Innovation-economic and Spatial Aspects of Firm Growth – The Contribution of Internal and External Factors

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Innovation-economic and Spatial Aspects of Firm Growth – The Contribution of Internal and External Factors

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Abstract

This thesis is explorative in nature. Based on empirical investigations of different research fields (i.e. Geography and Economics), it analyses firm growth in terms of factors and sources that come internal and external to firms. This book deals with the integration of different growth related dimensions, in particular with factors and knowledge sources for investigating and analysing growth processes of firms. Firm growth is important for the economic competitiveness and technological progress as well as for the regional development. Therefore, it can be considered as a heterogeneous process with high complexity and idiosyncratic characteristics. This idiosyncrasy is partially caused by the high number of dimensions, growth factors and knowledge sources which are basically involved in the growth process. An important purpose of this doctoral thesis is to combine different key dimensions and determinants of the firm growth process. Within this multidimensional concept, various growth factors and knowledge sources appear which potentially contribute to the growth of firms. In order to analyse and improve the understanding of the growth process itself, it is distinguished between internal and external growth factors and knowledge sources that might influence firm growth. An example of the combination of these key dimensions and growth factors is the usage and consideration of knowledge sources that are internal or external to firms. It has been discussed that these determinants of the growth process can influence or even complement each other. Nevertheless, these determinates have often been analysed separately and literature concerning how to combine them is (still) limited. The domain of firm growth and its growth determinants is considered complex since the growth process is characterised by many factors and sources influencing each other. It aims at particularly highlighting the issue of agile relationships between space, time and economic interactions. The space centred geography developed specific models of space, but has been largely neglected the spatial and temporal features of economic interactions. Economic interactions were understood as a 'Black-box-concept' without any further information (e.g. Werlen 2000). Then, the 'Black-box' comprises deterministic assumption understanding space as homogenous entity (see Petersen 1944). Contrarily to the deterministic belief, this work understands economic features and relationships as realistic and relational operations, using space and time as agile issues of economic interactions. A multidimensional investigation and evaluation for exploring growth factors, knowledge sources and the activities involved in the growth process of firms is therefore developed, and problems and obstacles are studied.

Moreover, firm growth can be considered as a process depending on interrelated growth factors and knowledge sources that influence and complement each other. Thus, firms operate in environments over which they might have full, or at least, partial influence. These environments are usually probabilistic with the effect that firm "growth results from adaptive search over a probabilistic fitness landscape with stochastic attractors" (Lee and Harrison 2001: p. 115). Hence, firms cannot expect the same output each time they process the same inputs. An important result of this property of the probabilistic approach is that firms operate in a multidimensional setting and environment where various growth-related factors and knowledge sources are embedded. An important result of this property of the probabilistic approach is that firms operate in a multidimensional setting and environment where various growth-related factors and knowledge sources are embedded. The following more suitable definition was provided by Alex Coad (2009 p: 110): "Firm growth is indeed a multifaceted phenomenon, it has a strong idiosyncratic character, and as a result it is difficult to generalise across firms and circumstances." None of these theories and empirical studies can provide a comprehensive explanation of the different key dimensions of firm growth. Moreover, different key dimensions of firms' growth processes can be revealed, reflecting the fact that

firm growth is driven by heterogeneity and complexity. A multidimensional concept of firm growth might be defined as a complex system containing a set of different dimensions and growth related factors which interact with or complement each other in order to reach their respective goal (e.g. employment growth, innovativeness). This thesis contributes to the existing knowledge by determining three different key dimensions of firms' growth processes: temporal, spatial and organisational dimensions. Additionally, literature mostly distinguishes between the firms' growth characteristics in terms of firm-internal growth (i.e. innovation effort, export orientation) and in terms of firm-external growth factors (e.g. Acar 1993). Generally speaking, the author argues that internal resources are neither sufficient nor adequate to achieve efficiency and firm growth. By contrast, for most firms a wide range of external factors is also relevant. Consequently, region-specific characteristics and their spatial relatedness engender differences in the way firms grow, and may be seen as substantial drivers for firm growth (e.g. universities, other firms, population, knowledge intensive business services).

More precise, firm growth has many growth stimulation factors and sources. Some of them are analysed in this book. A multidimensional approach of the firms' growth process is introduced. It is shown that a multidimensional consideration of the firms' growth process is of high importance because a multiplicity of interrelated factors and sources influence firm growth. This thesis captures aspects of time, space and organisations, and deals with the mixing of these dimensions. The detailed insight into 'unknown' factors, interrelationships and linkages is a great benefit in the explanation of the structure and procedure of firm growth processes. Generally speaking, this work allows for a detailed insight into the distinction between firm-internal and firm-external factors and knowledge sources to growth and controls for 'stylized facts' such as firm size, firm age and industry affiliation grounded in the previous empirical literature. More precisely, this book contributes to the literature by favouring the linkages and interrelationships between them: First, it analyses the interrelationships between firm-internal growth factors (i.e. innovation effort and export orientation) and time. It investigates whether firm characteristics, which – in literature - are related to firm growth, are also related to the development path of firms. A major conclusion is that the determinants of growth paths are not the same as the determinants of firm growth at one point of time. Obviously, the temporal structure of the impact of growth related factors on firm growth matters. Furthermore strong interrelationships and linkages between them exist. It is analysed whether the factors, which are found to be related to firm growth in literature, are also related to the continuous growth of firms in the medium term. In literature, it is usually examined whether certain characteristics are related to a higher average growth rate. In this work it is studied whether these characteristics are also related to the probability of various development paths, such as permanent growth. Hence, in this paper, the perspective is moved from average growth to the structure of development paths. Changing the perspective does not change the results fundamentally but provides many additional insights. Furthermore, the thesis examines the time structure of the effects of R&D activities (i.e. firm-internal) on firm growth. Also, the discussion about whether R&D investments are connected to firm growth in the subsequent periods and how this relationship depends on other firm characteristics (for example size and industry) is stressed. One main result is that, on average, R&D has a positive effect on turnover growth, but the effect and its temporal structure strongly depends on firm size and industry affiliation. To put it differently, firm-internal factors do affect firm growth and the temporal structure matters hereby. The occurrence of growth in the short run is to be distinguished from growth development paths (long-run). They each serve as own pattern of explanation and have to be interpreted separately. Second, the analysis accomplished improves the understanding of the emerging complementarities between the involved factors and knowledge sources. Therefore, it deals with the existence and the emergence of complementarities and the spatial embeddedness into cooperation networks (i.e. cooperative and non-cooperative) over time. This work particularly contributes to the existing literature by differentiating between cooperative and non-cooperative R&D subsidies, which are shown to have distinct effects. Moreover, the firms' spatial embeddedness into subsidized cooperation networks is evaluated with respect to its importance for employment growth. The findings however provide some evidence for efficient complementarities, i.e. subsidies for cooperation that support interactions between firms and research organizations can yield positive effects. As such, growth factors can complement each other over time and therefore stimulate the spatial embeddedness into cooperation networks. Thus, the respective design of the implementation of growth factors matters. Third, this book highlights the importance of firm-external factors and their internalisation into firm activities. The analysis places growth relevant knowledge spillover processes (i.e. firms and universities) in a concrete space. Instead of imposing artificial and arbitrary regional delimitations and constructing imprecise measures of the available regional knowledge, the author looks at the exact geographical point locations of firms and their economic distance to different external sources of potential knowledge dissemination. As a main conclusion of the analysis it can be stated that both, other related firms and universities, are associated with firm growth. Furthermore, this section examines the contribution of specialisation and industrial variety to employment growth and therefore highlights the controversial discussion about Marshallian (technical) externalities (i.e. specialisation) and Jacobian externalities (i.e. diversification). The findings show that the level of industry aggregation has a direct impact on firm growth. In the case of Jacobian variety, firm size plays a major role. Finally, the thesis analyses the contribution of local knowledge endowment to employment growth in nanotechnology firms. Nanotechnology firm growth is influenced by the locations hosting the firms. The main conclusion of this study is that local knowledge endowment indeed influences firm growth in nanotechnology positively, while local knowledge specialisation is surely not always positively affecting the growth of individual firms. To sum up, firm-external factors can be incorporated into the activities of firms the consideration of exact geographical locations, regional specialisation or industrial variety as well as local knowledge endowment bridges the gap between external factors and their internalisation into firms' growth process.

The work indicates high potential for creating the opportunity of implementing further research directions and issues such as an entrepreneurial dimension. One direction of future work could hence be the identification of additional dimensions of firms' growth processes that might be useful to integrate, or even complement with each other. Furthermore, more information about the complementarities and their effects are necessary in order to enhance detailed results and to obtain more insights into the indirect effects of growth related factors and knowledge sources. In particular, the question arises whether the impact of a firms' position within a network implies any knowledge complementarities and whether it matters with which types of organisations they cooperate with. The gained knowledge would be an additional, valuable achievement for understanding the complexity, heterogeneity and idiosyncrasy of firm growth. For future work, changing the perspective from the micro-level to the meso-level of spatial aggregation might also be decisive, because firms' growth properties are substantial features of the dynamics of regional growth. Finally, interested in how the particular features of the firms influence the firm growth processes, the empirical examinations are accomplished in the context of firm growth as showcase examples. Relevant and appropriate policy implications can only be derived for particular firm cohorts, while policy implications for the support of firms in general might fail to have a growth-sustaining impact. Hence, the implementation of policy instruments comes along seeking to regulate specific activities across different firm cohorts. With respect to the comprehensive analyses in this book, different firm groups can be determined requiring specific policy instruments.

Zusammenfassung

In der vorliegenden kumulativen Dissertation werden die verschiedenen Dimensionen (räumliche, zeitliche und institutionelle Dimension) und Determinanten (firmeninterne und firmenexterne Faktoren) des Firmenwachstums analysiert. Firmenwachstum ist ein heterogener und idiosynkratrischer Prozess, der durch eine Vielzahl von Faktoren bestimmt werden kann (Coad 2009). Diese Faktoren sind zum Teil hochdynamisch und hängen intertemporal voneinander ab. Nach Werlen (2000) entwickelt die raumzentrierte Geographie Raummodelle, welche die räumlichen und zeitlichen Dimensionen des ökonomischen Handelns ungeklärt lassen. Die Vielfalt von ökonomischen Aktivitäten werden daher nicht berücksichtig bzw. werden in einer sogenannten 'Black-Box' reduziert (z.B. Böventer 1962, Isard 1956, Krugman 1991, 1995). Das in dieser Arbeit entwickelte Modell geht über das 'Black-Box-Konzept' hinaus und analysiert die dynamischen Prozesse und räumliche Interaktionen im Wachstumsprozess von Unternehmen. Neben diesen zum Teil sehr heterogenen Einflussgrößen weisen die Firmen selbst sehr unterschiedliche Charakteristiken auf. Das führt dazu, dass bestimmte Faktoren Wachstumstreiber für die einen, jedoch Hemmnisse für die anderen darstellen. Aufgrund der Vielzahl bestehender Firmeneigenschaften wird in dieser Arbeit der Fokus auf Firmen gelegt, die entsprechend ihrer Größe, ihres Alters und ihrer Industriezugehörigkeit klar einzuordnen sind. Darüber hinaus wird im Verlauf der Analysen auf sogenannte stilisierte Fakten (Größe, Alter, Industriezugehörigkeit) überprüft. Neben detaillierten Untersuchungen bzgl. einzelner Wachstumsfaktoren wird in dieser Arbeit ein allgemeiner Analyserahmen entwickelt, der es ermöglicht in zukünftigen Untersuchungen bisher kaum berücksichtige Aspekte zu analysieren und einzuordnen.

Der erste Teil der Dissertation analysiert den Einfluss von firmeninternen Faktoren auf das Wachstum von Firmen. Als firmeninterne Faktoren sind hier in erster Linie F&E Aktivitäten (gemessen in explizitem Wissen u. materiellen Werten) und die Exportorientierung von Firmen gemeint. In den Untersuchungen werden zunächst die relevanten Firmen gemäß ihrer Wachstumspfade und Entwicklungsmuster charakterisiert, woraufhin der Einfluss der firmeninternen Faktoren auf ebenjene Entwicklungsmuster getestet wird. Darüber hinaus werden zeitliche Effekte, d.h. zeitverzögerte Wirkungen von F&E Aktivitäten untersucht. Ein zentrales Ergebnis dieser Analysen ist, dass interne F&E Aktivitäten sehr wohl Einfluss auf das Wachstum von Firmen haben. Präziser formuliert sind es bestimmte Entwicklungsmuster (Wachstum, Stagnation, Schrumpfung), zeitliche Effekte (zeitverzögerte Wirkung) sowie die Höhe interner F&E-Aktivitäten gleichermaßen, die das Wachstum von Firmen beeinflussen, d.h. beschleunigen oder sogar abschwächen können. Der zweite Teil der Arbeit analysiert die Wirkung von firmeninternen und firmenexternen Faktoren. Ziel dieser Analysen ist es, herauszufinden welche Rolle F&E Kooperationen, gefördert durch direkte und indirekte staatliche F&E Subventionen, auf das Wachstum von Firmen haben. Hierbei werden verschiedene F&E Kooperationen (z.B. kooperierend, nicht kooperierend) konstruiert und evaluiert, um den Einfluss von firmenexternen Faktoren sowie den Effekt von räumlicher Verfügbarkeit von externem Wissen in Form von F&E-Projekten zu analysieren. Wesentliches Ergebnis dieser Analysen ist es, dass die Wachstumschancen von Firmen durch F&E-Kooperationen und gemeinschaftliche F&E-Projekte entscheidend beeinflusst werden. Während das Wachstum von KMUs durch Interaktionen zu Forschungseinrichtungen wesentlich beeinflusst werden kann, treiben F&E-Kooperation das Wachstum von größeren Firmen nur selten voran. Der dritte Teil dieser Arbeit beschäftigt sich mit der Wirkung von firmenexternen Faktoren (z.B. Forschungseinrichtungen, Universitäten, andere Firmen) und räumlichen Beziehungen (z.B. räumliche Nähe) auf das Wachstum von Firmen. Dafür werden

Variablen wie räumliche Nähe der Akteure, Zugang zu Wissen in branchenähnlichen bzw. branchenfremden Industrien und regionale Verfügbarkeit von Wissen in Form von hochqualifiziertem Personal in Betracht gezogen und analysiert. Wichtige Ergebnisse sind, dass die Wirkung von externen Faktoren von den Firmeneigenschaften abhängen wie zum Bespiel Firmengröße, Art der Wissensquelle und dem Wachstumsniveau. Weiterhin können branchenähnliches und branchenfremdes Wissen gleichermaßen das Wachstum von Firmen beeinflussen. Sie sind deshalb wichtig um eine effektive Wissensnutzung zu gewährleisten und fachspezifische aber auch fachfremde Wissens-Spillover zu bieten. Die regionale Verfügbarkeit von hochqualifiziertem Personal, externem Wissen und dessen Zusammensetzung beeinflusst daher die Entwicklung und das Wachstum von Firmen.

Unter Kenntnis der empirischen Resultate werden politikrelevante Aspekte diskutiert. Die praktische Relevanz der Dissertation weist verschiedene Felder auf, die von firmenspezifischen Aktivitäten, Investitionen und Handlungen über räumliche Aspekte der Verfügbarkeit der regionalen Wissensbasis bis hin zu politischen Fragestellungen und Implikationen reicht. Die Ergebnisse dieser wissenschaftlichen Arbeit können als empirische Grundlage für firmeninterne Handlungsentscheidungen sowie als Basis für politische Handlungsempfehlungen - insbesondere für Implikationen im räumlichen und regionalen Kontext – dienen.

Die Arbeit ist unter Betreuung von Prof. Dr. Dr. Thomas Brenner am Fachbereich Geographie der Philipps-Universität Marburg entstanden und in englischer Sprache verfasst.

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Antje Schimke

Preface

This doctoral thesis includes the following six papers:

Paper I Schimke, A. and Brenner, T.: *Growth development paths of firms – A study of smaller businesses*, The 3rd Fraunhofer ISI-IPM Joint Summer School on Innovation Policy, Foresight Technology and Sustainable Development, Beijing, China, 12-20 June 2010.

Schimke, A. and Brenner, T. (forthcoming): Growth development paths of firms – A study of smaller businesses, Journal of Small Business Management.

Paper II Schimke, A. and Brenner, T.: *The role of R&D investments in highly R&D-based firms*, The DIME Final Conference, UNU-Merit & School of Economics and Business, Maastricht, The Netherlands, 6-8 April 2011; The 7th EMAEE, European Meeting on Applied Evolutionary Economics – Evolutionary Perspectives of Technical Changes and Industrial Dynamics, Pisa, Italy 14-16 February 2011; The ERSA, European Regional Science Association, Jonkoping, Sweden, 19-23 August 2010 (Submitted for publication).

Paper III Brökel, T., Schimke, A., and Brenner, T.: The effects of cooperative R&D subsidies and subsidized cooperation on employment growth (Submitted for publication).

Paper IV Duschl, M., Schimke, A., Brenner, T., and Luxen, D.: *Firm Growth and the Spatial Impact of Geolocated External Factors – Empirical Evidence for German Manufacturing Firms*, The PhD Colloquium IIDEOS Innovation, Industrial Dynamics, Entrepreneurship, Organisation and Space, Philipps-University of Marburg, Marburg, Germany, 10 October 2011 (Submitted for publication).

Paper V Schimke, A. and Brenner, T.: *Localisation economies and Jacobian variety: impact on firms' employment growth* (To be submitted for publication).

Paper VI Schimke, A., Teichert, N., and Ott, I.: *Impact of local knowledge endowment on employment growth in Nanotechnology*, The DRUID Academy conference 2012 Economics and Management of Innovation, Technology and Organizations, Cambridge, UK, 19-21 January 2012.

Schimke, A., Teichert, N., and Ott, I. (forthcoming): Impact of local knowledge endowment on employment growth in Nanotechnology, Industrial and Corporate Change.

The author of this thesis made major contributions to paper I, II, and V. In paper III, the first author made the largest contribution to the study. In paper VI and IV, the two main authors contributed equally.

The percentage of the authors' contribution to the respective paper is as follows:

Paper I:	Schimke, A. 85% and Brenner, T. 15%
Paper II:	Schimke, A. 85% and Brenner, T. 15%
Paper III:	Brökel, T. 55%, Schimke, A. 35% and Brenner, T. 10%
Paper IV:	Duschl, M. 40%, Schimke, A. 30%, Brenner, T. 20% and Luxen, D. 10%
Paper V:	Schimke, A. 50% and Brenner, T. 50%
Paper VI:	Schimke, A. 45%, Teichert, N. 45% and Ott, I. 10%

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List of Acronyms

BBR	Federal Office for Building and Regional Planning
BMBF	Ministry of Education and Research
BMU	Federal Ministry for Environment, Nature Conservation and Nuclear Safety
BMWi	Ministry of Economics and Technology
df	degree of freedom
et al.	et alii / and others
EC	European Commission
e.g.	exempli gratia / for example
ERSA	European Regional Science Association
EU	European Union
GMM	Generalized Methods of Moments
GPT	General Purpose Technology
OLS	Ordinary Least Squares
i.e.	id est / that is
IIDEOS	Innovation, Industrial Dynamics, Entrepreneurship, Organisation and Space
ISI	Fraunhofer Institute for Systems and Innovation Research
JEL	Journal of Economic Literature Classification System
KIBS	Knowledge Intensive Business Services
KIT	Karlsruhe Institute of Technology
KIS	Knowledge Intensive Sectors
Log	Logarithm
LQ	Location Quotient
MAR	Marshall externalities
NACE	Classification of Economic Activities in the European Community (Nomenclature generale des activites economiques)
SME	Small and Medium-sized Enterprises
t	t-statistics
RQ	Research Question
R&D	Research and Development
UK	United Kingdom
VIF	Variance Inflation Factor
WP	Working Package

Contents

1 Introduction

This book deals with the integration of different growth related dimensions, in particular with factors and knowledge sources for investigating and analysing growth processes of firms. Firm growth is important for the economic competitiveness and technological progress as well as for the regional development. Therefore, it can be considered as a heterogeneous process with high complexity and idiosyncratic characteristics. This idiosyncrasy is partially caused by the high number of dimensions, growth factors and knowledge sources which are basically involved in the growth process. An important purpose of this doctoral thesis is to combine different key dimensions (i.e. temporal, spatial and organisational) and determinants of the firm growth process. Within this multidimensional concept, various growth factors and knowledge sources appear which potentially contribute to the growth of firms. In order to analyse and improve the understanding of the growth process itself, it is distinguished between internal and external growth factors and knowledge sources that might influence firm growth. An example of the combination of these key dimensions and growth factors is the usage and consideration of knowledge sources that are internal or external to firms. It has been discussed that these determinants of the growth process can influence or even complement each other. Nevertheless, these determinates have often been analysed separately and literature concerning how to combine them is (still) limited. The domain of firm growth and its growth determinants is considered complex since the growth process is characterised by many factors and sources influencing each other. A multidimensional investigation and evaluation for exploring growth factors, knowledge sources and the activities involved in the growth process of firms is therefore developed, and problems and obstacles are studied. This work provides a detailed insight into different kinds and types of firms ranging, for instance, from manufacturing firms to service firms or from smaller firm sizes to larger firm sizes as well as from younger to older firms. Finally, this comprehensive study highlights directions for future work and raises current and new topics of interest.

This introductory section presents the motivation (section 1.1) and the outline of the study (section 1.2), including the definition of firm growth, the description of growth dimensions and the explanation of growth factors in terms of internal and external knowledge sources. Furthermore, the author discusses early and current contributions on how different key dimensions and growth factors can be considered simultaneously. Then the research questions and the working packages are presented (section 1.3 and 1.4), followed by a comprehensive presentation of the own contributions (sections 2-7). Finally, the main conclusions and directions for future work are given in section 8.

