0.002	4.2E-6	1.7E-5	-2.1E-5	-2.0E-5	-0.001	-9.7E-5	-9.5E-5	**-1.6E-4***	**-1.7E-4****	-1.4E-5
	(.005)	(.529)	(.003)	(.015)	(.612)	(.936)	(.109)	(.520)	(.668)	(.126)	(.339)	(.200)	(.023)	(.001)	(.813)
UNIV_gra	**0.004***	4.3E-4	3.2E-4	-0.002	-0.012	**0.007*****	**0.002*****	**0.004*****	**0.004*****	0.005	3.1E-4	**0.003****	**0.003***	**0.002****	**0.004*****
	(.019)	(.109)	(.712)	(.053)	(.710)	(.000)	(.000)	(.000)	(.000)	(.295)	(.914)	(.003)	(.013)	(.009)	(.000)
UNIV_res	0.098	0.006	0.040	**0.112****	-0.026	0.094	0.017	**0.072****	**0.100****	0.113	**0.378*****	**0.160*****	**0.168*****	0.049	-0.030
	(.125)	(.408)	(.075)	(.007)	(.966)	(.116)	(.270)	(.003)	(.007)	(.530)	(.000)	(.000)	(.000)	(.262)	(.418)
Distance decay function parameter															
r AGGL	90	(150)	120	200	(200)	(5)	(15)	15	300	300	60	60	10	200	(10)
s AGGL	13	(13)	13	13	(13)	(13)	(3)	13	1	1	13	13	13	13	(13)
r UNIV	300	(300)	300	300	(5)	300	300	300	300	(10)	300	300	300	300	200
s UNIV	1	(1)	1	1	(13)	1	1	1	1	(13)	1	1	1	2	13

*p-values in parentheses (*** p<0.001, ** p<0.01, * p<0.05)*

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