1.1 Motivation

Firm growth has positive micro- and macro-economic effects. Positive macro-economic effects for instance appear in terms of economic competitiveness and development as well as employment growth. It can be seen as a decisive driver for the innovative progress. Therefore, the domain of firm growth is increasingly recognised by policy-makers not last through its contribution to overall job creation. Towards a more micro-economic approach of firm-level effects, also meso-economic effects become apparent. The meso-level of spatial aggregation can be seen as the distribution of economic activities across regions (i.e. regional development, specific sector and industry differences). Examples of micro-economic effects caused by firm growth are: firm's job creation (i.e. employment growth) as well as turnover and profitability growth. Clearly, there are interdependencies between all fields of interest.

The literature on growth aspects contains comprehensive definitions and measurement concepts of the term "firm growth". Previous studies in this domain have already dealt with the definition of firm growth, the different measurement concepts and the cut-off point in terms of high-growth. Taking into account the fact that growth processes undergo non-linearities in their growth and business cycles (e.g. Sorensen and Whitta-Jacobsen 2010), firm growth can be calculated using the differences of the natural logarithms of the size of a firm for two or more successive years (e.g. Coad 2009). Besides, there are other ways of measuring growth such as the Birch index or absolute growth. There are ongoing controversial discussions about the measurement of growth and the level at which growth can be declared as high growth. It is a matter of common knowledge that firm growth can be measured and defined in terms of inputs (e.g. investment, funds and employees), in terms of value of the firm (e.g. assets, market capitalisation, economic value added) and in terms of outputs (e.g. sales revenues, profits) (e.g., Garnsey et al. 2006, Coad 2009). This thesis employs two different measurements of firm growth: Employment and turnover growth. It is also interesting to analyse the dynamic relationships between the different firm growth measures. In this vein, Coad (2009) found out that employment growth is associated with subsequent growth of sales. Besides discussions regarding the measurement, also content-related issues become apparent. Thus, it is highly important to observe the procedural conditions (i.e. regional coverage, industry affiliation, interrelated activity and temporal structure) in which firms operate. This leads to the necessity of handling different firm samples individually in terms of their economic and individual needs. Hence, this thesis also captures 'stylized facts' of firms' growth processes and activities such as the effect of firm size, firm age and their industry affiliation.

It can be assumed that firm growth and its explanations are an important and well exploited topic in the existing economic and geographic literature. Firm growth is considered as a heterogeneous process with high complexity, individual characteristics and various combinatorial and strategic issues (i.e. additive and multiplicative contributions) and can be regarded as idiosyncratic for several reasons that also emphasize the author's motivation. First of all, there are many theories and empirical approaches dealing with firm growth and growth related factors (for an overview, see Coad 2009) addressing the topic from very different perspectives. Within neoclassical approaches the theories of 'optimal size' (Coase 1937) and 'nature of a firm' state that the "limit to the size of the firm is set when the scope of its operations had expanded to the point at which the costs of organizing additional transactions within the firm exceeded the costs of carrying out the same transactions through the market or in another firm" (Coase 1988b: p. 19). Therefore, the transaction cost theory exclusively presents the optimal size of a firm but the explanation for endogenous firm growth is neglected. Another approach can be found within "evolutionary economics that embraces the phenomenon of innovation in a way that other perspectives are not able to do" (Coad 2009: p. 6). Thus, evolutionary concepts emphasize the importance of firm-internal innovation activities. Nevertheless, it is up to discussion whether the contribution of innovation activities does exclusively explain the process of growth in firms. Penrose theory and the sociological concepts focus on the availability of resources and highlight them as a central source of firm growth (e.g., Penrose 1959, Metcalfe 1993, Hannan and Freeman 1977). Although there is a discussion about resources which might influence growth, theory and empirical studies miss the contribution of internal and external resources affecting firm growth. The theoretical discussion regarding the impact of a firms' location in proximity to other actors relies on the rather implicit assumption that knowledge spillovers are somehow bound in space (e.g., Marshall 1890, Polanyi 1957, Krugman 1991, Sorensen et al. 2006). Therefore, potential actors could be located at a certain place generating knowledge spillovers which might lead to growth. Empirical studies only highlight the existence of knowledge bound in space but ignore the question whether or how this knowledge can be internalised and incorporated into firm activities. The variety of theories and empirical studies led to an increased interest in understanding and stimulating different growth activities. In fact, there are still a non-negligible number of outstanding issues in the context of firm growth. A second reason is that one can hardly observe and model (all) growth related factors and knowledge sources potentially contributing to firm growth. Still, the challenging task of addressing 'unknown' variables which might be involved in the growth processes of firms is ahead. A third reason is that most empirical studies have only considered growth related factors and knowledge sources separately. Hence, most studies focus their investigations on firm-internal growth factors and on one single dimensions, thereby neglecting a whole range of other growth related factors and knowledge sources. A fourth issue is that prior empirical studies often ignored the impact of firm-external growth factors and knowledge sources. The problems in this context are typically large and require combinatorial properties and further methodological issues. Fifth, properties of the firms constitute idiosyncratic characteristics of the growth processes and can therefore be hardly transferred to an overall conclusion. A further fact of which the reader should be aware of is the discussion of current economic and social developments such as the demographic changes or the recent financial crises. For instance the changing age distribution of the population may be important for the rate of new firm formation or firm growth that has not been studied so far. Due to the complexity in this domain, there is a need for additional research on key dimensions, related factors and knowledge sources. Finally, this thesis helps to improve the understanding of current developments and generates an informational value by updating the existing knowledge in the domain of firm growth. Put differently, this thesis is motivated by the linkage between firm-internal and firm-external variables exploring the joint effect and the complementary effect of both.

1.2 Outline

The purpose of chapter 1.2 is to derive the underlying processes resulting in firm growth. The explanation and investigation of the firm growth domain is useful for understanding the overall topic of firms' growth processes and to extract the own motivation. Following a brief overview on firm growth in general, the description of the growth dimensions is introduced (i.e. section 1.2.1). It thereby becomes clear that the multidimensional approach of firm growth underlies different factors and knowledge sources potentially affecting the processes. Section 1.2.2 therefore presents a discussion on the existence and emergence of these factors and sources. The core of this thesis is presented in section 1.2.3 by explaining the distinction between internal and external growth factors and by presenting the outline of the thesis. After the theoretical basis, section 1.3 develops the research questions and prepares the reader for the elaboration of working packages in section 1.4. This subsection also presents the workflow and a short description of previously published papers. This comprehensive and theoretical chapter concludes with the references (see section 1.5).

1.2.1 Growth dimensions

The firm growth process may be seen as a process that follows a random walk. Gibrat's Law (1931) states that firm growth is essentially random and concludes that the growth rate of firms is independent of their size. Being one of the first contributions on firm growth, Gibrat's law is considered falsified by most researchers nowadays. Otherwise, firm growth can be considered as a process depending on interrelated growth factors and knowledge sources that influence and complement each other. Thus, firms operate in environments over which they might have full, or at least, partial influence. These environments are usually probabilistic with the effect that firm "growth results from adaptive search over a probabilistic fitness landscape with stochastic attractors" (Lee and Harrison 2001: p. 115). Hence, firms cannot expect the same output each time they process the same inputs. An important result of this property of the probabilistic approach is that firms operate in a multidimensional setting and environment where various growth-related factors and knowledge sources are embedded.

Several theoretical definitions and empirical investigations exist which deal with the discussion of additive contributions of firms' growth (e.g. Blumentritt et al. 2005) as well as the well-known multiplicative processes of firms' growth (e.g. Gallegati and Palestrini 2010). This investigations' aim is to shed some light on the complexity of firms' growth process. However, none of the previous studies gained universal acceptance. The following more suitable definition was provided by Alex Coad (2009 p: 110): "Firm growth is indeed a multifaceted phenomenon, it has a strong idiosyncratic character, and as a result it is difficult to generalize across firms and circumstances." None of these theories and empirical studies can provide a comprehensive explanation of the different key dimensions of firm growth. Moreover, different key dimensions of firms' growth processes can be revealed, reflecting the fact that firm growth is driven by heterogeneity and complexity. A multidimensional concept of firm growth might be defined as a complex system containing a set of different dimensions and growth related factors which interact with or complement each other in order to reach their respective goal (e.g. employment growth, innovativeness). The core idea of this book is to model a multidimensional approach to firm growth, which highlights relevant features of (here: spatial and temporal structures of economic interactions) firm growth. It aims at particularly highlighting the issue of agile relationships between space, time and economic interactions. The space centred geography developed specific models of space, but has been largely neglected the spatial and temporal features of economic interactions. Economic interactions were understood as a 'Black-box-concept' without any further information (e.g. Werlen 2000). Then, the 'Black-box' comprises deterministic assumption understanding space as homogenous entity (see Petersen 1944) in terms of the role of homo economicus. Contrarily to the deterministic belief, this work understands economic features and relationships as realistic and relational operations, using space and time as agile issues of economic interactions. This approach properly accounts for space- and time-based modelling of economic interactions and operations. This therefore contributes to the existing knowledge by determining three different key dimensions of firms' growth processes. The key dimensions are pictured in Figure 1.1 and are described and summarised as follows:

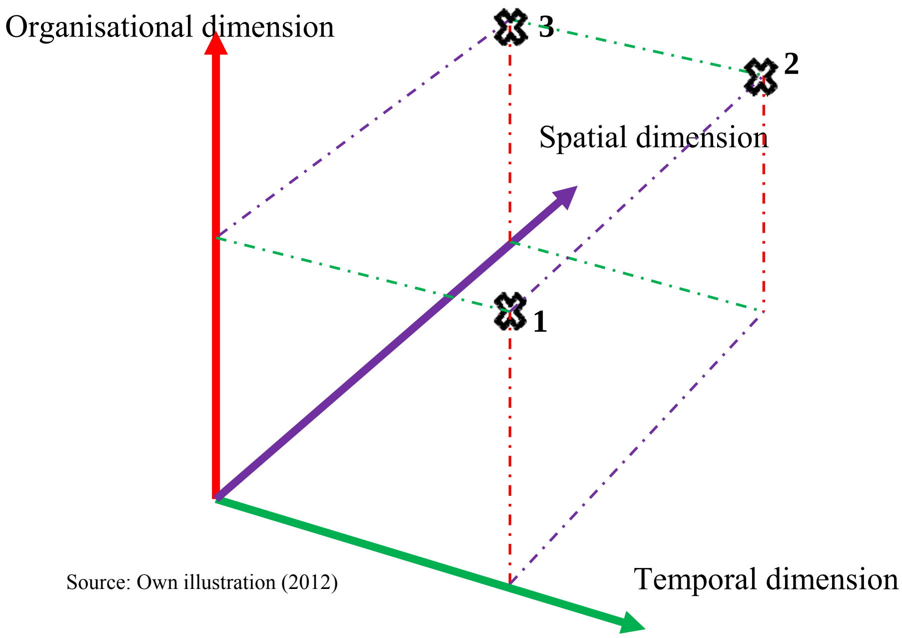
Temporal dimension: Firms' growth processes imply dynamic associations between growth and time. First, there might be intertemporal relationships between the determinants and growth. The temporal structure of the impact of different growth related factors and knowledge sources on growth might interfere with the time structure of the growth process itself. If growth in one year depends on growth in previous years and growth in previous years depends on different activities in the years before, a relationship between current growth and previous activities might be a direct or an indirect effect. To disentangle this structure, the issue of whether the impact of growth related factors exhibit positive or negative 'feedback loops' or even show statistically insignificant impacts (e.g. Coad 2009) is highlighted. However, the latter in particular points to the fact that one cannot take it for granted that growing firms will reinvest their profits in further innovation activities or growth enhancing factors (e.g. Coad 2009). Hence, the strategic orientation of firms appears to be heterogeneous, i.e. firms growth activities may be pooled in other growth enhancing activities (for an overview see section 1.1.3). Second, firm growth characteristics are also related to the probability of various development paths, such as permanent growth or decline. Thus, the growth of firms tend to be non-linear and prone to interruptions and setbacks (Garnsey et al. 2006 p: 1) especially in smaller and younger firms. There might be recurring patterns of the firm growth processes in certain firm groups associated with the emergence and existence of typical development paths. Hence, exploring non-linearities in the growth processes highlight the question whether development paths may be seen as explanatory patterns for its own that might follow exogenous developments. It is highly interesting to study growth development paths to understand whether development paths can be seen as explanatory patterns of growth in firms. Therefore, this thesis moves the perspective from average growth (short-run) to the structure of development paths (medium-run). Changing perspectives might provide additional and detailed insights into firms' growth processes.

Spatial dimension: Firm growth is dependent on regional characteristics, where the firm is spatially embedded in. It appears as if firm growth is associated with geographical distance (e.g., Petruzzelli 2011), spatial proximity (e.g., Laursen et al. 2011, Huggins and Johnston 2010), related variety as well as unrelated variety (e.g., Boschma and Iammarino 2009, Frenken et al. 2007) and local embeddedness (e.g., Audretsch and Dohse 2007) of the actors. More precisely, the controversial discussion about localization economies (Marshall's externalities) and Jacob's externalities becomes apparent and it can be argued that both issues have advantages and drawbacks from an economic and geographic point of view. Put differently, space is considered as an important dimension within the complex system of the firms' growth process where intraregional activities and events might lead to growth. Common properties that a firms' spatial embeddedness might possess are classified into (i) Impact of subsidized cooperation networks, (ii) geolocating firms to other knowledge sources, (iii) the effect of specialisation and industrial variety, (iv) and the impact of local knowledge endowment in knowledge intensive sectors. More precisely, this book explains firm growth, among others, from an explicit spatial perspective, reflecting the fact that the impact of space appears as a decisive component of the firm growth process.

Organisational dimension Literature on determinants of firm growth focusses on several factors, such as entrepreneurial characteristics (e.g., education), firm characteristics (e.g., location, firm size, firm age, industry affiliation) and firm strategy (e.g., international market strategy, external knowledge, and innovation activities) (for an overview see Storey 1994). A firm might be considered adaptive and intelligent if it exhibits an appropriate balance of these factors and sources in order to grow. Therefore, the author describes firms' growth activities as a complex structure of interactions. The various variables and determinants operate to fulfil an economic purpose and provide a return on investment costs. To a large extent, firms' growth opportunities are constrained by its activities. Furthermore, its competitive advantage rests on accumulated firm-specific internal and external resources as well as on capabilities which have been developed over time (e.g. Coad 2009). The authors' understanding of the organisational dimension is therefore closely related to the capability perspective (e.g. Williamson 1975, 1985, 1991), i.e. a firm is an organization of capabilities combining a bundle of resources and activities (Penrose 1959, Schumpeter 1942). More precisely, a firm operates to manage complexities and idiosyncrasy of transaction and tries to ensure collective learning processes by using organisational processes and structure. Capabilities of a firm are parts of a firm's inimitable resources (Penrose 1959) and can be seen as competitive advantages in terms of activities to actors in the market such as other firms, education institutes or regional authorities. As such, firms can be interpreted as organisations and entities bound in space and time, which leads to the fact that they have linkages to other organisations in space. By adopting the approach of the capability perspective, the author considers firms' activities and linkages to others as an organisational form. Put differently, this thesis understands the organisational dimension as firms' relatedness to other knowledge sources and actors (such as firms, universities, local authorities) that are bound somewhere in space and time. A dynamic view of the firms' activities is developed by introducing factors and sources impacting firms' growth. It appears useful to relate this topic to the distinction between internal and external growth factors and knowledge sources. It is also interesting to observe that firm growth not only depends on internal but also on external factors.

Figure 1.1 presents a summary of the multidimensional relationships between the components. The picture shows how the temporal dimension is related to the organisational dimension and *vice versa* (see X1). For instance, the time structure of the impact of R&D on firm growth might interfere with the time structure of the growth process. If growth in one year depends on growth in previous years and growth in previous years depends on R&D activities in previous R&D activities, a relationship between current firm growth and previous R&D activities might have a substantial effect. Figure 1.1 shows that several dimensions are likely to interact with each other (see X2). Actually, interactions are time- and space-consuming. It is conceivable that, for example, R&D subsidies for cooperation aim at supporting interactions between firms and research organizations can yield positive growth effects in the subsequent years. The same is true when subsidized joint projects connect firms to other firms located at a larger geographical distances. Finally, it is also interesting to observe that the spatial dimension is strongly associated with the organisational dimension and *vice versa* (see X3). This is clarified by the following example: The spatial characteristics of the relationships between firms and other external knowledge sources can be examined by geolocating firms into a more realistic relational space. This approach accounts for growth relevant knowledge spillovers and allows for an estimation of their spatial range and functional form. Furthermore, this investigation disentangles different degrees of relatedness and major functional roles of universities, namely higher education and research institutes as well as other firms. This study allows analysing whether geographical distance and spatial proximity matters. Although some other minor relationships between the dimensions and factors can occur, but they are neither depicted in the figure nor highlighted in this book.

Figure 1.1 Interrelated key dimensions of the firms' growth process



Source: Own illustration (2012)

1.2.2 Growth factors and knowledge sources

Growth related factors and knowledge sources are determinants that might affect the firm growth process. In particular, a set of characteristics, factors and sources might be existent which incrementally drive or hamper the firm growth. It is useful to distinguish between firm-specific (initial) characteristics (e.g., size, age, industry affiliation) and firm-surrounding characteristics (e.g., cooperation activities, R&D expenditures, export orientation). A decisive starting point for this thesis concerning firms' growth process and activities is the discussion about firm-specific characteristics the so-called 'stylized facts' of firm size, firm age and industry affiliation. 'Stylized facts' are observations which have been repeatedly made so that they are widely understood to be empirical reliable and to which macroeconomic theories should fit (for an overview see Cabral 2007). A prominent 'stylized fact' is that the firm size is one of the most influential factors of firm growth (e.g. Birch 1981, Bottazzi et al. 2011). More precisely, "small and large firms appear to operate on different frequencies" (Coad 2006: p. 3) meaning that firm growth seems to depend on firm size. Accordingly, it has been repeatedly found that firm growth tends to decrease as a firm becomes larger (e.g., Audretsch and Dohse 2007). Concerning the impact of firm age, literature emphasises that younger and smaller firms tend to exhibit higher growth rates than larger firms meaning that firm growth declines as a firm becomes older (e.g. Jovanovic 1982). In particular, it is commonly assumed that firms uncover their true efficiencies over time; hence, there is an inverse relationship between growth and age (e.g. Evans 1987). Finally, firm growth processes and especially R&D processes entirely differ across industries, sectors and technologies. In this manner, different industries, sectors and technologies have different growth structures regarding the dynamic inherent in these processes (e.g., Mansfield 1962) and innovation activities. Thus, one expects strong differences in the findings as various sectors and industries are analysed separately. Hence, analyses are performed either by sectors (or at least by a group of sectors), industries or even technologies that give important information according to the similarities and differences of their firm's growth processes (e.g., R&D processes). The impact of firm size, firm age and industry or sector affiliation continues to receive attention in this doctoral thesis and is tackled in all contributions.

Another subject of interest is the number of additional factors and characteristics, i.e. 'idiosyncratic facts'. These characteristics can be described as factors and sources which idiosyncratically enhance and stimulate the growth process of firms. Especially these idiosyncratic factors require a deeper comprehension of the firms' growth processes. In particular, a set of factors and sources is highlighted and the characteristics and relationships between these issues are studied over some period of time. One motivation for analyzing these factors and sources is that the relation between them is very complex, thereby explicitly recognizing the heterogeneity of the firms' growth process. Another fact is that the dynamic view of firm-level activities (within different firm size classes, age groups and industries) has become an essential part in economic geography, even among issues such as cooperation activities and local knowledge endowment of firms. Economic geography has grown closer to topics of economics (e.g., Iammarino et al. 2008, Storper 2010). Due to the fact that firm growth is pervasive and multi-faceted, different kinds of idiosyncratic characteristics are derived and are taken into account in this work: First, the influence of innovation activities plays a substantial role within the firm growth process in evolutionary economics (e.g., Coad 2009). Some studies focus on the impact of innovation on the growth prospects of firms (e.g., Coad and Rao 2010), since already Mansfield (1962) pointed to the fact that innovation activity determines firm growth. This makes it rewarding to consider how innovative activities (i.e. R&D expenditures, R&D employees, innovation projects and R&D subsidies) stimulate and contribute to firm growth. Second, it appears that the emphasis is put on cooperation and network activities. While significant empirical evidence exists for cooperation and R&D subsidies facilitating firms' development (e.g. Brouwer et al. 1993, Czarnitzki et al. 2007), it is rarely considered that firms engage into inter-organizational cooperation in order to be rewarded with R&D subsidies. Then, it is useful to consider whether firms become embedded into (subsidized) cooperation networks (e.g. Broekel and Graf, 2011) and generate positive knowledge spillovers, which might lead to firm growth. The contribution to this literature stream highlights the relevance of non-cooperative and cooperative activities with the aim of a firms' growth. More precisely, the impact of a firms' position in these cooperation networks and the corresponding functional form of the organisations they cooperate with is investigated. Third, it has also been repeatedly suggested that the impact of being located in proximity (or, the other way around, in geographical distance) to other knowledge sources might be beneficial to firm growth. Regarding the co-location in proximity to other firms, Marshall (1890) already pointed to the fact that firms are relatively more efficient and hence perform better when located within or nearby an agglomeration. The issue of firms' relatedness and spatial embeddedness is tackled by different terms, for instance, the impact of the spatial range and the functional form of the knowledge sources. This approach properly accounts for geolocating firms into a more realistic relational space and for investigating the growth relevant knowledge spillovers. Moreover, it also allows for the estimation of their spatial range and functional form. Furthermore, regional specialisation and industrial variety (e.g., Boschma and Iammarino 2009, Frenken et al. 2007) might also engender differences in the way firms grow. The notion of related variety describes the effect that "knowledge will spill over effectively only when complementarities exist among sectors in terms of shared competences" (Boschma and Iammarino 2009: p. 290). Thus, the regions might co-locate many industries that might be specialized (i.e. potentially triggering Marshall's externalities). This kind of "knowledge spillover effect should be distinguished from the effect of unrelated variety" (Boschma and Iammarino 2009: p. 290), i.e. regions might contain many diversified and unrelated industries (i.e. potentially triggering Jacobs's externalities). The regional knowledge base itself and the degree of regional specialisation as a potential source of positive external effects (i.e. technological spillovers) might be a crucial factor of firm growth. Finally, it might be preferable to consider whether the growth of firms is dependent on the local knowledge endowment measured by different kinds of knowledge sources (e.g., Audretsch and Dohse 2007). In this context, it is not necessarily regional embeddedness per se that positively contributes to firm growth. For instance, local specialisation might inhibit the usage of one technology in a multitude of application fields, thereby possibly suppressing potential opportunities for cross-fertilization and innovation-enhancing feed-back mechanisms across diverse and so far unrelated value creation chains.

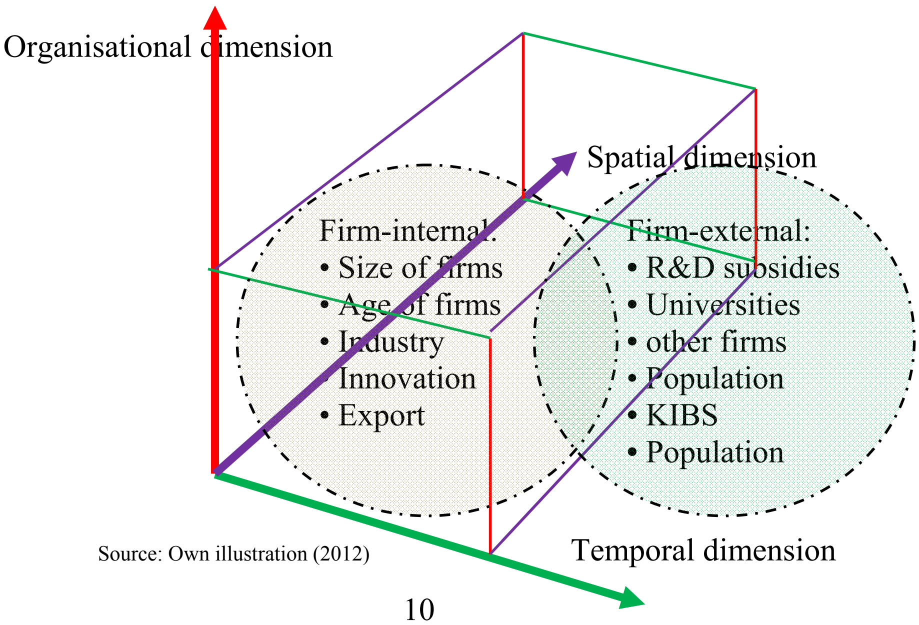
1.2.3 Distinction between firm-internal and firm-external factors

As discussed in section 1.2.2, so far, the previous literature on growth factors and variables has focused on growth-related factors and knowledge sources. Based on the firm-level, literature mostly distinguishes between the firms' growth characteristics in terms of firm-internal growth factors and in terms of firm-external growth factors (e.g., Acar 1993). On the one hand, in evolutionary economics, empirical studies on firm growth have mainly studied firm-internal factors such as size, age (e.g., Coad 2010), industry affiliation (e.g., Luttmer 2011), strategic and organizational issues (e.g., Acar 1993, Zahra et al. 2006), as well as more recently R&D activities (i.e. innovation-economic aspects) and export orientation (e.g., Schimke and Brenner 2011, Coad and Rao 2010). Previous research tends to emphasise that especially smaller firms experience higher growth rates than their larger counterparts. However, Coad (2007b) argues that age causes growth rather than size. Independent of the issue of causality, it was found that the dynamics and patterns of growth vary with firm size. Underlying mechanisms, such as the time scale on which firms operate (e.g. Coad 2006) differ and consequently preclude the possibility to group firms of different size. Particularly smaller firms rely on external resources and operate on different frequencies (e.g. Coad 2006). Most studies conclude that firm growth is related to specific sectors and industries (e.g. Mansfield 1962). Besides these characteristics, innovation and R&D activities are broadly discussed. Grupp (1998) pointed to the fact that "the identity of R&D expenditure and innovation input is untenable, because it is based on the assumption that it is possible to distinguish strictly between formalized internally generated technical knowledge and institutional arrangements which may gain external R&D knowledge through co-operative efforts through licensing, the acquisition of R&D intensive components or from other transaction cost minimizing sources" (Grupp 1998: p. 190). As such, it is not necessary for the innovating company to consider funds; it is rather that a company can independently decides on its allocation (e.g. Grupp 1998). This leads to the fact that "the financing sources can be corporate entities of the concern in the originator principle (internal accounting), an apportionment procedure between the organization's head office and various sources of external financing (government research programmes, grants, European Union funding, and so on)" (Grupp 1998: p. 190). To compete with other actors firms are motivated to combine internal and external processes and knowledge sources to meet environmental demands (e.g. Fores and Camison 2011). Therefore, it is common practice for firms that external knowledge is absorbed and accumulated (e.g. Cohen and Levinthal 1990). This very issue guides to the existence and emergence of the importance of external growth factors and knowledge sources. Cohen and Levinthal (1990) famously pointed out that a firm's competence in absorbing external information and knowledge is crucial in this respect and thereby introduces the term "absorptive capacity". O'Regon et al. (2006) argue similarly that firms are unlikely to sustain their competitive advantage without access to greater (and potentially external) research and development resources.

Put differently, there are also firm-external growth factors and sources which become interesting. Some studies argue that internal resources are not sufficient to achieve competitiveness and firm growth. By contrast, a wide range of external factors is relevant for most firms. Empirical literature reveals that region-specific characteristics engender differences in the way firms grow (for a recent study see Barbosa and Eiriz 2011). Much attention is dedicated to the regional economic structure, which is assumed to represent the availability of resources and market opportunities (Storey 1994), or in general agglomeration advantages and disadvantages, which make up the New Economic Geography literature to a large part. Exclusively focusing on innovative performance, some studies systematically attempt to disentangle firm-specific internal factors from firm-surrounding factors, with the former turning out to predominate by far (e.g. Sternberg and Arndt 2001, Beugelsdijk 2007). However, these studies are characterised by the simple assumption that regional characteristics affect firms. By contrast, this thesis focuses on the presence and emergence of entities which can be considered as external factors and knowledge sources. More precisely, it is particularly valuable to look at the spatial, statistical and economical impact of subsidized cooperation networks (e.g. Broekel et. al 2011) as well as of other related firms (e.g. Duschl et. al 2011) and universities (e.g. Audretsch and Feldman 2004) on firm growth. This thesis focuses on the presence and geolocation of entities that can be considered as external knowledge sources. Hence, growth factors are understood as entities which are internal and/or external to the firm. Empirical literature reveals that region-specific characteristics engender differences in the way firms grow. Therefore, the regional economic structure (e.g.

population, start-ups) might be a crucial driver of firm growth. Recently, an economic focus on the existence and impact of knowledge intensive business services (i.e. KIBS) has been laid. Mainly it is argued "that changing competitiveness conditions are heightening the requirements for firms in most sectors to innovate and take advantages of their core competences and knowledge" (Huggins 2011: p. 1459). As a result, many firms outsource their knowledge intensive business services (e.g., Aslesen and Isaksen 2007, Huggins 2011, Raspe and van Oort 2011). Furthermore, it can be stated that a high population density positively affects firm survival. Hoogstra and van Dijk (2004) show in their investigation that firms located in regions with a high population density are more likely to experience stronger growth. For the authors understanding, this effect is also captured by the industry affiliation. This, in turn might engenders differences in the way firms grow. Another subject of interest is the success of the formation of start-ups or new firms. Their emergence is not entirely independent from employment and competitive environment in the agglomerated area (e.g. Baptista and Preta 2011, Fritsch 2011). More precisely, this book stresses the relationship between firms' local embeddedness (e.g., Audretsch and Dohse 2007) and industrial variety (e.g., Boschma and Iammarino 2009) on the way firms grow. In particular, the thesis investigates the contribution of cooperative and non-cooperative R&D subsidies to firm growth. In this respect, the firms' embeddedness into subsidized cooperation networks and the corresponding complementarities is of particularly interest. Furthermore, the relationship between firm growth and various external knowledge sources, such as related firms and universities, is studied. Thereby, different degrees of relatedness and major functional roles of universities, namely education and research, are disentangled. Then, the discussion about knowledge diffusion occurring when firms are embedded in a more specialised environment (Marshallian externalities) or in regions which are more diversified (Jacobian externalities) is highlighted. Finally, the thesis also highlights the contribution of local knowledge endowment to employment growth in specific technologies' firms (e.g., Audretsch and Dohse 2007). Cohen and Levinthal (1990) already pointed to the fact that a firms' competence in absorbing external information and knowledge, i.e. absorptive capacity, is crucial to achieve growth-enhancing effects. To summarise the effect of internalising external knowledge (e.g., Lichtenthaler 2008), it appears that "an extended knowledge base to which a firm has privileged access" (Lichtenthaler 2008: p. 200) is of importance. Figure 1.2 depicts the outline of firms' growth process highlighting the different key dimensions (as discussed in section 1.2) and growth factors.

Figure 1.2 Outline of the mechanism of the firms' growth process



Source: Own illustration (2012)

1.3 Research questions

The superordinate goal of this thesis is to examine how the different, growth-impacting key dimensions, factors and knowledge sources are interrelated, so that the mechanism of growth processes can be analysed. By doing so, the aim is to gain a better understanding of the heterogeneity and complexity of the firms' growth processes. More specifically, this thesis aims to delineate a growth model and to derive important factors associated with firm growth. The purpose is also about gaining detailed knowledge on whether firms are dependent on growth related factors and knowledge sources (or even that growth follows a random walk). Furthermore, it might appear that some dimensions, factors and sources are more important than others, especially in different firm growth stages. Therefore, another purpose is to investigate how the multidimensional concept can be used for the exploration and detection of decision making and innovation-economic activities involved in firm growth. Throughout the process, three main research questions (RQ) are derived. In this section presents each of these questions are presented together with a brief motivation and a short introduction of the research methods used. The first research question is formulated to conduct research in the purpose of firms' internal determinants that come together with firm growth over time.

RQ1 Do firm-internal factors and knowledge sources affect the growth of firms and which kind of intertemporal relationships exist?

RQ1 deals with the general aim of this thesis, which is to analyse and to generate detailed knowledge about the interrelationships between the temporal dimension and internal growth factors. At first, it is explored which firm characteristics are involved in growth dynamics during a longer period of time. The purpose is to classify developmental paths of the firms. Logit estimations are employed to identify the firm characteristics (i.e. innovation activities, firm size and export rate) accompanying developmental paths. Second, the time structure of the effects of R&D activities on firm growth is explored. The main issue is whether R&D activities accompany firm growth in the subsequent periods and how this relationship depends on other characteristics such as size and industry affiliation. In addition, the relationship between R&D effects and the autocorrelation dynamics of firm growth is studied. A linear regression approach is applied considering R&D activities over time and autocorrelation dynamics of firm growth. Additionally, the intertemporal relationships are discussed and interpreted in order to understand the impact of the internal growth related factors on the process itself. As previously discussed it might appear that an innovating company not only funds itself; it is rather that the company can decide on its allocation independently (e.g. Grupp 1998). Therefore, the acquisition of additional funds is current practice for firms. Hence, "the financing sources can be corporate entities of the concern in the originator principle (internal accounting), an apportionment procedure between the organization's head office and various sources of external financing" (Grupp 1998: p. 190) such as the German federal ministries. This work aims to study the complementary effects between internal and external factors and knowledge sources. It is therefore possible that firm-internal and firm-external growth factors complement each other and stimulate the growth of firms. This leads to research question two.

RQ2 Do growth related factors and knowledge sources complement each other and stimulate the spatial embeddedness of firms into cooperation networks over time?

RQ2 mainly focuses on the second aim of this thesis, i.e. to investigate interdependencies and complementarities between growth related factors, knowledge sources and the spatial dimension over time. The firms' embeddedness into subsidized cooperation networks hereby is or particular interest. The author investigates the contribution of cooperative and non-cooperative R&D subsidies to firm growth. A dynamic panel estimation technique is employed to control for growth autocorrelation. Throughout the process of dealing with the internal growth related factors and knowledge sources it is possible for external factors and sources to emerge and to affect the firm growth. Thus, the internalisation of external factors and sources come into focus. It demonstrates dynamic capabilities of firms' activities to implement knowledge strategies and innovation-economic issues. This leads to RQ3.

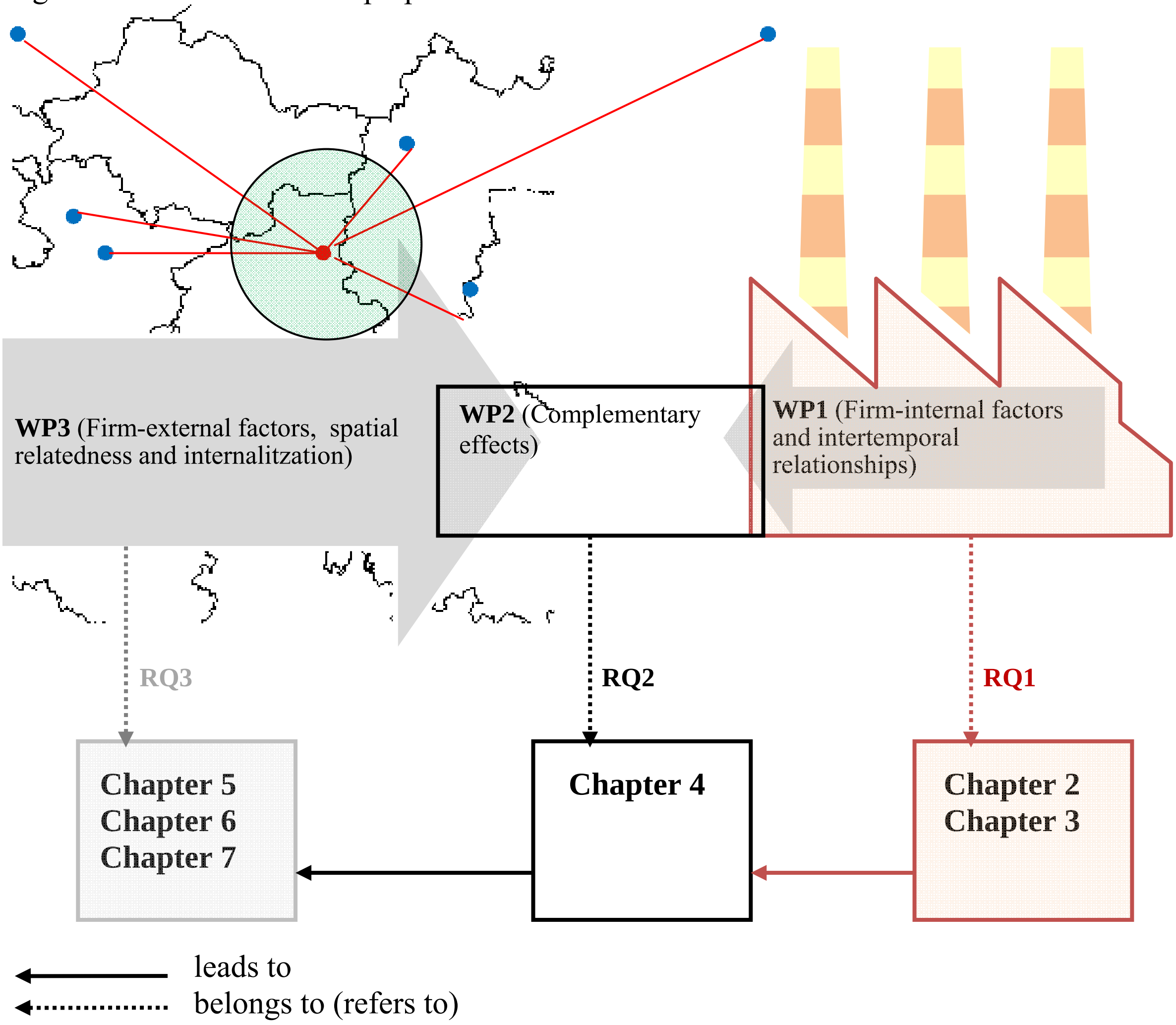
RQ3 How can firm-external factors and spatial relatedness be internalised and incorporated into firm activities?

RQ3 covers three major contributions to examine the spatial dimension, external growth factors and knowledge sources. This is done with the following intention: First, the spatial characteristics of these relationships are examined by geolocating firms into a more realistic relational space to other external knowledge sources, such as related firms, universities and higher education institutes. A quantile regression is applied to control for high-growth and shrinking firms, which are a prominent feature in growth dynamics of firms. Second, the author investigates external knowledge sources (i.e. knowledge intensive business sectors, population density, and start-ups), which might be very well in generating positive knowledge flows through which firms become more prone to growth. As such, the investigation stresses the fact of whether regional specialisation or industrial variety engenders differences in the way firms grow. For this contribution the author applies a simple OLS estimation with pooled panel data and cross-sectional time series estimation. Third, the contribution of location-specific characteristics and local knowledge endowment to employment growth in general purpose technology firms is analyzed. It seems adequate to expect strong differences in the findings since various sectors and industries are analysed separately. Therefore, a specific technology (i.e. nanotechnology) is analysed to give valuable insights into the firm growth processes. The empirical analysis includes an online survey and two regression techniques, a simple OLS estimation and cross-sectional time series estimation.

1.4 Workflow and preparation of working packages

In order to analyse the mechanisms of firm growth as discussed in the previous sections, the research questions RQ1, RQ2 and RQ3 (see section 1.3) have to be split into working packages. For an illustration see Figure 1.3. With regard to the three main research questions, three different working packages (WP) are defined. Figure 1.3 illustrates the relevant aspects addressed in this doctoral thesis. In a first step (WP1), the author analyses firm-internal factors and their intertemporal relationships. Here, the impact of firm-internal factors on the development is investigated. Additionally, the temporal structure of firm growth is analysed. Hence, WP1 contributes to RQ1. Furthermore, WP2 highlights the complementarities and spatial embeddedness that might be derived from the contribution of cooperative and non-cooperative R&D subsidies. Therefore, WP2 contributes to RQ2. As a major part of this doctoral thesis, the author highlights the impact of firm-external factors and their spatial relatedness to firm growth in WP3 (contributes to RQ3). More illustratively, Figure 1.3 presents the structure of this thesis, starting with WP1 (Firm-internal factors and intertemporal relationship). The WP 1 is covered by chapter 2 and chapter 3. Chapter 4 elaborates on working package WP2 (Complementarities and spatial embeddedness). The core of this thesis, i.e. the implementation of working packages WP3 (Firm-external factors and internalisation), is embedded in chapter 5–7. The following sections give an overview of each chapter's content.

Figure 1.3 Workflow of the preparation for WP1 - WP3



Source: Own illustration (2012)

1.4.1 WP1: Firm-internal factors and intertemporal relationships

Work package 1 guides to deal with the first aim of this thesis, i.e. to investigate and to create knowledge about firm-internal factors and their intertemporal relationships. WP 1 is divided into two analyses treated in chapter 2 and chapter 3 to capture RQ1.

Chapter 2: Impact of firm-internal factors on development path

Chapter 2 provides an analysis of firm growth and its internal growth related factors. As such, the question is whether certain characteristics of firms trigger higher growth at a certain point of time. This differs from question whether certain firm characteristics imply higher permanent growth. Knowledge about whether certain firm characteristics relate to enduring firm growth or decline is rare. Hence, it is unclear whether most innovation-economic factors (i.e., innovation activities) influencing firm growth actually remain effective and sustainable over time. Understanding the characteristics of firms with a permanent growth (or decline) path is important in the context of economic competitiveness, structural change and growth, especially in the small business sector. One important step is to understand the characteristics of firms showing a high one-time or average growth, because this provides information about growth factors in general. This step is widely discussed in literature. However, additional information is obtained by studying the details of the growth (or decline) dynamics, which we call firms development paths. It makes a difference whether a firm experiences an average growth (showing years of growth and years of decline) or if a firm experiences a permanent growth. Hence, firms have different growth strategies to consider. Furthermore, having more detailed knowledge about growth dynamics helps to partly understand exit events. Finally, the approach distinguishes between the characteristics of firms experiencing a permanent slow growth and those with partially strong growth. Hence, it is important to examine what kind of firm can be expected to show what kind of development path. This paper aims to provide this, at least partly, by studying the relationship between firm characteristics and their development paths. It starts from the comprehensive knowledge about firm characteristics that are related to growth, at least in the short run. The author then deduces from these knowledge expectations about the characteristics of firms that are expected to be related to permanent growth before testing these expectations empirically. In addition, the thesis focuses on the robustness of the findings with respect to changes in the definition of development paths. The analysis provides detailed knowledge about firm-internal factors and their intertemporal relationships, thereby contributing to RQ1.

Chapter 3: Temporal structure of firm growth

Chapter 3 examines the short-term structure of the impact of R&D investments on turnover growth, indicating differences between tangible and intangible investments. The main questions are whether R&D and capital investments accompany firms' growth in the subsequent periods and how this relationship depends on other characteristics of the firms, such as size and industry. In addition, it studies the relationship between R&D investments and the autocorrelation dynamics of firm growth. A regression approach is applied with a linear model taking into account R&D activities at points in time and autocorrelation dynamics of firm growth. We find that R&D activities have, on average, a positive effect on turnover growth, while capital investments show both, positive and negative, relationships with firm growth. The relationship and its temporal structure strongly depend on firm size and industry affiliation as well as whether investments are considered as one-time or permanent activities.

1.4.2 WP2: Complementary effects

Working package 2 is approached by exploring complementary effects of internal and external factors on firm growth. This discussion is highlighted in chapter 4 and contributes to RQ2.

Chapter 4: Complementary effects and embeddedness into cooperation networks

In this chapter, the contribution of cooperative and non-cooperative R&D subsidies to firm growth is presented. Of particular interest are hereby the complementary effects of firms' spatial embeddedness into subsidized cooperation or non-cooperative networks. The study discusses the issue whether the adoption of knowledge from firm specific factors and sources is another growth stimulating factor. This factor is particularly emphasised in endogenous growth theory. The absorption and utilization of such knowledge is achieved via various mechanisms including the firms' engagement in inter-organizational cooperation. It is widely accepted that in general, firms benefit from cooperating with other organizations. However, it is rarely considered that firms frequently (and to an increasing extent) engage into inter-organizational cooperation in order to be rewarded with R&D subsidies. By participating in such programs firms become embedded into (subsidized) cooperation networks which can have significant effects on their innovation and growth activities. Chapter 4 contributes to these literature streams with an empirical study on the relevance of non-cooperative and cooperative R&D subsidies for firms' employment growth. Their relative importance is evaluated and, in case of cooperative subsidies, their function of embedding firms into (subsidized) cooperation networks is taken into account. More precisely, the author particularly investigates the impact of a firms' position in these networks. It is also investigated whether it matters with what types of organisations a firm cooperates. Consequently, the analysis contributes to RQ2 since it tackles the interaction between growth related factors and knowledge sources and their spatial embeddedness.

1.4.3 WP3: Firm-external factors and internalisation

Working package 3 covers approaches to deal with the overall topic of firm-external factors and their internalisation into firm activities. With WP3, the author connects different dimensions, growth factors and knowledge sources which are affiliated to firm growth. This comprehensive investigation is adopted by chapter 5, 6 and 7 and helps to answer RQ3.

Chapter 5: Spatial relatedness to other actors

Chapter 5 provides a discussion on firm external factors which might contribute to firm growth. It points to the fact that firm growth does not only depend on firm-internal but also on factors-external factors. In this analysis the relationship between firm growth and various external knowledge sources, such as related firms and universities, is studied. By doing so, the author is geolocating firms to other actors in space. Obviously, it disentangles different degrees of relatedness and major functional roles of external factors and knowledge sources. Therefore, chapter 5 presents an analysis which highlights the location of firms in a concrete space relational to the external factors that matter. This study predominantly contributes to RQ3.

Chapter 6: Impact of Industrial variety on firm growth

Chapter 6 explores the contribution of regional specialisation and industrial variety to employment growth. It highlights the controversial discussion about Marshallian specialisation and Jacobian diversification. Usually, the impact of regional factors on regional aggregates is studied without explicitly considering the firm-level. By contrast, this study focusses on the direct effects of regional conditions on the firms' employment growth, especially on the impact of specialisation and industrial variety. Therefore, the notion of related variety describes the effect that "knowledge will spill over effectively only when complementarities exist among sectors in terms of shared competences" (Boschma and Iammarino 2009: p. 290). Thus, regions comprise of many industries which are related and specialized (i.e. Marshall's externalities), and/or in contrast, some that are unrelated and hence contribute to a diversified industrial landscape (i.e. Jacobs's externalities). It can be argued that too much embedded knowledge of the same industries in the specialized region might engender regional lock-in (e.g. Bathelt et al. 2004), while knowledge that is very different from the industry that a region is specialized in might be inefficiently processed. Furthermore, the regional knowledge cannot easily be absorbed and it is much harder to learn and benefit from it (e.g. Boschma and Iammarino 2009). This analysis provides the reader with valuable ideas concerning the effects of being embedded into a related and specialized environment or rather in an unrelated and diversified surrounding. It therefore contributes to RQ3.

Chapter 7: Local knowledge endowment and specialisation

Finally, chapter 7 investigates the contribution of local knowledge endowment to employment growth in nanotechnology firms. It seems adequate to analyse a young and knowledge intensive technology for gaining more information about the similarities and differences of the firms' growth process. Nanotechnology is still a young and dynamic technology. There is still room for improvements and innovation activities are essential firm activities. Due to fragmented R&D and production processes, most of the firms only provide parts of complex value creation chains while being embedded in various networks. Due to their high innovation intensity, the anchorage of the actors within regional specialisations is central. One general expectation concerning the overall role of nanotechnology firms is their contribution to job generation, thereby strengthening regional competitiveness. It is reasonable to assume that the characteristics of the economic surrounding feed back to the performance of nanotechnology firms and vice versa. Along this line of reasoning this chapter addresses the impact of two economic key characteristics of nanotechnology and its potential to create employment and growth: As a 'high technology', the usual arguments in the context of the proximity-productivity relationship, i.e. the linkages between innovation, spillovers and economic performance also apply to nanotechnologies. Hence, not only firm specifics but also a sufficiently specialised surrounding for translating spillovers into actual productivity gains is of special importance. Thus, a sufficiently high overlap of firm activities (absorptive capacity) and the availability of qualified labour are key determinants. Consequently, the actors' regional anchorage and especially the composition of regional labour markets are key drivers for success. This is contradictory to the 'general purpose character' of nanotechnology, which basically allows introducing the technology in any context. This implies that a certain degree of regional specialisation is not mandatory per se, but, depending on the technologies' developmental state, even the contrary may be the case: Too narrow regional specialisation patterns may inhibit the technology's use in a multitude of application fields, thereby possibly suppressing potential opportunities for cross-fertilisation and innovation-enhancing feed-back mechanisms across diverse and so far unrelated value creation chains. The analysis of chapter 7 contributes to RQ3 by addressing the two major issues: (i) the impact of firm-external factors and (ii) the impact of regional specialisation on employment growth in nanotechnology. Put differently, the question is which characteristics of nanotechnology predominate: its character as a high technology or its character as a general purpose technology.

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2 Impact of firm-internal factors on development paths

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Growth Development Paths of Firms – A Study of Smaller Businesses

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Abstract

This paper investigates whether firm characteristics that are related to firm growth in the literature are also related to the development path of firms. This means that we test which firm characteristics come together with the growth dynamics during a longer period of time, referring to the sequence of growth and decline steps. We examine three variables: firm size, innovation effort and export share. To this end, we use panel-data on 178 German manufacturing firms over the period from 1992 to 2007. We find that the determinants of growth paths are not the same as the determinants of firm growth at one point in time.

Keywords: Firm growth, firm growth paths, SME, firm size, export, innovation effort

2.1 Introduction

Firm growth and its explanation is an important and well studied topic in the economic literature. A wide range of factors exist that affect the growth of firms. However, the question whether certain characteristics of firms come together with higher growth at a certain point of time is not the same as the question whether certain firm characteristics come together with higher permanent growth. Knowledge about the relationship between certain firm characteristics and enduring firm growth or decline is rare. Hence, whether most of the economic factors influencing firm growth remain effective and sustainable over time is unclear. Understanding what characterises firms with a permanent growth (or decline) path is important in the context of economic competitiveness, structural change and growth, especially in the small business sector. One important step is to understand the characteristics of firms that show high one-time or average growth, because this provides information about growth factors in general. This step is widely discussed in the literature. However, additional information is obtained by studying the details of the growth (or decline) dynamics, which we call firm's development paths. It makes a difference whether a firm grows on average but shows years of growth and years of decline or if a firm grows permanently. If growth dynamics are less permanent, evaluating the growth or decline of a firm should be considered over longer periods. Furthermore, having more detailed knowledge about growth dynamics helps to understand partly exit events. Finally, our approach distinguishes the characteristics of firms that show permanently slow growth from those firms that show sometimes strong growth. Hence, it is important to examine which kind of firm can be expected to show which kind of development path. This paper aims to provide this, at least partly, by studying the relationship between firm characteristics and development paths. The existing literature on firm growth provides a wide range of theoretical and empirical findings on the influence from a number of factors and firm characteristics on firm growth. Many studies have searched for significant relationships between various variables and growth (for an overview see Coad 2007, more details are presented in Section 2.3). We start from this comprehensive knowledge about firm characteristics that are related to growth, at least in the short run. We deduce from these knowledge expectations about the characteristics of firms that are expected to be related to permanent growth. Then, we test these expectations empirically. The study is based on a sample of small and medium-sized manufacturing firms operating in Germany. The data is taken from the Mannheimer Innovation Panel, which allows us to follow 178 firms through the period from 1992 to 2007. Furthermore, the data base provides information about size, innovation activities and export shares of these firms. We classify the development paths of the firms and conduct regression analysis to identify the firm characteristics that come together with permanent growth.

The structure of the paper is as follows. Section 2.2 provides a review of literature in the field of firm growth, which presents the starting point of the paper. The findings in the literature are used to deduce expectations for the empirical examination. Section 2.3 focuses on the methodology and sampling. It describes the used data and the applied methods. Section 2.4 discusses the results and draws conclusion on the determinants of development paths. In addition, it focuses on the robustness of the findings with respect to changes in the definition of development paths.

2.2 Background and hypotheses

2.2.1 Theoretical background

A wide range of theories and empirical approaches exist that deal with firm growth (for an overview see Coad 2007). Thereby, firm growth is considered as a heterogeneous process with high complexity, individual characteristics and various combinatorial and strategic issues (i.e. additive and multiplicative contributions) and can be regarded as idiosyncratic for several reasons that also emphasize the author's motivation. First of all, there is a wide range of theories that deal with firm growth and its growth related factors (for an overview see Coad 2009), which address the topic from very different perspectives. Within neoclassical approaches the theories of 'optimal size' (Coase 1937) and 'nature of a firm' state that the "limit to the size of the firm is set when the scope of its operations had expanded to the point at which the costs of organizing additional transactions within the firm exceeded the costs of carrying out the same transactions through the market or in another firm" (Coase 1988b: p. 19). Therefore, the transaction cost theory explains the optimal size of a firm but does not offer the explanation for the process leading to this size. Another approach can be found within "evolutionary economics that embraces the phenomenon of innovation in a way that other perspectives are not able to do" (Coad 2009: p. 6). Evolutionary concepts emphasize the importance of firm-internal innovation activities. Nevertheless, it is debatable whether the contribution of innovation activities does exclusively explain the process of growth in firms. Penrose's theory and the sociological concepts focus on the availability of resources and highlight them as a central source of firm growth (e.g., Penrose 1959, Metcalfe 1993, Hannan and Freeman 1977). Although various important aspects are highlighted by the above theories, they all ignore the role of path-dependent processes within firm growth. Firm growth should be seen as complex and more precisely as path-dependent process characterized by interdependencies and linkages of a variety of idiosyncratic variables with firms being "able to learn and react creatively with subjective and procedural rationality (Antonelli 2009 p: 611).

In particular, McKelvie and Wiklund (2010) "have identified three research streams (growth as an outcome, the outcome of growth, and the growth process) and three basic modes of growth (organic, acquisitive, and hybrid)" (McKelvie and Wiklund 2010 p: 280). In respect to this issue, two fields are important in our study. First, there are approaches that aim at identifying and analysing firm growth stages and firms' development paths (e.g. Delmar et al. 2003). Delmar et al. (2003) identifies different firm growth patterns that are related to firm age, size and industry affiliation. Additionally, they focus their analysis on the variation of measures of firm growth (i.e. relative, absolute sales growth, organic growth). Among them are approaches, such as Garnsey et al. (2006), which focus on the sequence and duration of growth phases during the life-cycle of firms. They analyse new firms' growth paths that are categorized by patterns of survival, continuousness of growth, turning points, reversals and cumulative growth (for more information see Garnsey et al. 2006). A few studies have focused their investigations on the importance of growth rates. Hence, the literature for the variation of growth rates and the conceptualization of growth is quite sparse. Second, there are approaches that aim at identifying resources that contribute to the growth of firms (e.g., Penrose 1959). Nevertheless, Gibrat's Law states that firm growth is quite random, and is considered as falsified by most current researchers (e.g., Lotti et al. 2009). Nevertheless, there seems to be an agreement that firm growth, especially in a short run, is much more random (e.g., Liu et al. 1999). In this manner, Coad (2006) suggests that smaller and larger firms "operate on different frequencies due to the fact that smaller firms are quite unlikely to repeat this growth performance in the following year" (Coad 2006 p: 3). Apart from these issues, it is commonly assumed that there are some determinants which exert influence on firm growth. For example, Oliveira and Fortunato (2006) find that firms with higher foreign participation (e.g. export orientation) appear to grow faster than others. Other empirical studies examine whether firm growth can be explained by firm characteristics, such as size and industry affiliation (e.g., Harhoff et al. 1998, Bottazzi and Secchi 2006). Another important issue is the relation between strategic decision-making and firm performance (e.g., Baum 2003). Simultaneously, Baum (2003) suggests that the speed of the entrepreneurs' decision-making (e.g., investments in R&D) predicts subsequent firm growth and profits.

2.2.2 Empirical evidence

The economic literature on factors that contribute to the growth of firms has focused on various aspects. This literature mostly distinguishes between firms' characteristics in terms of internal growth factors and in terms of external growth factors. Thereby, the empirical studies on firm growth have mainly studied the internal firm-specific factors, such as the size of firms (e.g. Luttmer 2011), and more recently R&D activities (e.g., Coad and Rao 2010).

The so-called 'stylized facts' on the dependence of firm growth on firm size and industry affiliation are the starting point for our study. For instance, previous research tends to emphasis that especially smaller firms experience higher growth rates than their larger counterparts. It was found that the dynamics and patterns of growth vary with firm size. Underlying mechanisms, such as the time scale on which firms operate (e.g. Coad 2006) differ and consequently preclude the possibility to pool together differently sized firms. Particularly smaller firms rely on external resources and operate on different frequencies (e.g., Coad 2006). Researchers like Storey (1994), Kirchhoff et al. (2002), Davidsson et al. (2002) and Henrekson and Johansson (2008) conclude that firm size is one of most important factors for the determination of firm growth. Bigsten and Gebreeyesus (2007) find that the size of manufacturing firms is inversely related to their growth. Caves (1998 p: 1947) concludes that "Gibrat's law holds for firms above a certain size threshold, whilst for smaller firms growth rates decrease with size". A study by You (1995) surveyed the literature and arrived at a similar conclusion. Hart and Oulton (1996) study the relationship between size and growth and they find that the growth in smaller firms is entirely related to size. In contrast, Haltiwanger et al. (2010) argue that the correct causality runs from age to growth rather than from size to growth. Their results imply that often size might be an operationalisation of age. A bigger part of the studies conclude that firm growth is related to specific sectors and industries. Gallagher and Miller (1991) confirm that growing firms are overrepresented in some industries, especially in services, finance and distribution. Likewise, Davidsson and Delmar (2003) study commercially active firms in the private and non-governmental sector of Sweden and prove that high-growth firms are overrepresented in growing industries.

A magnitude of the studies focuses on the impact of innovation on the growth prospects of firms (e.g., Almus and Nerlinger 1999, Coad and Rao 2006, Autio et al. 2007). Already Mansfield (1962) stated to the fact that innovation activity determines firm growth. In his study he shows that firms that introduced innovation seem to growth much faster than others do. Simultaneously, he finds that smaller firms benefit much stronger from innovation activities than others firms (e.g. larger firms). Based on these and further studies, innovation is acknowledged as one of the key drivers of firm performance and firm growth. Similarly, Del Monte and Papagni (2003) show that the growth rate of firms is positively correlated with research intensity. Apart from this finding, they additionally find that R&D impacts firm growth much stronger in the case of traditional industries than in high-tech sectors. In line with this, Adamou and Sasidharan (2007) argue that R&D is an essential determinant of firm growth and find that an increase in R&D induces higher growth irrespective of the industry. By relating innovation efforts to sales growth for incumbent firms, Coad and Rao (2008) observe that innovation is of crucial importance to high-growth firms. Coad and Rao (2010) also find that firms are willing to increase their R&D activities after a positive growth shock. However, the findings for growing and shrinking firms are not symmetric: "firms are less willing to reduce their R&D levels following a negative growth shock than they are willing to increase R&D after a positive shock" (Coad and Rao 2010 p: 127). Some study show that especially university R&D expenditures are positively related to new firms formations (e.g. Kirchhoff et al. 2007). However, some studies have difficulties in identifying a significant impact of innovation efforts on firm growth. For example, Brouwer, Kleinknecht and Reijnen (1993) find that R&D expenditure has no significant impact on the growth rates of firms. Corsino and Gabriele (2011) state that innovations, in general, do not affect firm growth significantly. In contrast, they find that incremental product innovations affect the revenue of certain business units. Finally, the study by Yasuda (2005) points to the fact that the impact of R&D on firm growth is positively related to each other.

In contrast to the high acknowledgement of R&D activities, only few studies in the field focus on the importance of *exports*. An article by Wijewardena and Corray (1995) presents weak statistical support for the hypothesis that greater export orientation leads to better growth performance in small industries. In this line, Wijewardena and Tibbits (1995) support the hypothesis that greater export orientation leads to better firm performance. As a theoretical explanation, the learning-by-exporting hypothesis was brought forward by Clerides et al. (1998). Some empirical studies confirmed the importance of trade for intra-firm learning that might lead to subsequent growth (e.g. Dosi et al. 1990). However, an increase in technological competences affects positively the firms' competitiveness and opens up new possibilities for trading (Boschma and Iammarino 2009) and growth. In this study we primarily want to study the contribution of internal factors and their direct impact on firm growth in smaller firms. Hence the involvement in trading activities can be used as a growth related driver (especially in smaller firms). As we know high- and medium-tech firms are characterized by higher export intensities (Raspe and van Oort 2008). Actually, the study by Bojnec and Xavier (2007) shows that export orientation reduces the firm exit. Another study by Liu and Hsu (2006), based on 280 Taiwan manufacturing firms, finds that the growth of firms is positively related to export. Using data on Austrian manufacturing firms, a paper by Pfaffermayr (2004) analyses the impact of the propensity to export on the growth performance of firms. The results show that foreign affiliate activity seems to preserve and even reinforce a firm's growth process.

Firm growth characteristics are also related to the probability of various development paths, such as permanent growth or decline. The growth of firms tend to be non-linear and prone to interruptions and setbacks (Garnsey et al. 2006 p: 1) especially in smaller and younger firms. There might be recurring patterns of firm growth processes in certain firm groups associated with the emergence and existence of typical development paths. Hence, exploring non-linearities in the growth processes highlights the question whether development paths may be seen as explanatory patterns for their own, with determinants that differ from those of average growth. Obviously, the literature on development paths of smaller businesses is quite sparse and is still a challenging task in the field. Therefore, this study moves the perspective from average growth (short-run) to the structure of development paths. Changing the perspective from short-run to development paths might provide many additional detailed insights into firms' growth processes.

However, studying longer growth paths faces the problem of data availability. Only few data bases provide information about growth path of firms of, at least, ten years. Using one of the few such data bases come with the disadvantage that our study does not have many independent variables. However, this is not a severe problem, because growth is largely random, and hence there are no pressing concerns of missing variables bias. Nevertheless, we are aware of the fact that there are other growth-enhancing variables that might contribute to the existence and emergence of development paths.

2.2.3 Derivation of hypotheses

A few studies have focused their examinations on the sequence and duration of the growth phases during the life course of panel-firms. A study by Garnsey et.al (2006), based on 25 evolving firms operating in four different sectors, dealt with the categorization of these firms. This categorization was based on different features of new firms' growth paths. Similarly, Garnsey and Heffernan (2005) show "that many different development paths exist and that the actual paths can be traced by a variety of growth measures at varying intervals" (Garnsey et al. 2006 p: 11). However, while this literature provides good knowledge about different potential development paths, it provides little knowledge about what firm characteristics are connected to which development paths. Therefore, we combine that literature on growth paths with the literature on the determinants of firm growth. We examine whether the findings for the explanation of firm growth can be transferred to the explanations of firm's development paths. Hence, the question is whether the determinants of growth are robust with respect to changing the perspective from a single growth step or average growth to a development path. To our knowledge the characteristics of firms that are related to certain development paths have not been comprehensively studied so far. Since no other information is available, the basic assumption is that growth determinants are robust to such a change in perspective. This would imply that we can transfer the findings on growth determinants in the literature to the explanation of development path. Therefore, we formulate this assumption as our embracing hypothesis:

H1: The firm characteristics that are related to one-step or average growth are the same as those that are related to permanent growth paths.

However, it is far from clear whether such an assumption is adequate. In fact, whether this assumption is adequate is the embracing research question in this paper. Nevertheless, we will formulate hypotheses in the following that are based on the assumption that each finding on one-time or average growth can be transferred directly. Hence, rejecting hypotheses in the empirical part implies that there are differences between one-time or average growth on the one side and the detailed growth dynamics on the other side. Above we reported that the size of firms is a determinant of firm growth that is repeatedly confirmed in the literature. An inverse relationship is found. Hence, if these results can be transferred we should find that development paths with permanent growth are more frequently found among small firms. However, it is also known that small firms show higher fluctuations in their growth rates than large firms. Larger firms are often very stable. We suggest:

H2: (a) Permanently growing firms are more frequently found among small firms, (b) while large firms are more often characterised by a stable size.

As discussed above (section 2.1), innovation activities are found in most of the literature to be a crucial determinant of firm growth. The database that we use provides information about two variables related to innovation activities of the studied firms: the well-studied indicator of R&D expenditure and the expenditure for innovation projects. The expenditure for innovation projects is even more related to innovation activities, since it excludes development activities. Although there are studies that do not find a significant impact, we assume that innovation effort helps firms to grow and that this effect can also be transferred to our growth dynamics perspective. Furthermore, we assume that innovation expenditures lead to even higher innovativeness and, thus, even higher competitive advantages on the market, so the effect on firm growth is even stronger. We put forward:

H3: Persistent growth paths are more likely to be found among firms that are characterised by high innovation efforts measured by (a) the total amount of R&D expenditure and more explicitly (b) the expenditure for innovation projects.

Finally, the literature reports a positive effect of the export share of firms on its growth rate. Again, it is plausible that this effect is of permanent nature. Firms that are highly export oriented should show continuously higher growth rates. Hence, we investigate:

H4: Persistent growth paths are more likely to be found among firms that have high export shares.

2.3 Methodology and data

2.3.1 Data source and firm sample

We use the Mannheimer Innovation Panel as data source. In this panel some more than 2.500 firms are questioned each year about their economic situation and processes. All firm characteristics that are relevant for our study are recorded in the Mannheimer Innovation Panel. Nevertheless, we are not able to use the entire data set. The aim of our analysis is the identification of determinants for firms' growth paths. The growth paths are explained in section 3.2. Data for several years is required. We consider the period from 1992 to 2007 and include in our analysis only firms that have participated in the questionnaire in each two-year period at least once. There are 441 firms that satisfy this criterion. Two additional conditions are applied that reduce the sample further. First, we restrict our analysis to the manufacturing sector (NACE-2-digit industries: 15 - 36), reducing the sample to 278. We examine the manufacturing sector, because no survey took place in the service sector in the years before 1995. Hence, for the manufacturing sector studying a longer time period is possible. Second, our sample includes only small and medium sized enterprises with less than 250 employees. In the case of larger firms growth is influenced by mergers and acquisitions. We find that about 43 percent of the large firms are influenced by mergers. On average, the turnover of large firms increases by 10 percent due to these mergers. Therefore, we exclude these firms from the analysis. Finally, the sample consists of 178 manufacturing firms. The distribution of firm size is presented in the appendix Table 2.1. Most of the firms in our sample are considered as small-sized firms (55.6 percent).

2.3.2 Operationalisation of firms' development path

As presented above, there is a huge literature on firm growth. This literature provides clear concepts for the measurement of the growth of firms. In respect to a study by Garnsey et al. (2006 p: 11) "firm's growth can be measured in terms of inputs (e.g. employees), in terms of value (e.g. assets) and in terms of outputs (e.g. sales)". There is little agreement in the literature about what measure should be taken. Most common is the use of turnover growth rates or the number of employees (i.e. logarithms). In our case, numbers of employees tend to be the best choice. Employment data is less influenced by price effects, productivity effects, exchange rate effects and tax consideration. Furthermore, in our sample, employment data is less deteriorated by missing data. Therefore, we use the relative growth indicator on the basis of employment to measure firm growth:

$$\text{growth}_{i,t} = \log\,(size_{i,t+1}) - \log\,(size_{i,t})$$

However, we are not interested in growth as such, but in development paths. We want to analyse whether firms grow continuously and what characteristics these continuously growing firms share. Therefore, we have to classify firms according to their development path. The idea is to classify for each time step whether a firm grows, declines or stagnates. Continuously growing firms are those firms that grow in each time step. Therefore, we require a cut-off point that indicates the level at which firms are classified as being growing. In the empirical literature on firm growth, there is no explicit consensus of how to define such a cut-off point. Studies measuring cut-off points of growth differ in terms of their definitions of growing firms, measurement of growth and the determination of the time period or time frame of study. Furthermore, they differ regarding the industries they observe, age and size of firms, methods and geographical coverage. This leads to a different identification of these firms in specific countries and sectors. In this paper, we employ the codes of the growth rates in reference to a paper by Garnsey et al. (2006) that dealt with the categorization of new growing firms. However, we do not restrict our analysis to one cut-off point. On the one hand, the choice of the cut-off point is arbitrary and has a strong influence on the results. Using different cut-off points allows us to check the robustness of our results. On the other hand, more information is gathered by repeating the analysis with different cut-off points, because varying results provide additional information. We use four different cut-off points: 2.5%, 5.0%, 7.5% and 10.0%. Growth rates above 10.0% are already rare, so that cut-off points above 10.0% are not helpful. Four different cut-off points provide a good picture of the dependence of the results on the cut-off point. Although a cut-off point of 2.5% is fairly low, maybe too low for some industries, we use it to obtain a complete picture. Examining further cut-off points does not provide further crucial information. We define the following classes:

One-step growth = employment growth at least 2.5%, 5.0%, 7.5% or 10.0% p.a.
One-step stagnation = employment change less than 2.5%, 5.0%, 7.5% or 10.0 % p.a.
One-step decline = employment decline at least 2.5%, 5.0%, 7.5% or 10.0% p.a.

This basic definition of growth, stagnation and decline for one time step is now used to define development paths. Similar to Garnsey et al. (2006) we explore sample firms to identify trends in their paths of growth without losing important information on comparative patterns. In our sample we actually have data for the years 1992 to 2007. However, many firms participate in the Mannheimer Innovation Panel not every year, so that our data base has missing data. Growth path of firms can only be studied if we have data for each period. Hence, to ensure maximum data availability, we aggregated the whole time span into 8 time periods: 1992/1993, 1994/1995, 1996/1997, 1998/1999, 2000/2001, 2002/2003, 2004/2005 and 2006/2007. This reduced the number of time periods from 16 to 8 but increases the number of firms that can be included in the analysis tremendously. A further aggregation of year (three or four years) increases the number of firms only slightly, so that such a further reduction of time periods is not justified. We measure the growth rates of firms between two time periods, such as 1992/1993 to 1994/1995. By this we obtain seven growth steps for our analyses. In each time period we have for each firm, at least, information for one of the two years.

Hence, we are able to classify each firm into the above three categories for each of the seven time-steps. Table 2.2 (in the appendix) pictures the total number of firms in the different development paths. To examine the development paths along these seven time steps we employ the following three main categories of development paths: Growth (GR), Stagnation (ST) and Decline (DC). The three main categories comprise different variations of sub-categories. Our categorisation is determined by a simple justification. We already know from Coad (2006 p: 3) that "small firms and large firms appear to operate on different frequencies", meaning that small firms are quite unlikely to repeat the same growth performance in the following year. Therefore, the growth of smaller firms is considered as erratic and 'start-and-stop' dynamics (Coad 2006). Knowing this dynamics, we set up categories that are less strict to the assumption that smaller firms could follow a steady and constant development path such as larger firms. Larger firms are more likely to experience positive feedback in their year-to-year growth rates (Coad 2006). To capture persistent paths and 'start-and-stop' growth dynamics of smaller firms, we define different variations of more or less persistent developments. In a very strict definition one could argue that persistent growth is only present if a firm grows in all seven time steps that are analysed. However, such a persistent growth is extremely rare in our sample. Therefore, one has to be less strict and require only six, five or even four growth events within the seven time steps. Again, we aim to obtain as much information as possible and use all these weaker definitions adopting a 4-5-6 criterion representing different levels of strictness. With this categorisation the firms retain their natural growth characteristics and can easily be grouped. Furthermore, we expect that most firms show, at least, in four out of seven of the time steps a similar development (i.e. GR, ST, DC). If this condition is failed the firm falls into the category of Mixed. Thus, our development paths are classified as:

Growth path (GR)
GR_6: We say that a firm follows a very persistent growth path if it grew, at least, in six of the seven time steps and never experienced a period of decline.
GR_5: Firms show an average persistent growth path if they grew, at least, in five of the seven time steps and never experienced a period of decline.
GR_4: We say that a firm follows a less persistent growth path if it grew, at least, in four of the seven time steps and never experienced a period of decline.

Stagnation path (ST)
ST_6: We say that firms very persistently stagnate if they stagnate, at least, in six of the seven time steps.
ST_5: We say that firms show average persistent stagnation if they stagnate, at least, in five of the seven time steps.
ST_4: We say that firms show less persistent stagnation if they stagnate, at least, in four of the seven time steps.

Decline path (DC)
DC_6: We say that a firm very persistently declines if it declined, at least, in six of the seven time steps and never experienced a period of growth.
DC_5: Firms show an average persistent decline if they declined, at least, in five of the seven time steps and never experienced a period of growth.
DC_4: We say that a firm shows less persistent decline if it declined, at least, in four of the seven time steps and never experienced a period of growth.

Mixed path (Mixed)
Mixed_6: We are not able to allocate the firm to the category of GR_6, ST_6 or DC_6.
Mixed_5: Firms that can not clearly be grouped into GR_5, ST_5 and DC_5.
Mixed_4: We say that the firm cannot be classified into GR_4, ST_4 and DC_4.

Finally, we define for each set of categories (GR_6, ST_6, DC_6), (GR_5, ST_5, DC_5) and (GR_4, ST_4, DC_4) a category that contains all other firms (Mixed_6, Mixed_5, Mixed_4). Through this we obtain a complete categorisation for each level of strictness. The Mixed_ category contains all firms that do not show a persistent development. These firms show a quite volatile development and it is also interesting to study which firm characteristics are related to a volatile development path. This implies that we have 12 categories in total. As stated above, we use four different cut-off points for the identification of the development paths, implying that there are 48 categories in total. Each combination of cut-off point and strictness with respect to persistency defines one classification system. For each such combination we have four different classes, such as GR_6, ST_6, DC_6 and Mixed_6.

The numbers of firms categorized in these different categories are shown in Table 2. For each cut-off point and strictness 178 firms are grouped into four different growth paths (GR_6, ST_6, DC_6, Mixed_6=178), (GR_5, ST_5, DC_5, Mixed_5=178) and (GR_4, ST_4, DC_4, Mixed_4=178).

Each of these categories is used as dependent variable in one of the regressions conducted below, except of those categories in which the number of firms is too small. Hence, we are going to deal with a dependent variable that is binary, i.e. the dependent variable takes only two values: 0 or 1. The idea of our analyses is to examine the characteristics of firms that make certain development paths more or less likely. Above we have seen that defining development paths contains a number of arbitrary decisions, such as choosing a cut-off point for growth and decline or the strictness in the persistency definition. In order to obtain results that do not depend on such arbitrary decisions, we analyse 48 categories. Each category is studied separately, meaning that we compare the characteristics of the firms that fall in this category with the characteristics of all other firms. This leads to a complete picture of the characteristics that are specific for each category. Furthermore, it allows for an easy comparison of the results for different cut-off point and levels of strictness.

2.3.3 Independent variables

In line with the hypotheses in Section 2.2.3, we use four independent variables for which we examine whether they are good predictors for the category in which a firm falls. These four independent variables are the size of the firm, the export rate, the R&D expenditures and the innovation activity. In addition, we use industry assignment as a control variable because it is repeatedly reported in the literature that firms in different industries differ in their growth rates. However, it is beyond the scope of this paper to examine the differences between industries. Therefore, the results for the industry dummies are not discussed. Attention should be paid to the handling of missing values. These missing values are assumed to occur at random. In each conducted regression the cases with missing values are excluded. However, this step is taken for each regression separately, so that the number of considered observations differs between the conducted regressions. The data used and the definitions of the independent variables are described in the following.

The independent variable *SIZE* is the log-value of the number of employees. To control for firm size and to avoid endogeneity we use the log form of employment reported in the first year of observation, in time period 1992-1993. In the Mannheimer Innovation Panel the firms report their export orientation (*EXPO*) in the form of the ratio between export and total turnover. We use the value of this ratio in the first year or the first available value of observation as independent variable *EXPO* in order to avoid endogeneity problems. The firms are also asked in the Mannheimer Innovation Panel to report their expenditures for innovation activities. The firms are asked to estimate the amount of expenditure for different innovation activities such as total expenditure for *R&D* and expenditures for innovation projects (*INNO*). Thus, the amount of expenditure for *INNO* is also captured by the independent variable of *R&D*. We distinguish between both variables to gain a deeper insight in the impact of different innovation activities on the different development paths. First, firms report in the Mannheimer Innovation Panel also the ratio between their R&D expenditure and their total turnover (*R&D*). We use the value for the first year of observation or the first available value in case of missing values. Second, we highlight the impact of innovation projects (*INNO*) measured as the ratio of total expenditure to total turnover. Again, we use the value for the first year of observation or the earliest available value. Therefore, *INNO* and *R&D* measure approximately the same things and are highly correlated. We use only one of these two variables in each regression. As a last step, the Mannheimer Innovation Panel reports for each firm its industry classification (*INDUSTRY*). With a total number of 178 firms, there are only a few firms in each class. Therefore, we aggregated the NACE-2-digit industries classification. Our aggregated industry classes are presented in Table 2.3 (in the appendix).

2.3.4 Regression approach

In order to compare the results for development paths with the results of the standard approach explaining average growth, we set up a regression approach with a linear model. The dependent variable is a continuous variable. It measures the relative growth of firms in terms of the change in the logarithms of employment from first year to last year of observation:

$$
\begin{aligned}
&(\log(empl_{2006/2007}) - \log(empl_{1992/1993}))_j \\
&= a_0 + a_1 \cdot EXPO_j + a_2 \cdot INNO \mid R\&D_j + a_3 \cdot SIZE_j + a_{4-16} \cdot IndDummy_{1-13,j} + \varepsilon
\end{aligned}
\tag{1}
$$

As independent variables we use the *EXPO* activity and the R&D expenditures as well as the log form of employment number *SIZE*. Due to multicollinearity we also conduct a separate regression excluding *R&D* and including the variable *INNO* instead[1]. The analysis explores the relationship between average firm growth and the potential determinants. It provides a comparison basis for our main analysis and allows answering the question whether average growth and various growth paths are related to the same firm characteristics.

We apply a multiple regression with a logit model. The dependent variable is discrete, 0 or 1, denoting whether a firm shows the category of development path under consideration or not. The regression framework follows a discrete choice model specifying the probability for each category Cat ϵ {GR_6, GR_5, GR_4, ST_6, ST_5, ST_4, DC_6, DC_5, DC_4, Mixed_6, Mixed_5, Mixed_4} as dependent variable with Pr (Cat=..) = 1/(1+exp(x'β)). The independent variables are defined as follows:

[1] Moreover we find *R&D* to be highly correlated with *INNO* (r=0.94***).

$$x_j^{'}\beta = a_0 + a_1 \cdot INNO \,|\, R\&D_j + a_2 \cdot EXPO_j + a_3 \cdot SIZE_j + a_{4-16} \cdot IndDummy_{1-13,j} + \varepsilon \quad (2)$$

As independent variables all the above described variables are used. Employing different variations of development path categories, the analysis attempts to explore the prospective long term relationship between firm size, export orientation, R&D expenditure, innovation projects and firm growth. As mentioned above, the variables *R&D* and *INNO* are highly correlated, so that the statistical phenomenon of multicollinearity appears. To avoid multicollinearity between the variables *R&D* and *INNO* we set up two different logistic regression models, in which each time one of the variables is excluded.

2.4 Results and interpretation

2.4.1 Regression results

We conducted two regressions for the average growth of firms: one including all independent variables except *R&D* and one including all independent variables except *INNO*. The results are reported in the appendix Table 2.4[2]. Above we defined 48 development path categories. For some categories the number of firms that are classified into these categories is so small that we did not conduct a regression analysis. For all other categories two regressions are conducted: one including all independent variables except *R&D* and one including all independent variables except *INNO*. The results are reported in the appendix Tables 2.5 and 2.6[3]. We discuss the results in the following separately for the different hypotheses that have been set up in Section 2.2.

2.4.2 Average growth vs. development paths

The literature provides comprehensive knowledge about firm characteristics that cause growth, at least for a short term or on average. We start our result discussion with a comparison between the firm characteristics that relate to average growth and the firm characteristics that relate to various development paths. Above we formulated Hypothesis 1, which states that *firm characteristics that are related to one-step or average growths are the same as those that are related to permanent growth paths*. To check this hypothesis, we compare the results in Table 2.4 and Tables 2.5 and 2.6. First, we find no significant coefficients for the independent variables *EXPO*, *R&D* and *INNO* in the case of average growth (Table 2.4 in the appendix). If we consider only the growth paths (GR_4, GR_5 and GR_6), there are also no significant results for these variables in the case of growth paths (Tables 2.5 and 2.6). Hence, for the variables *EXPO*, *R&D* and *INNO* we find similar results for their relationship with average growth and growth paths. This confirms Hypothesis 1. However, the results for the other development paths provide additional significant information that is discussed below. Hence, Hypothesis 1 does not hold for all development paths. Second, if we look at *SIZE* as independent variable, there is a significant negative relationship found between *SIZE* and average growth, as it is usually found in the literature. The result is more volatile in the case of development paths. The coefficients are always negative for the growth paths (GR_), except in one case, so that we may conclude that smaller

[2] The results for the industry dummies are not presented because they are not in the focus of this paper.
[3] The results for the industry dummies are not presented because they are not in the focus of this paper. Most dummies have never or rarely significant coefficients. Exceptions are the coefficients for the dummies for plastic, metal, machinery and electrical equipment. They become especially significant for the stagnation and decline paths.

firms are more likely to show growth paths (GR_4, GR_5 and GR_6). However, this result is not always significant, especially not for strong growth paths (GR_6). Again the analysis of development paths provides additional information that is discussed below. To sum up, Hypothesis 1 is partly confirmed by our results. The result for average growth and the growth paths, GR_4, GR_5 and GR_6, are at least similar. Hence, the characteristics that come together with high average growth are usually also related to occurrence of repeated growth. However, an analysis of development paths provides additional information, as discussed below.

2.4.3 Firm size

We concluded above from the findings in the literature that small firms should be expected to grow permanently more often (Hypothesis 2a), while large firms should be expected to show more often stagnation (Hypothesis 2b). The former claim (Hypothesis 2a) is confirmed by our results. We find for most categories that denote permanent growth (GR_6, GR_5 and GR_4) a significantly negative coefficient for the size of firms. This means that larger firms are less likely to show permanent growth, while smaller firms are more likely to show growth paths. The details of the results show two interesting aspects. First, the coefficients increase in almost all cases with the size of the cut-off point. This means that the difference between smaller and larger firms in the probability to show permanent growth increases with the cut-off point. While larger firms seem to show continuous slow growth as well, only smaller firms seem able to show continuous fast growth. Second, we find differences between the growth categories. The coefficients increase from GR_6 to GR_5 and from GR_5 to GR_4. Significant results are also found for GR_5 and especially GR_4. Hence, if we only consider firms that grow almost at all time steps (GR_6), smaller firms do not differ strongly from larger firms. If we are less rigorous and include firms that also show phases of stagnation, smaller firms are strongly over-represented in the growth path (GR_4), meaning that they are much more likely to show continuous growth with some stagnation steps in between. This provides additional information about the growth process and its dependence on size. Other studies show that smaller firms grow on average faster than larger firms. However, these studies look at one-time or average growth. If we extend the perspective to a longer period, smaller firms are also more likely to show continuous growth. However, the regression results also show that smaller firms are more likely to be found in the mixed categories (Mixed_6 and Mixed_5). Smaller firms are more influenced by economic fluctuation (e.g. price effects, productivity effects). Hence, smaller firms exhibit greater up- and downturns in their life cycles. The literature states that firm size is one of the most important factors for the determination of firm growth (e.g., Wijewardena and Tibbits 1999). We also find a strong relationship between firm size and permanent growth. Thus, the results from the literature can be transferred to our research question. While the literature finds that small firms make a larger contribution to net employment growth (Davidsson et al. 2002, Henrekson and Johansson 2008, Halabisky et al. 2006), we find that larger firms are less likely to grow continuously. Small firms might grow faster but their growth is more volatile. The other part of Hypothesis 2 (part b) is confirmed by our analysis. Although this finding is not always significant, we find evidence for the claim that larger firms are more likely to show continuous stagnation. Larger firms seem indeed to be less vulnerable to changes in their circumstances. We might conclude that large firms are more often found in all categories of permanent development. However, this does not hold for permanent growth, while it also holds for the categories of continuous decline (DC_6 and DC_5). Hence, the higher sustainability of development in larger firms only applies to stagnation and decline.

2.4.4 Innovation efforts

In the literature innovations are usually seen as a determinant of growth. Empirical research on firm growth confirms this belief. Therefore, Hypothesis 3 states that firms with higher innovation efforts should also be more likely to show persistent growth paths. Put differently, we highlight the impact of (a) the total amount of R&D expenditure and more explicitly (b) the expenditure for innovation projects on development paths. Hence, in our analysis we use two measures for innovation efforts: R&D expenditures (*R&D*) and innovation projects (*INNO*). Both cannot be used in the same regression analysis due to multicollinearity problems. Therefore, we use two regressions, including one of these measures each time. We expect innovation efforts measured by *R&D* and *INNO* to be important especially for permanent growing firms. Furthermore, we expect (Hypothesis 3b) that this effect is stronger for innovation projects (INNO).

This is only partially confirmed by our analyses. First, we do not find any significant relationship between innovation efforts and the likelihood of permanent growth or permanent decline. High innovation efforts seem neither to come together with continuous growth nor to relate to less likely decline. Looking at the coefficients, we find a quite mixed picture for the growth paths, while in the case of the decline paths most coefficients are negative. Hence, we find, at least, a weak tendency that firms with high innovation efforts are less likely to decline continuously. One significant result is found for the stagnation paths: A positive relationships is found between innovation efforts (*R&D* and *INNO*) and weak stagnation (ST_4) for a 7.5% cut-off point. For cut-off points above 2.5% most coefficients of the relationship between innovation effort and stagnation are positive. Thus, we find some evidence that firms with higher innovation efforts show a more stable development. For a cut-off point of 2.5% we find the opposite: Significant positive relations between *R&D* expenditures and mixed development paths (Mixed_6 and Mixed_5). This means that higher innovation efforts come together with a higher probability of small fluctuations and a lower probability of large fluctuations in the development of the firm. The latter is significant only for R&D expenditures. To sum up, Hypothesis 3 is not confirmed by our results. Firms with high innovation efforts are neither more likely to show continuous growth nor less likely to show continuous decline. However, we find that firms with high R&D expenditures are less likely to show large fluctuations. In contrast to our expectation (Hypothesis 3b), this effect is less strong (even not significant) for expenditures on innovation projects.

2.4.5 Export share

Above we hypothesised that higher export shares lead to a higher probability of continuous growth (Hypothesis 4). This is not confirmed by our empirical examination. We find no significant coefficient for the relationship between export shares (*EXP*) and growth paths (GR_4, GR_5 and GR_6). However, except for the very small cut-off point of 2.5%, all coefficients are positive, so that we may conclude in line with Hypothesis 4 that high export shares rather come together with growth. In the case of decline paths the results are mixed. Looking at strongly permanent decline (DC_6) all coefficients are negative and one even significant, while for weak permanent decline (DC_4) we find significantly positive coefficients. Hence, firms with high export rates are more likely to show weak decline paths but are less likely to show strongly repetitive decline. Similar to high innovation efforts, high export shares are related to a higher probability to show stability in size and a lower probability to show mixed development paths. This holds especially for strong stability (ST_6) with rather narrow cut-off points (5% and 7.5%). Hence, firms that show extreme stability are mainly firms with high export shares. To sum up, Hypothesis 4 is not confirmed by our results. Firms with high export shares are not more likely to show continuous growth. However, these firms are at least less likely to show strong continuous decline. Furthermore, we find that these firms are less likely to show fluctuations.

2.5 Implications and limitations

Firm growth and its growth-enhancing factors have been repeatedly studied, but the existence and emergence of development paths has been largely neglected. Every firm can be said to have a development path, but what exactly do we mean by 'development path' or 'growth path'? Further studies are needed to elaborate the definition of development paths and also the sequence and duration of such patterns. Firm growth, in the short run, is much more random. Therefore it might be interesting to take a more long-run perspective, and see if it is possible to find some regularity in the growth process here (e.g., Liu et al. 1999, Lotti et al. 2009). One of the main characteristics of firm growth is that it is largely idiosyncratic. To get new insights, we need new statistical approaches. We used a multiple regression with a logit model. But a multinomial logit model seems additionally adequate to handle this situation, i.e. a model with multiple mutually exclusive outcomes given by the four possible development paths. An alternative approach to looking at growth paths might be sequence analysis (e.g., Malo and Munoz-Bullon 2003). Therefore our original statistical approach that we use here is interesting but highlights a small part of a heterogeneous and idiosyncratic process. The detailed insight into 'further' variables, interrelationships and interdependencies is a great benefit in the explanation of the structure and procedure of the firms' growth processes. Generally speaking, this work derives a detailed insight of the distinction between short-run and long-run perspective of growth and controls for 'stylized facts' such as firm size and industry affiliation grounded in the previous empirical literature. It is also highly important to gain more knowledge about firms' market strategy. It moreover lies beyond the scope of this paper to investigate the mechanisms behind our findings. A limitation of quantitative analyses is that the properties of the firms constitute idiosyncratic characteristics of the growth processes and can therefore be hardly transferred to an overall conclusion. It would be interesting to learn how exactly sustainable growth is processed, where specific variables indeed are effective and how smaller firms exhibit continuous growth or attempt to establish a position as a successful market participant. Further studies should provide case analyses to capture the individual and idiosyncratic characteristics and activities of firms.

Most quantitative empirical studies have only considered growth-enhancing factors and the existence of growth paths separately. Hence, most of these studies focus on growth drivers and on one single development patterns (i.e., growth paths), thereby neglecting the linkages between both fields of interests. Furthermore, implications of our analysis indicate that further studies are required that analyse variables and success drivers that might affect development paths such as firm-internal strategy and entrepreneurial orientation. This study should be seen as a starting point for implementing further research directions (e.g. entrepreneurial issues).

2.6 Conclusion

In this paper we analyse whether the factors that are found to be related to firm growth in the literature are also related to continuous growth of firms in the medium term. The literature usually examines whether certain characteristics are related to a higher average growth rate.

We study whether these characteristics are also related to the probability of various development paths, such as permanent growth. Hence, this paper moves the perspective from average growth to the structure of development paths. We find that changing the perspective does not change the results fundamentally but provides many additional detailed insights. Smaller firms are more likely to show growth paths, especially growth paths in which they experience sometimes growth and sometimes stagnation. In contrast, larger firms are more likely to show stagnation paths or decline paths. Paths of permanent decline are especially rare among smaller firms. We do not find statistical confirmation for relationships between export shares and innovation efforts and growth paths. However, this might be a result of the small sample size. Furthermore, high export shares and innovation efforts come, on average, along with a higher stability of firm size. One might interpret that high export shares and innovation efforts make firms less vulnerable to unexpected circumstances (e.g. short-term fluctuations), although more research on this is needed to make this claim substantial. With reference to our approach we conclude that studying the development paths of firms instead of average growth provides many additional insights. We find that certain characteristics of firms are related to specific development paths. For example, development paths with a mixture of growth and stagnation are especially found among small firms, while extreme stability (not more than one one-step change of more than 5%) is especially found among firms with high export shares. In dealing with the overall discussion about firm growth, it can be suggested that firm growth is understood as heterogeneous process with high complexity and idiosyncratic characteristics (Coad 2009). This idiosyncrasy is partially caused by the high number of patterns, growth factors and knowledge sources which are basically involved in the growth process. So far studies on firms' development paths are quite rare; so that there is great potential for further studies on what determines how firms develop. This study is only a first step in this direction.

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2.8 Appendix

Table 2.1 Firm size in terms of employment

Size*	Cut-off points	Frequency	Percent [%] of Firms
small-sized	< =50 employees	99	55.6
medium-sized	>50 – <=250 employees	79	44.4
Total		178	100

*SME definition of European Commission (2003)

Table 2.2 Absolute number of firms in the different development paths categories

Growth Paths	Growth Rates			
	2.5%	5.0%	7.5%	10.0%
GR_6	25	29	30	18
ST_6	3	34	69	101
DC_6	20	24	20	16
Mixed_6	130	91	59	43
Total	178	178	178	178
GR_5	27	24	15	12
ST_5	15	59	102	134
DC_5	29	17	11	6
Mixed_5	107	78	50	26
Total	178	178	178	178
GR_4	46	22	10	2
ST_4	28	95	131	164
DC_4	47	17	7	4
Mixed_4	57	44	30	8
Total	178	178	178	178

Table 2.3 Type of industry

Description*	Code	NACE	Frequency	Percent [%]
Food, beverages, tobacco	1	15, 16	9	5.1
Textiles	2	17, 18	5	2.8
Leather articles	3	19	1	0.6
Wood products	4	20	2	1.1
Paper	5	21, 22	13	7.3
Petroleum products, nuclear fuel	6	23	1	0.6
Chemicals, man-made fibres	7	24	14	7.9
Rubber, plastic products	8	25	18	10.1
Non-metallic mineral products	9	26	10	5.6
Metals	10	27, 28	30	16.9
Machinery, equipment	11	29	28	15.7
Electrical and optical equipment	12	30 - 33	34	19.1
Transport equipment	13	34, 35	5	2.8
Furniture, consumer goods	14	36	8	4.5
Total			**178**	**100**

*NACE Codes Description

Table 2.4 Regression results for average growth

	Regression results with industry dummies (I)	(II)
EXPO	-0.0004 (0.0026)	-0.0002 (0.0026)
R&D	0.0036 (0.0058)	-
INNO	-	0.0020 (0.0026)
SIZE	-0.1019* (0.0519)	-0.1028** (0.0518)
Constant	-0.2636 (0.3108)	-0.2768 (0.3104)
R-squared	0.17	0.17
obs.	178	178

standard errors in parentheses
***p<0.01 ** p<0.05 *p<0.1

Table 2.5 Regression results for development paths (excluding INNO)

Growth Paths	Cut-off Point for Yearly Growth Rates	Regression Results			
		EXPO	R&D	SIZE	R^2
GR_6	2.5%	-0,000194 (0,0134891)	-0,1072251 (0,0911337)	0,0175335 (0,2399883)	0.05
	5.0%	0,0106093 (0,0112088)	0,0032537 (0,0322588)	-0,2788156 (0,2244873)	0.03
	7.5%	0,00000675 (0,0120477)	-0,0116556 (0,0372524)	-0,3115377 (0,228517)	0.07
	10.0%	0,0050014 (0,0147073)	-0,0362687 (0,0673911)	-0,3953065 (0,2795329)	0.06
GR_5	2.5%	0,0033268 (0,0123821)	0,0517871 (0,0516863)	-0,1484932 (0,2274938)	0.03
	5.0%	0,0081139 (0,0121429)	-0,0029378 (0,0377108)	**-0,4071087* (0,245125)**	0.05
	7.5%	0,0094123 (0,0143902)	-0,038148 (0,0628641)	-0,1930735 (0,2948141)	0.05
	10.0%	0,0119974 (0,0160003)	-0,0652353 (0,0960453)	-0,3789479 (0,3391613)	0.12
GR_4	2.5%	-0,0078695 (0,0098533)	-0,0066363 (0,278094)	-0,2827801 (0,188122)	0.06
	5.0%	0,0037855 (0,0136334)	0,0068772 (0,036174)	**-0,6571929** (0,2620098)**	0.09
	7.5%	0,0294806 (0,0214809)	-0,0647972 (0,0920625)	**-0,9598933** (0,4075694)**	0.18
	10.0%	-	-	-	-
ST_6	2.5%	-	-	-	-
	5.0%	**0,0272044** (0,011806)**	-0,0975521 (0,0757926)	**0,4227732* (0,2269102)**	0.16
	7.5%	**0,0152428* (0,0092133)**	0,0343222 (0,0284951)	0,2457256 (0,1730662)	0.09
	10.0%	0,0094215 (0,0084537)	0,0134732 (0,0266615)	0,2545539 (0,1643948)	0.05
ST_5	2.5%	0,0073121 (0,0154955)	-0,2931162 (0,2379768)	0,0537344 (0,2872276)	0.09
	5.0%	**0,0159811* (0,0090156)**	0,0185222 (0,0295344)	**0,4393431** (0,1832164)**	0.09
	7.5%	0,0072016 (0,0087337)	0,0322091 (0,0288701)	**0,360337** (0,1701649)**	0.08
	10.0%	-0,0048906 (0,009531)	0,0040855 (0,0303395)	**0,6716347*** (0,2026649)**	0.11
ST_4	2.5%	0,0147752 (0,0117236)	-0,1216343 (0,1138708)	0,3789972 (0,2340384)	0.13
	5.0%	0,0043355 (0,0084066)	0,015508 (0,0266854)	0,2531695 (0,1658811)	0.07
	7.5%	-0,0038929 (0,0090565)	**0,0859392* (0,0492618)**	**0,3351418* (0,1833653)**	0.07
	10.0%	-0,0100294 (0,0129035)	0,025554 (0,0590174)	**0,5759192* (0,2983868)**	0.09
DC__6	2.5%	-0,0049626 (0,0147955)	-0,8741478 (0,7506648)	**0,6590478** (0,2968549)**	0.22
	5.0%	**-0,0283487* (0,0155907)**	0,0159169 (0,0353228)	**0,4117424* (0,2478435)**	0.12
	7.5%	-0,0071369 (0,0143223)	-0,0692619 (0,0789537)	0,4054833 (0,2775025)	0.18
	10.0%	-0,0000205 (0,0134335)	-0,1780407 (0,1363345)	0,1868922 (0,2854144)	0.11
DC_5	2.5%	0,0017148 (0,0115019)	-0,1798977 (0,1227194)	**0,5877075** (0,2429721)**	0.15
	5.0%	-0,0134151 (0,015792)	-0,1088607 (0,109622)	0,3826658 (0,2759899)	0.11
	7.5%	-0,0118387 (0,0179079)	-0,0670652 (0,0871901)	0,0604756 (0,3270182)	0.10
	10.0%	0,0118194 (0,0250767)	-0,02410 (0,09523)	-0,2635206 (0,5065568)	0.12
DC_4	2.5%	0,0036273 (0,0089399)	-0,001052 (0,030488)	0,1407884 (0,186062)	0.07
	5.0%	**0,0200393* (0,0113134)**	-0,0111622 (0,0470762)	-0,0084522 (0,2782099)	0.13
	7.5%	**0,0384135** (0,0183158)**	-0,1543521 (0,1936998)	-0,4870835 (0,4484052)	0.23
	10.0%	-	-	-	-
Mixed_6	2.5%	0,0042157 (0,0104044)	**0,2163116* (0,1241115)**	**-0,328463* (0,192744)**	0.10
	5.0%	-0,0072461 (0,0082773)	0,0137483 (0,0272602)	**-0,2933241* (0,1628703)**	0.04
	7.5%	-0,0110625 (0,009256)	-0,003931 (0,0275343)	-0,2427228 (0,1735601)	0.05
	10.0%	-0,0142318 (0,0105614)	0,0258138 (0,0277206)	-0,2167041 (0,1894902)	0.06
Mixed_5	2.5%	-0,0041968 (0,0087696)	**0,131738** (0,0599865)**	-0,2490878 (0,1673309)	0.08
	5.0%	-0,0131491 (0,0090182)	0,0077772 (0,0270831)	**-0,3179033* (0,1671133)**	0.06
	7.5%	-0,0083807 (0,0095227)	-0,0080419 (0,0295739)	**-0,3735083** (0,1855768)**	0.08
	10.0%	-0,0017256 (0,0115505)	0,0312513 (0,0310355)	**-0,6293488*** (0,2402166)**	0.12
Mixed_4	2.5%	-0,0053332 (0,0097433)	0,028056 (0,0270276)	-0,0940575 (0,1780879)	0.06
	5.0%	**-0,0268563** (0,0122787)**	-0,0161956 (0,0315854)	0,0955103 (0,1920314)	0.09
	7.5%	**-0,0233896* (0,0135435)**	-0,0631852 (0,0540711)	0,0273385 (0,2113452)	0.06
	10.0%	-	-	-	-
standard errors in parentheses ***p<0.01 **p<0.05 *p<0.1					
Significant industry dummies: min = 0, avg. = 1.5, max = 10					

Table 2.6 Regression results for development paths (excluding R&D)

Growth Paths	Cut-off Point for Yearly Growth Rates	Regression Results EXPO	INNO	SIZE	R^2
GR_6	2.5%	-0,0027157 (0,0134673)	-0,0030869 (0,0110256)	-0,0045648 (0,2413978)	0.03
	5.0%	0,0108253 (0,011201)	0,0016284 (0,0101787)	-0,2799805 (0,2245619)	0.03
	7.5%	0,0004932 (0,0120787)	0,0104185 (0,0092236)	-0,3513555 (0,2323479)	0.07
	10.0%	0,0034449 (0,014538)	-0,0058355 (0,0161282)	-0,3991862 (0,281101)	0.06
GR_5	2.5%	0,0018625 (0,0123448)	-0,0062557 (0,013432)	-0,1565962 (0,2284698)	0.03
	5.0%	0,0082115 (0,121356)	0,0025345 (0,0106983)	**-0,4147112* (0,24587)**	0.05
	7.5%	0,0081274 (0,0142793)	-0,0021888 (0,0153428)	-0,2087795 (0,2966008)	0.04
	10.0%	0,0093936 (0,0155605)	0,0031371 (0,0173861)	-0,4197469 (0,3417277)	0.11
GR_4	2.5%	-0,0081587 (0,0098451)	-0,0028822 (0,0108656)	-0,2831093 (0,1879994)	0.06
	5.0%	0,0044026 (0,0136931)	0,0047575 (0,0110339)	**-0,6624091** (0,2625682)**	0.09
	7.5%	0,0272473 (0,0206172)	0,0028384 (0,0223423)	**-0,9881859** (0,41045)**	0.17
	10.0%	-	-	-	-
ST_6	2.5%	-	-	-	-
	5.0%	**0,0239972** (0,0111917)**	-0,0016224 (0,0108016)	**0,4260021* (0,227497)**	0.15
	7.5%	**0,0160397* (0,0091836)**	0,002931 (0,0086414)	0,2471928 (0,1721249)	0.08
	10.0%	0,0103946 (0,0084679)	0,0124581 (0,0114139)	0,2505186 (0,1643932)	0.05
ST_5	2.5%	0,0043458 (0,0151178)	-0,0085268 (0,02734)	0,0609862 (0,2891413)	0.06
	5.0%	**0,0165586* (0,0090242)**	0,0029642 (0,0087837)	**0,4393022** (0,1828911)**	0.08
	7.5%	0,0086299 (0,0087528)	0,0153752 (0,0125232)	**0,3600767** (0,170121)**	0.08
	10.0%	-0,0049308 (0,0095604)	-0,0012854 (0,0111665)	**0,6751778*** (0,2026326)**	0.11
ST_4	2.5%	0,0134873 (0,01155)	-0,0023246 (0,0111012)	0,3856412 (0,2360244)	0.12
	5.0%	0,0054322 (0,0084355)	0,0131521 (0,0116964)	0,2505607 (0,165982)	0.08
	7.5%	-0,0011659 (0,0089747)	**0,0361244* (0,0205899)**	**0,3534757* (0,1844332)**	0.07
	10.0%	-0,0093444 (0,0130566)	0,0109528 (0,0269872)	**0,5808198* (0,2977658)**	0.09
DC_6	2.5%	-0,0108046 (0,0156628)	-0,0331566 (0,0344176)	**0,6313557** (0,298622)**	0.19
	5.0%	-0,0281936* (0,015488)	-0,0038009 (0,0159319)	**0,4062764* (0,2455236)**	0.12
	7.5%	-0,0099985 (0,0145181)	-0,0202226 (0,264709)	0,4021561 (0,2783777)	0.17
	10.0%	-0,0047679 (0,134625)	-0,0464181 (0,0374567)	0,1392497 (0,2816532)	0.09
DC_5	2.5%	-0,0012332 (0,0115361)	-0,0297281 (0,0261421)	**0,5686524** (0,242163)**	0.13
	5.0%	-0,0175001 (0,0162138)	-0,0437258 (0,0358458)	0,3754808 (0,2797235)	0.11
	7.5%	-0,0165264 (0,0184401)	-0,0550588 (0,0454161)	0,0756552 (0,3306344)	0.11
	10.0%	0,0137028 (0,0242048)	-0,0994217 (0,0911406)	-0,5993803 (0,4745522)	0.16
DC_4	2.5%	0,0027134 (0,0089704)	-0,191403 (0,0163415)	0,1480148 (0,1859965)	0.08
	5.0%	**0,0199563* (0,011331)**	0,0010521 (0,0159406)	-0,0160145 (0,2789478)	0.13
	7.5%	**0,0334228* (0,0184677)**	-0,1326915 (0,1148853)	-0,5413325 (0,4568203)	0.26
	10.0%	-	-	-	-
Mixed_6	2.5%	0,0078864 (0,0103625)	0,0122917 (0,0129691)	-0,3042204 (0,1916758)	0.07
	5.0%	-0,0068497 (0,0082784)	0,0019366 (0,0081993)	**-0,2916406* (0,1628679)**	0.04
	7.5%	-0,0117133 (0,0092651)	-0,0110276 (0,0121754)	-0,2374774 (0,1734295)	0.06
	10.0%	-0,0138773 (0,0104496)	-0,0039162 (0,0113421)	-0,2036985 (0,1875864)	0.05
Mixed_5	2.5%	-0,0010796 (0,0084826)	0,0164166 (0,0124484)	-0,2393134 (0,1662557)	0.05
	5.0%	-0,0128781 (0,0090252)	0,0017004 (0,0082199)	**-0,3173805* (0,1670879)**	0.06
	7.5%	-0,0089218 (0,0095281)	-0,0087916 (0,0128548)	**-0,3714599** (0,1583048)**	0.08
	10.0%	-0,0013128 (0,0115148)	0,0060611 (0,0111541)	**-0,6119732** (0,2371305)**	0.11
Mixed_4	2.5%	-0,0037064 (0,0097013)	0,0127953 (0,0096335)	-0,1000738 (0,1782451)	0.07
	5.0%	**-0,0283366** (0,0122643)**	**-0,0326833* (0,0197879)**	0,097293 (0,1930825)	0.09
	7.5%	**-0,0252287* (0,0134987)**	-0,0379005 (0,0252935)	0,0148418 (0,2134385)	0.07
	10.0%	-	-	-	-
standard errors in parentheses ***p<0.01 **p<0.05 *p<0.1					
Significant industry dummies: min = 0, avg. = 1.7, max= 10					

3 Temporal Structure of Firm Growth

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The role of R&D investments in highly R&D-based firms

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Abstract

This paper examines the short-term structure of the impact of R&D investments on turnover growth, indicating differences between tangible and intangible investments. The main questions are whether R&D and capital investments accompany firms' growth in the subsequent periods and how this relationship depends on other characteristics of the firms, such as size and industry. In addition, we study the relationship between R&D investments and the autocorrelation dynamics of firm growth. We use firm level data of 1000 European companies with details on R&D investments in 2003 to 2006. A regression approach is applied with a linear model taking into account R&D activities at points in time and autocorrelation dynamics of firm growth. We find that R&D activities have, on average, a positive effect on turnover growth, while capital investments show both, positive and negative, relationships with firm growth. The relationship and its temporal structure strongly depend on firm size and industry affiliation as well as whether investments are considered as one-time or permanent activities.

Keywords: Firm growth, turnover, R&D investment, firm size, industry, capital investment, tangibles, intangibles, autocorrelation, temporal structure

JEL codes: G32, L60, M21, O32

3.1 Introduction

The growth of firms has positive macro- and micro-economic effects. Therefore, firm growth, the related factors and its explanation is a well studied field of research in the economic literature. There exists a wide range of factors that are found to affect firm performance. Usually the impacts of firm characteristics on firm growth are studied without explicitly considering time. Firm characteristics and firm growth are usually measured and examined at the same point in time. In contrast, our study will focus on the temporal structure of the influence of firm characteristics on firm growth, especially the impact of R&D activities.

R&D activities are repeatedly found to have a positive impact on growth (e.g., Banbury and Mitchell 1995, Schreyer 2000, Autio et al. 2007, Adamou and Sasidharan 2007, Yang and Lin 2007, Coad and Rao 2008). In the context of the time structure of firm growth, R&D activities have four characteristics that make them especially interesting. First, it takes time for R&D activities to become economically effective and influence growth. Investments in R&D can be expected to lead to innovations in the following years, and as a consequence, to higher sales. However, this takes some time. Therefore, we do not expect that R&D investments lead to firm growth in the same year. However, the size of the time lag is unclear. Second, we might distinguish between tangibles and intangibles investments. Tangible expenditures, in general, have a longer time horizon than intangible expenditure. We study capital expenditures, as an example of tangible expenditures, and R&D expenditures, as an example of intangible expenditures, here. The effect of R&D expenditures on firm growth is usually found to show some delay. There might be differences in the strength as well as the temporal structure of the effects of these two kinds of expenditures on firm growth, which are not studied in the literature so far. Third, most firms show quite stable R&D activities. This means that research-intensive firms usually remain research-intensive, whereas firms that do not invest in R&D usually remain R&D-inactive. Hence, it would be interesting to distinguish between direct effects of R&D activities that occur after a certain time period and a more long-term relationship between average research-intensity and firm growth. Fourth, the temporal structure of the impact of R&D activities might be influenced by the firms' characteristics – primarily firm size and industry. Besides focusing on the time structure of the R&D impacts, we also examine the time structure of growth, because it is impossible to study the first kind of time structure without knowing the latter. The autocorrelation of firm growth has been repeatedly studied in the literature (e.g. Almus and Nerlinger 2000, Bottazzi and Secchi 2003, Coad 2006, Coad and Hölzl 2008). The findings vary. We repeat this analysis in order to benchmark our results.

The study is based on a sample of 1000 firms operating in Europe. The data are recorded in the European Innovation Scoreboard, in the period from 2003 to 2006. The collected data provide firm names as well as information on R&D activities, capital expenditures, industry affiliation and size. However, the data are limited to firms with high R&D investments. We use regression analysis to identify firm growth related factors and the temporal structure. Especially, we study the impact of R&D expenditure and capital expenditure on firm growth and its corresponding time lags. The structure of this paper is as follows. Section 3.2 provides an overview of the literature on firm growth related factors and autocorrelation dynamics in regard to firm growth. Several empirical findings are used to deduce expectations for the analysis. Section 3.3 focuses on the methodology and data source. In Section 3.4, we present, discuss and interpret the results and answer our research questions. Section 3.5 concludes.

3.2 Background and hypotheses

A wide range of empirical studies exist dealing with firm growth and firm growth related factors. Research issues are the identification of firm growth stages and firms' development paths (e.g., Delmar, Davidsson, and Gartner 2003), Gibrat's Law (meaning that firm growth follows a random walk) (e.g., Bottazzi and Secchi 2006) as well as the examination of firm- and industry related growth factors on different geographical scale (e.g., Harhoff, Stahl and Woywode 1998). Previous studies have already dealt with the identification of (innovation) factors contributing to firm growth (e.g. Hölzl 2009, Coad 2009). Hence, some issues examined here, have already been addressed in previous research and can thus be used to inform our expectations.

3.2.1 R&D activities and firm growth

A magnitude of studies maintains that firms with a strong commitment to *R&D* and technology-based innovations tend to have higher growth rates than firms with a weaker commitment. Banbury and Mitchell (1995) conclude, for instance, that incremental product innovation is an important competitive factor in growing companies. The German panel results by Schreyer (2000) show that the share of firms that are qualified as 'growers' increases with the intensity of R&D activities. Del Monte and Papagni (2003) prove growth rates to be positively correlated with research intensity. They show that sales growth of firms performing R&D is higher than sales growth of firms without R&D activities. In line with this, Adamou and Sasidharan (2007) study the impact of R&D by using panel data on Indian manufacturing firms. They argue that R&D is an essential determinant of firm growth and find that an increase in current R&D induces higher growth irrespective of the industry. Likewise, Yang and Lin (2007) examined the effects of innovation on firm growth in terms of employment growth in Taiwan. Their empirical results are that innovations, measured by R&D investments and patent counts, have a positive impact on firm growth. Analysing the impacts of R&D investments in time, a few studies find these impacts to be time lagged. For example, Ravenscraft and Scherer (1982) study the lag between R&D activities and their impact on profit. They find that R&D activities impact profits with a time gap of four years. Baum and Wally (2003) show that fast decision-making affects subsequent firm growth and profit.

In our study we especially focus on the distinction between tangible and intangible innovation. The literature distinguishes between tangible and intangible factors that might contribute to growth and innovativeness (e.g., Lev and Zambon 2003, Lee 2008). Already Lev and Zambon (2003 p: 600) pointed to the fact that "integrating intangibles with tangibles […] has the potential to move" the research stream forward, meaning that "most intangibles, such as organizational capital and human resource practice, are enablers of corporate resources, rather than standalone assets". In this sense, we might distinguish R&D and capital investments. On the one hand, firms might invest in tangible factors, such as production sites, laboratories etc. On the other hand, "a more intangible issue of innovation is the processes and routines of a firm. Whether they are called intellectual capital, organizational learning, organizational routines, or simply human capital composed of proficient employees, they are part of the intangible innovation or a firm" (Lee 2008 p: 33). Investing in innovation projects increases experience and capabilities of the work force as well and shapes routines within the firm. Therefore, we study in detail the differences of the effects between R&D and capital expenditures. We understand R&D expenditures as intangible innovation and capital expenditures as tangible innovation. In the literature, little emphasis is put on the investigation of the differences between these two kinds of expenditures and their effects on firm growth as well as the temporal structure of these effects. To put it differently, economic literature has not been sufficiently focused on the impact of capital investments on firm growth and innovative performance of firms. The article by Czarinitzki and Kraft (2004 p: 325) heads in this direction showing that “the growth of firms is realized among other determinants by merger and capital investments”.

Additionally, it has been recognized that the impact of R&D activities described above is influenced by firm size (e.g. Lichtenberg and Siegel 1991, Cohen and Klepper 1996) and vary across sectors and industries. For example, larger firms are better able to exploit the outcomes of R&D activities and firms in high-tech industries put much more emphasis on R&D activities than firms in low-tech industries do. In our case, we especially deal with European (large-sized) firms with high R&D investments. Hence, the firms are more likely to pursue an international market strategy in terms of R&D investments in foreign locations. Consequently, foreign R&D investments might be able to influence the innovation performance as well as the growth of domestic firms and vice versa (e.g. Arvantis and Hollenstein 2011). We should therefore keep in mind that those firms might have strong linkages and interdependencies in their international R&D activities between the domestic and foreign locations (so-called multinational enterprises) (e.g., Chuang and Li 2010).

3.2.2 Autocorrelation dynamics in firm growth

The *autocorrelation* of growth rates provides crucial information about the firms’ growth processes (see Coad and Hölzl, 2008). Autocorrelation patterns have been examined in various studies with different results. Positive autocorrelation is found by Bottazzi and Secchi (2003). They find that firms growing in any one year of observation are more likely to repeat this performance in the following year. Other studies find no significant autocorrelation in firms’ growth rates (e.g., Almus and Nerlinger, 2000). Coad (2006) considers how serial correlation changes with two firm aspects, its size and its growth. He concludes that small firms typically are subject to negative correlation of growth rates, whereas larger firms display positive correlation. A study by Kafouros and Wang (2008) investigates the impact of R&D investments by estimating different lagged measures. They conclude that R&D activities have direct impact on firm performance. In contrast, Bottazzi and Secchi (2003) also examine time lags in their analysis of autocorrelation. They find that only one lag is significant whereas Geroski et al. (1997) find significant autocorrelation at the 3rd lag. Obviously, autocorrelation dynamics of firm growth are not only dependent on time patterns, but might also be influenced by firm characteristics such as their size. Furthermore, positive autocorrelation of growth rates might be caused by firm characteristics that stay constant in time and have an impact on growth rates.

3.2.3 Hypotheses for the impact of R&D activities on firm growth

The autocorrelation of firm growth has been repeatedly studied in the literature (e.g., Almus and Nerlinger 2000, Bottazzi and Secchi 2003, Coad 2006, and Coad and Hölzl 2008). The findings vary. We repeat this analysis for two reasons: First, we examine which results from the literature are confirmed for our data. Second, we use the results on autocorrelation for the interpretation of our results on other issues. Having in mind the research studies mentioned above, especially the study by Coad (2006), we investigate:

H1: Autocorrelation dynamics of firm growth vary with the size of firms: larger firms show positive autocorrelation, while smaller firms show negative autocorrelation.

Next, we focus on the temporal structure of R&D impacts (in terms of tangibles and intangibles) on firm growth. Investments in R&D may be expected to lead to firm growth in the following years, and as a consequence, to higher sales. The literature review concludes that R&D activities are an important growth factor. We therefore suggest that the impact of R&D activities is positive.

H2: The impact of R&D activities on firm growth is positive.

However, R&D activities do not necessarily have an impact immediately, i.e. in the same period. Tangible investments, in general, also require some time to develop an impact on firm growth. Nevertheless, we suggest that the impact of capital expenditures appears more immediately than the impact of intangibles, such as R&D expenditures, because human capital and routines are build over time and take longer to be established and R&D activities need time to result in innovations and finally market shares. We hence suggest:

H3: The positive effect of R&D expenditures tends to be time-lagged and its time lag is larger than the time lag of the effect of (tangible) capital expenditures.

Fourth, previous research shows that the impact of R&D activities might be influenced by firms' characteristics – primarily its size (e.g. Shefer and Frenkel 2005). Among others, Kafouros and Wang (2008) found that firm size is an important factor influencing the impact of R&D investments. To gain a more detailed insight into the R&D activity impacts we analyse the impact of R&D activities in relation to different firm size classes. We therefore hypothesise:

H4: The impact of R&D activities on firm growth and its temporal structure varies with firm size.

Finally, our sample covers a range of different manufacturing industries and service activities. We also know that a majority of conglomerate firms exhibit growth across specific industry segments (e.g., Maksimovic and Phillips 2002). R&D processes in these industries work differently (e.g., the chemicals and the metal industry have different structures and innovation processes). Hence, although there is no detailed literature on this issue, it seems adequate to expect strong differences in our findings if various industries are analysed separately. We pose the following hypothesis:

H5: The temporal structure of the impact of R&D activities and capital expenditures on firm growth varies across industries.

3.3 Methodology and data

3.3.1 Data source and firm sample

We use the European Industrial R&D Investment Scoreboard as data source. This data source includes 1000 European companies (see Table 3.8 in the appendix) with information on employees, turnover, sector affiliation and details on capital expenditure and R&D expenditure. These data are available for the time frame from 2003 to 2006. Hence, we are able to generate the growth rates for three time periods. It is important to mention that we exclude outliers in terms of turnover growth. The descriptive analysis shows that the data set faces a high frequency of extreme growth events which would strongly influence OLS estimates. We therefore exclude these extreme values. Additionally, we cannot distinguish organic from acquired growth. Hence, we study total growth. Finally, the sample consists of 978 firms. Table 3.8 (in the appendix) shows the firm sample differentiated by country. The highest number of observations can be found in the UK with 310 observations, which is 31.8 percent of the firm sample. Table 3.1 displays our sample within firm size classes measured by the number of employees. These size classes (by number of employees) are derived from European Commission's definition of SMEs (see European Commission (2003)).

In order to examine differences between industries, we analyse a number of industries separately. Since innovation processes are of more importance in the manufacturing sector than in the service sector, we focus on manufacturing industries. However, our firm sample contains a large number of firms from the real estate industry. Therefore, we also examine the real estate firms in comparison to the sample from the manufacturing industries. All other service industries are ignored because the sample contains only few firms of each of these industries and they have less relevance for an analysis of the effects of R&D activities. Table 3.2 presents the firm numbers for those industries that are studied separately (manufacturing industries with low numbers of firms are also not considered, such as Textiles (17), leather articles (19) or paper (21)). Furthermore, we build two further subpopulations containing all firms in high-tech manufacturing industries and all firms in low-tech manufacturing industries[1] (see Table 3.10 in the appendix). Each of these industry and technology classes is used as estimation basis of the regressions conducted below. The number of firms (final column in Table 3.2) considered in this way does not add up to the 978 firms in the sample because some are considered twice (according to their high- and low-tech classification and for a separate industry study). The descriptive stats for the individual variables are presented in the appendix (see Tables 3.12 – 3.15).

Table 3.1 Firm size in terms of number of employees (SIZE)

SIZE*	**Cut-off points**	**Frequency**	**Percentage**
SME	$5 \leq x \leq 250$	144	14.8
large	$250 < x \leq 1000$	182	18.6
very large	>1000	652	66.6
Total		978	100

Table 3.2 Type of industry within manufacturing

Industry	NACE code (2-digit NACE classification)	obs.
high-tech industries	24+29+30+31+32+33+34+35	408
low-tech industries	15+16+17+18+19+20+24+25+26+27+28+36+37	124
Food products, beverages, tobacco	15 + 16	36
Chemicals and chemical products	24	105
Basic metals and metal products	27+28+29	79
Electrical and optical equipment	30+31+32+33	172
Transport equipment	34+35	66
Real estate	72+73+74	218

[1] The classification is based on the study by Legler and Frietsch (2006). They allocate firms into high-tech (knowledge intensive) industries and low-tech industries (2-digit industrial classes).

3.3.2 Operationalisation of firm growth

Before starting with our analysis, an operationalisation of the term firm growth is necessary. In the empirical literature, there exists a wide range of definitions of firm growth. Some definitions are based on the number of employees (e.g. Kirchhoff and Greene, 1998; Schreyer, 2000; Garnsey, Stam, and Heffernan 2006; Hoelzl and Friesenbichler, 2008) whereas others are based on turnover (Daunfeldt, Elert, and Johansson 2010). More precise, Garnsey et al. (2006) shows that firm growth can be measured in terms of inputs (e.g. employees), in terms of value (e.g. asset) or outputs (e.g. turnover, profit). In our analysis, we use turnover data which is one of the most commonly used measures for growth. In the regression model we apply the relative turnover growth indicator. The characteristics of this indicator are important for the choice of an adequate regression approach. From the literature it is well-known that the logarithm of the growth of firms (e.g., profit rates) is Subbotin (exponential power distribution) distributed. However, regressions with a Subbotin distributed error term are no standard tool. The use of standard regression approaches can be justified by the fact that our residuals as well as the independent variable are approximately normally distributed. There is no evidence for a deviation from a normal distribution in our data. We also do not find other problems, such as heteroscedasticity, for our regressions with the logarithm of relative growth as dependent variable. In addition, we use the variance inflation factor (VIF) to test for multicollinearity (see appendix 3.11). To avoid multicollinearity between the different items of R&D expenditure (i.e. R&Dexp05, R&Dexp04, R&Dexp03) and capex (i.e. capex05, capex04 and capex03) we set up different regressions, each time one average values (i.e. R&Dexp or Capex) and one of the single values (i.e. R&Dexp05, R&Dexp04, R&Dexp03 and capex05, capex04 capex03) is included in the model. This procedure removes all problems with multicollinearity. Hence, we use a standard regression approach, although we are aware of the fact that the real distribution of growth differs slightly from the assumptions on which this approach is based. We define our dependent variable by measuring turnover growth *(TURN)* as the change in the logarithms of the turnover from year t-1 (2005) to turnover to year t (2006). A study by Coad and Rao (2010) investigates that sales growth are followed by growth of R&D expenditures. We therefore suggest strong associations ('positive feedback loops') between R&D activities and turnover growth. Hence, we see turnover growth as an adequate growth measure for our study. The equation for the dependent variable follows as:

$$\mathrm{TURN}_{j,t} = \ln\,(size_{j,t}) - \ln\,(size_{j,t-1})$$

3.3.3 Independent variables

To test the hypotheses, we employ five general independent variables (including the control variables there are seven). These variables are the relative turnover growth in the periods 2003 to 2004 and 2004 to 2005, firm size, R&D expenditures - which we see as mainly intangible - and capital expenditures - which we see as mainly tangible. In addition we use industry affiliation and profit as control variables because some empirical studies claim that sales growth is related to certain industry affiliation and is associated with subsequent growth of profits. As discussed above (section 3.2) we basically deal with the relevance and importance of resource-based innovation indicators (Grupp 1998), such as R&D expenditures, and investments in tangible goods, such as capital expenditures. It is beyond the scope of this study to explore performance indicators such as market cap and cash flow. As such, this enables the analysis of inputs such as R&D expenditure and capex investment to be related to outputs such as sales neglecting the performance indicators such as market capitalisation and cash flow. The independent variables are defined as follows:

Turnover (Turn03/04; Turn04/05)
We use the relative growth indicator in terms of sale to measure the firm growth from 2003 to 2004 and from 2004 to 2005. These independent variables testify whether firms that experience growth in any one year repeat this performance in the following year or two years later.

Size of firms (Size)
First, we classify the firms into three size classes: small- and medium-sized (SME) enterprises (less than 250 employees), large-sized enterprises (251 to 1000 employees) and very large-sized enterprises (more than 1000 employees). We conduct most regressions for these size classes separately. Second, in the other cases to control for firm size and to avoid endogeneity we use the log form of the employment number reported in year 2003. The frequency of the different size classes is presented in Table 3.2.

R&D expenditure (R&Dexp)
In the European Scoreboard, firms report the R&D expenditure (which we see as mainly intangibles) for each year. We measure the ratio between their R&D expenditure and their total turnover. First, we use the average of this R&D expenditure ratio for the observed years (2003-2006). Second, we use this R&D expenditure ratio for each year separately *(R&Dexp03, R&Dexp04 and R&Dexp05).*

Capital expenditure (Capex)
Furthermore, the European Industrial R&D Investment Scoreboard database presents additions to tangible fixed assets such as capital expenditure. Capital expenditures are investments used by a company to acquire or upgrade physical assets. Again, we measure the average capital expenditure as the ratio of capital expenditure to total turnover (2003-2006). Additionally, we use the capital expenditure ratio for each year separately *(Capex03, Capex04 and Capex05).*

Profit (Profit)
From a micro-economic perspective, we control for profit efficiency. To avoid endogeneity, we use the operating profit for the year 2003. We hence suggest that turnover growth might be associated with (subsequent) growth of profit (see Coad 2009). We control for this 'feedback loop' to investigate whether firms behave superior as profit has grown previously. Coad (2009 p: 73) shows that "if turnover growth have grown recently, aim to keep R&D levels at a roughly constant ratio with respect to the firm size".

Industry classes (IndDummy)
As mentioned above we use industry affiliation as a control variable. For this purpose we aggregated the NACE-2-digit industries classification. We use 11 different types of industry which are presented in Table 3.9 (in the appendix). For each sector, except one, a dummy is included in the regression analyses.

3.3.4 Regression approach

We set up a regression approach with a simple linear model (see Equation (1)). In the course of the regression analysis we find that the variables R&Dexp03, R&Dexp04 and R&Dexp05

are highly correlated with each other. The same holds for the variables capex03, capex04 and capex05. To avoid multicollinearity (see correlation matrix 3.11 in the appendix) between these explanatory variables, we set up different regression models. The comparison of the results provides information about the time structure of the impact of R&D on firm growth.

(1) $GROWTH_j = a_0 + a_1 \cdot R\&D_j + a_2 \cdot capex_j + a_3 \cdot profit_j + \varepsilon$

R&D stands for the various measures of R&D expenditures and *capex* stands for the various measures of capital expenditures as discussed above. In regressions that are done for all firms of any size together, the log value of the size of the firms is included in the regression as an independent variable. Similarly, in regressions that consider firms from all sectors dummies are included as independent variables, which reflect each of the industries as described in Table 3.2. Hence, if all firms are analysed together, the following model is used:

(2)
$$GROWTH_j = a_0 + a_1 \cdot R\&D_j + a_2 \cdot capex_j + a_3 \cdot profit_j + a_4 \cdot \log(size_j) + a_{5-14} \cdot IndDummy_{1-10,j} + \varepsilon$$

The time structure of the impact of R&D on growth might interfere with the time structure of the growth process itself. If growth in one year depends on growth in previous years and growth in previous years depends on R&D activities in previous years or R&D activities further in the past, a relationship between current growth and previous R&D activities might be a direct effect or an indirect effect. To disentangle this structure we conduct each regression one time including measures of R&D and capital expenditures as independent variable but without considering growth in the past (see Equations (1) and (2)), one time without any R&D activity considered but including growth in the past (Equation (3)), and one time with past growth rates and R&D and capital expenditures as independent variables at the same time (Equation (4)).

(3)
$$\begin{aligned} GROWTH_j &= a_0 + a_1 \cdot growth03/04_j + a_2 \cdot growth04/05_j + a_3 \cdot profit_j \\ &+ a_4 \cdot \log(size_j) + a_{5-14} \cdot IndDummy_{1-10,j} + \varepsilon \end{aligned}$$

(4)
$$\begin{aligned} GROWTH_j &= a_0 + a_1 \cdot growth03/04_j + a_2 \cdot growth04/05_j + a_3 \cdot R\&D_j + a_4 \cdot capex_j \\ &+ a_5 \cdot profit_j + a_6 \cdot \log(size_j) + a_{7-16} \cdot IndDummy_{1-10,j} + \varepsilon \end{aligned}$$

Furthermore, we conduct one regression set for all firms together and then three regression sets for each firm size separately. Through this, we are able to analyse whether our findings depend on the size of firms. In order to analyse the differences between industries, we also study a number of firm subsamples that are defined by their industry classification as discussed above.

3.4 Results and interpretation

The complete regression results are reported in Tables 3.16 –3.32 (in the appendix). In the next subsections, we discuss the results according to our hypotheses that have been set up in Section 2 and present within each discussion only the relevant parts of the results.

3.4.1 Autocorrelation dynamics

The autocorrelation of firms' growth has been repeatedly studied in the literature, but the results vary. The autocorrelation dynamics of firm growth are found to depend on firm characteristics such as their size. We repeat this analysis. Hypothesis 1, stating positive autocorrelation for larger firms and negative autocorrelation for smaller firms, is partly confirmed by our empirical examination. If autocorrelation is used as an independent variable in the regression analyses, we find significant positive autocorrelation for larger and very large firms. The results do not change if we exclude or include the variables related to R&D and capital investments. Hence, we only present the results for the model with no R&D and capital variable included and only present the findings for the independent variables Turn03/04 and Turn04/05.

Table 3.3 Estimates for turnover growth for different firm size
Estimates for turnover growth of firms, sorted by size, regressed on prior growth (see appendix 3.16; standard errors in parentheses).

Variable	**All firms**	**SME**	**Large firms**	**Very large firms**
Turn04/05	**0.0673*** (0.0140)**	0.0050 (0.0278)	**0.127*** (0.0538)**	**0.234*** (0.0247)**
Turn03/04	**0.0586*** (0.0128)**	0.0171 (0.0296)	-0.00216 (0.0388)	**0.0637*** (0.0171)**

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Looking at the results of all firms, we find positive autocorrelation dynamics. The results are in line with the results by Bottazzi and Secchi (2003), who examine serial correlation for US manufacturing companies. They explore positive autocorrelation dynamics in their sample. Bottazzi et al. (2001) found positive autocorrelation for every year up to and including the seventh lag, although only the first lag is statistically significant. We find significant positive autocorrelation for both lags that we are able to consider. However, this finding only holds for the analysis of all firms and the analysis of the very large firms. For the other firm subgroups the time lag of two years does not lead to significant results. Hence, the positive autocorrelation is confirmed for very large firms for both lags as well as for large firms for the first lag. For SMEs we are not able to confirm any autocorrelation neither for the first nor for the second lag. However, the insignificant results for SMEs might either be caused be the small number of these kinds of firms in our sample or by a lack of autocorrelation in their growth process.

We confirm the finding in the literature that especially large firms show autocorrelation in their growth (e.g., Coad 2006 concludes that larger firms experience positive feedback in year-to-year growth rates). For small and medium-sized enterprises we do not find any significant autocorrelation. This means that we are not able to confirm the findings in the literature that smaller firms experience significant negative autocorrelation (Coad 2006).

3.4.2 R&D activities and capital investments

The literature review concludes that the growth of firms is driven by innovation activities (e.g. R&D expenditure) as well as by capital expenditures. Therefore, hypothesis 2 states that *the impact of R&D activities on firm growth is positive.* Furthermore, it has been recognised that the impact of R&D may be time lagged. We therefore suggest that *the positive effect of R&D expenditures tends to be time-lagged and its time lag is larger than the time lag of the effect of (tangible) capital expenditures* (hypothesis 3). To gain a deeper insight into this issue, we set up several regressions, each time using one of the R&D variables and one of the capital expenditure variables as independent variables. Each regression is conducted for all firms and is run twice, one time including prior growth rates and one time without considering prior growth rates. The results are presented in Table 3.4.

Table 3.4 Estimates for turnover growth for all firms
Estimates for turnover growth for all firms, regressed on different variables of R&D and capital expenditures (see appendix 3.17 and 3.18; standard errors in parentheses).

Variable	Past growth included	Past growth not included
R&Dexp **Capex**	**0.000209** (0.000930)** **-0.000000029** (0.000000014)**	**0.000383** (0.000156)** **-0.000000004* (0.000000003)**
R&Dexp **Capex05**	-0.000138 (0.0000967) **0.00316*** (0.000514)**	-0.000194 (0.000160) **0.00530*** (0.000944)**
R&Dexp **Capex04**	0.000119 (0.000115) 0.000267 (0.000868)	-0.0000009 (0.00011) **0.00186** (0.00077)**
R&Dexp **Capex03**	0.000139 (0.0000925) 0.0000290 (0.000348)	**0.00019** (0.000094)** 0.00016 (0.00036)
R&Dexp05 **Capex**	**0.000207*** (0.0000666)** **-0.000000031** (0.000000014)**	**0.000996*** (0.000114)** **-0.00000009***(0.000000002)**
R&Dexp04 **Capex**	0.0000397 (0.0000559) -0.00000002 (0.000000013)	**0.000162*** (0.0000468)** **-0.000000002* (0.0000000001)**
R&Dexp03 **Capex**	0.000126 (0.0000786) **-0.00000003* (0.00000001)**	**0.000308*** (0.0000768)** **-0.00000003** (0.000000014)**

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

While the variables R&Dexp and capex represent the average investments over four years, the other variables in Table 3.4 represent the investments in one year. Hence, we might assume that the variables R&Dexp and capex represent the overall attitude of a firm, while the other variables represent singular events (single steps). Therefore, if the growth rate of firms depends on their long-run average investment in R&D and capital we should see this effect in the variables R&Dexp and capex. However, such a long-run relationship might also show up in a strong autocorrelation of the growth development, meaning that a firm with an R&D attitude that leads to growth will continuously grow. Therefore, we have to compare the findings for the regressions considering temporal autocorrelation and for the regressions that do not consider temporal autocorrelation.

We find a permanent positive significant relationship between R&Dexp and firm growth. The positive relationship for R&Dexp and growth still holds if past growth is included in the model (see Table 3.18 in the appendix). Hence, this relationship is confirmed even if we control for autocorrelation. We also find positive significant results for R&D expenditures in all prior years if prior growth is not included in the model. However, if prior growth is considered, most of these significant results turn insignificant. Hence, at least, parts of the findings for R&D expenditures are due to the autocorrelation of the growth process. The positive relationship between R&D expenditure in the previous year and firm growth is the only robust finding. This confirms our hypothesis 2 and suggests that the impact of R&D expenditure (intangible investments) is positive. This result accompanies the impact of the overall attitude of R&D expenditure as well as the impact of singular R&D activities. In contrast to hypothesis 3, we find that the impact of singular R&D activities on firm growth shows up already in the following year. Our evidence for later impacts can be explained by the autocorrelation of the growth process.

The results for capital expenditures are different and show the importance of distinguishing between permanent effects and singular event. We find a significant negative relationship of the overall capital expenditures with growth regardless of whether we include prior growth or not. This suggests that firms with permanent high tangible expenditures, represented by capital expenditures, show smaller firm growth. In contrast, if we look at singular events (each individual year) a significant positive relationship between capex and growth appears, at least for the years 2005 and 2004 (if prior growth is not included). Hence, capital expenditures are positively related to firm growth in the following year. In line with this, Czarinitzki and Kraft (2004) head in this direction showing that firm growth is realised among capital efforts. Putting the two results together, we find that increases in capital expenditures are followed by increases in growth, while firms that have higher shares of capital expenditures show, on average, smaller growth rates.

In hypothesis 3, we suggest that the positive effect of R&D expenditures (intangibles) tends to be time-lagged and its time lag is larger than the time lag of the effect of (tangible) capital expenditures. Likewise, Ravenscraft and Scherer (1982) have studied the lag between R&D activities and their impact on profit. They have found that there is a time gap of about four years. Contradicting to our suggestion, we do not find any evidence for such a time gap in our study. Although we are not able to study a time gap of four years explicitly, our results suggest that R&D activities in earlier years matter less than those in the previous year. The significant results for earlier years disappear if the autocorrelation of firm growth is explicitly considered. This finding also holds for capital expenditures. Hence, we are not able to confirm our hypothesis 3, neither the time gap for the effect of R&D expenditures nor the difference between R&D and capital expenditures. The main difference between R&D and capital expenditures is that high permanent capital expenditures are connected to low overall growth rates, while high permanent R&D expenditures are connected to high over growth rates.

To sum up, our expectations (hypothesis 2 and 3) are only partly confirmed by our results. Tangible and intangible investments differ in their long-run relationship with growth: Permanent R&D expenditures are positively related and permanent capital expenditures are rather negatively correlated to growth. In contrast, they do not differ in the time structures of their effects: A significant positive relationship is found for one-time capital as well as R&D expenditures in the year just before growth is measured.

3.4.3 Firm size

We also have claimed based on the findings in the literature, that the importance of R&D activities is influenced by a firm's characteristics – primarily its size (e.g. Shefer and Frenkel, 2005). We formulated the hypothesis that *the impact of R&D activities on firm growth and its temporal structure varies with firm size* (Hypothesis 4). Therefore, we conducted the regressions for several firm size classes separately. The results do not differ between the regressions including past growth and the regressions not including past growth, except of a positive relationship between R&Dexp05 and firm growth for SMEs if prior growth is not included. Hence, we discuss here mainly the results for the regressions including prior growth. The relevant part of the results is presented in Table 3.5.

Table 3.5 Estimates for turnover growth for firms
Estimates for turnover growth for firms, sorted by size, regressed on different variables of R&D expenditures (see appendix 3.19 to 3.24; standard errors in parentheses).

Variable	SME	Large-sized firms	Very large-sized firms
R&Dexp	0.0000502 (0.000175)	**0.0108*** (0.00386)**	-0.00269 (0.00176)
R&Dexp05	-0.000004 (0.000121)	**0.0184*** (0.00288)**	-0.00188 (0.00169)
R&Dexp04	0.00006 (0.000103)	**0.00999*** (0.00288)**	-0.00231 (0.00173)
R&Dexp03	-0.000004 (0.000143)	**0.00624*** (0.00141)**	-0.00193 (0.00133)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.5 clearly confirms Hypothesis 4: the relationship between R&D activities and firm growth varies with the size of firms. Coad (2006 p: 3) finds that small firms and large firms appear to operate on different 'frequencies'. The R&D activities of smaller firms are characterised by an unstable, 'stop and go' dynamics, whilst larger firms operate more constantly (implying that it is sustainable). We find similar dependency, but also some different details. We find significant relations between R&D expenditures and firm growth for the large-sized firms. For SMEs and very large-sized firms, we do not find any significant relationships. These insignificant results do not allow us to make any definite statement about the relationships for these firm size classes. The lower number of observations might play a role in the case of SMEs. However, the mostly negative signs of the coefficient estimates rather suggest that there is no positive relationship between R&D expenditures and firm growth in the case of SMEs and very large-sized firms.

The results are the same for the average R&D expenditures as for one-time R&D expenditures and the various time gaps. However, confirming the results above, the coefficient estimates decrease with the time gap for large-sized firms.

To sum up, Hypothesis 4 is confirmed by our results: the relation between R&D activities and firm growth varies with firm size. While large firms show high growth if they invest in R&D before (independent of the time-gap), we do not find significant relationships for very large-sized firms and SMEs. The mainly negative coefficient estimates suggest that no positive relationship between R&D expenditures and firm growth exists for these firm size classes.

3.4.4 Industry dynamics

As a last point, we analyse the temporal structure of the impact of R&D and capital expenditures across sectors. Our sample covers a number of sectors ranging from manufacturing to services, which are characterised by very different R&D processes. In Hypothesis 5 we set up the natural expectation: *The temporal structure of the impact of R&D activities and capital expenditures on firm growth varies across industries.* Therefore, we compare the temporal structure of the impact of R&D and capital expenditures in different industries. To gain a clearer picture of the temporal structure and dynamics within the industries, we repeat our analyses for several kinds of manufacturing industries and services such as real estate. For the detailed analysis we choose those industries for which our firm sample contains a high number of firms. Again, we only discuss the findings for the regressions considering temporal autocorrelation.

Table 3.6 Estimates for turnover growth for high-tech and low-tech firms
Estimates for turnover growth for high-tech and low-tech firms regressed on different variables of R&D and capital expenditures (see appendix 3.25 and 3.26; standard errors in parentheses).

variable	High-tech	Low-tech
R&Dexp **Capex**	**0.000291*** (0.00009)** **-0.0000003* (0.0000001)**	-0.00187 (0.00789) 0.0000104 (0.000040)
R&Dexp **Capex05**	0.000109 (0.0001) **0.00127** (0.000626)**	-0.00328 (0.00509) **-0.0104** (0.00482)**
R&Dexp **Capex04**	0.000147 (0.000116) 0.000589 (0.000806)	-0.00268 (0.00506) **-0.0123** (0.00515)**
R&Dexp **Capex03**	**0.000225** (0.00001)** -0.000162 (0.000413)	-0.00284 (0.00511) **-0.0103* (0.00579)**
R&Dexp05 **Capex**	**0.000454*** (0.000110)** **-0.0000004** (0.0000001)**	-0.000164 (0.00808) -0.000023 (0.00006)
R&Dexp04 **Capex**	**0.000263*** (0.00005)** -0.0000002* (0.0000001)	-0.00105 (0.00789) -0.000009 (0.000121)
R&Dexp03 **Capex**	0.000009 (0.00008) -0.00000004 (0.0000001)	-0.00236 (0.00753) 0.00003 (0.000177)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Before we examine various individual industries, we compare high-tech and low-tech manufacturing firms (see Table 3.6). For firms in the high-tech manufacturing we find results similar to the ones above. On the one hand, firm growth is positively related to the average R&D expenditures and to one-time R&D expenditures one and two years before the measurement of growth. On the other hand, permanent capital expenditure is negatively related with growth in high-tech manufacturing industries, while we find also a significant positive coefficient for capex in the previous year. The same has been found for the total firm population and was comprehensively discussed above.

For firms in low-tech manufacturing industries different results are obtained. Most coefficient estimates are insignificant. Only for capital expenditures one, two and three years before the measurement of growth we find significant negative estimates. Capital investment in one year is related to lower growth rates in the successive years in low-tech industries. R&D expenditures do not seem to play a positive role in low-tech industries. All estimates are negative, although not significantly.

Let us now considered those industries separately for which we have sufficient firm numbers in our data base. The results in Table 3.7 as well as the results before clearly confirm our Hypothesis 4 stating that the relevance of R&D and capital expenditures depends on the industry.

Table 3.7 Estimates for turnover growth for firms by industry
Estimates for turnover growth for firms, sorted by industries, regressed on different variables of R&D and capital expenditures (see appendix 3.27 to 3.32; standard errors in parentheses).

variable	Food and beverages	Chemicals	Metal
R&Dexp **Capex**	-0.0209 (0.0132) **0.0198** (0.00921)**	**0.000332*** (0.000117)** **-0.0000003* (0.0000002)**	0.00757 (0.0120) -0.00421 (0.00533)
R&Dexp **Capex05**	-0.0123 (0.0121) **0.0110* (0.00582)**	0.000128 (0.000122) 0.00210 (0.00143)	-0.000130 (0.00722) -0.00669 (0.00865)
R&Dexp **Capex04**	-0.00740 (0.0126) 0.00244 (0.00628)	0.000181 (0.000177) 0.000703 (0.00209)	-0.000312 (0.00725) -0.00326 (0.00790)
R&Dexp **Capex03**	-0.00793 (0.0126) -0.00123 (0.00673)	**0.00304** (0.000118)** -0.00130 (0.00109)	-0.000158 (0.00725) 0.00108 (0.00980)
R&Dexp05 **Capex**	-0.0161 (0.0120) **0.0184* (0.00920)**	**0.000461*** (0.000137)** **-0.0000003** (0.0000002)**	0.0130 (0.0119) -0.00584 (0.00490)
R&Dexp04	-0.0237 (0.0146)	**0.000292*** (0.00005)**	0.00394 (0.0119)

Capex	0.0195* (0.00908)	-0.0000002* (0.0000001)	-0.00273 (0.00488)
R&Dexp03 Capex	-0.0318** (0.0142) 0.0209** (0.00862)	0.0000003 (0.000125) -0.00000004 (0.0000002)	0.00331 (0.0104) -0.00323 (0.00627)
variable	Electrical and optical equipment	Transport	Real estate
R&Dexp Capex	0.000490* (0.000249) -0.0000007 (0.000003)	0.0430*** (0.00699) -0.000351*** (0.00005)	0.00007 (0.000280) -0.00000002 (0.00000002)
R&Dexp Capex05	0.000537* (0.000287) -0.000291 (0.000817)	-0.00181** (0.000685) 0.0429*** (0.00357)	-0.000300 (0.000418) 0.00243 (0.00323)
R&Dexp Capex04	0.000855* (0.000467) -0.00133 (0.00143)	-0.00669*** (0.00144) 0.0509*** (0.0105)	-0.000102 (0.000322) 0.000884 (0.00312)
R&Dexp Capex03	0.000889*** (0.000339) -0.000929 (0.000592)	-0.0125*** (0.00158) 0.0429*** (0.00541)	-0.00004 (0.000239) -0.00006 (0.000668)
R&Dexp05 Capex	0.00130*** (0.000294) -0.000007** (0.000004)	0.0117 (0.0139) -0.00009 (0.00008)	0.00006 (0.000123) -0.00000002 (0.00000002)
R&Dexp04 Capex	0.00111*** (0.000223) -0.00002*** (0.000005)	0.0183*** (0.00127) -0.000305*** (0.00002)	0.00002 (0.000226) -0.00000001 (0.00000002)
R&Dexp03 Capex	0.000543*** (0.000193) -0.0000004 (0.000003)	0.0116*** (0.00115) -0.000547*** (0.00005)	0.00003 (0.000251) -0.00000002 (0.00000002)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

First, we consider the chemical industry and the electrical and optical equipment industry because these industries shows results similar to those we found and discussed for the high-tech industries and the complete firm sample. Hence, we can refer to the discussion above and repeat here only that growth is positively related to R&D activities one, two and - in the case of electrical and optical equipment - three years before and also to the average R&D activity. Furthermore, we also find a negative significant relationship between permanent capital expenditures and growth, at least in some regression. In contrast to the findings for all firms, we do not find a significant positive relationship between one-time capital expenditures and later growth rates. In the case of chemicals the respective estimates are mainly positive, so that the insignificance might be a result of the smaller number of firms. In the case of electrical and optical equipment the negative estimates suggest that one-time capital expenditures are, at least, not followed by higher growth rates.

In contrast, for the food, beverages and tobacco industry we find positive coefficients for average capital expenditures. This holds for permanent capital investment as well as for capital investment in the year before measuring growth. Hence, in this industry capital expenditures and growth are clearly positively related. In contrast, for R&D expenditures mainly insignificant estimates are found and in one case even a negative significant estimate is obtained. In the food, beverages and tobacco industry it seems not to pay off to invest in intangible assets such as R&D, maybe because it is a low-tech industry.

The transport equipment industry shows very distinguished results. Again, permanent capital expenditures show a significantly negative relationship with growth. This negative relationship turns into a positive relationship if we consider one-time values of capital investment. This means, as discussed above, that firms with high capital expenditures show, on average, lower growth rates, which might be caused by differences within the industry, e.g. between suppliers and car manufacturers. In contrast, one-time capital investment is related to successive growth. For the permanent R&D expenditures we find the significant positive relationship with growth that is also found for high-tech industries. Looking at one-time R&D investments, the same positive relationship is found, decreasing with the time gap. Hence, R&D seem to have a positive impact on growth in this industry. However, the coefficients for average R&D expenditures turn significantly negative if one-time capital investments are considered in the regressions instead of average capital investments. This is another indication that our firm sample in the transport equipment industry is far from homogeneous. Therefore, the finding for this industry should be interpreted with care. A further separation of the firms in this industry would provide further insights.

For the metal industry we do not find any positive or negative coefficient for the independent variables. This means, R&D efforts do not play a key role for growth in the metal industry. This is in line with the findings on the aggregated level for low-tech industries (see Table 3.10 in the appendix). The same is true for firms in real estate.

To sum up, Hypothesis 4 is confirmed by our results: the relationship between R&D and capital expenditures and firm growth and their temporal structure varies across industries. In general, we find that R&D investments are positively related to growth in high-tech industries. Permanent capital investments are positively related to growth in one industry (food, beverages and tobacco), while they are negatively related to growth in many other industries.

3.5 Conclusion

In this paper we analyse the short-term structure of the relationship between R&D and capital investments and turnover growth. The literature usually states that R&D activities are related to firm growth. We deviate from the usual approach by focusing on the time structure of the relationship between tangible investments (i.e. capital expenditure) as well as intangible investments (i.e. R&D expenditures) and firm growth, including the autocorrelation in the growth dynamics. In addition, we differentiate between different firm sizes and industries. This leads to a more detailed picture.

We find that the autocorrelation of growth rates varies with firm size. Considering all firms in the sample, the firms show strong autocorrelation in their year-to-year growth rates. We find confirmation for the finding from the literature that this autocorrelation is stronger for larger firms. For small- and medium sized enterprises we do not find significant autocorrelation of growth rates. For the relationship between expenditures and firm growth we find a strong dependency on firm size and industry. While we obtain nearly no significant results for small and medium sized enterprises (neither tangibles nor intangibles), we find a strong positive relationship between intangible innovation activity (R&D expenditures) and growth for large firms.

For intangible investments (capital expenditures) we find for many of our firm samples the interesting features that permanently high capital expenditures are related to low growth rates, while one-time capital expenditures are often followed by higher firm growth.

Besides these general finding, most relevant for the results is the kind of industry that is analysed. No relationships are found, e.g., for the metal industry and real estate. Within the manufacturing industry strong differences are detected between high-tech and low-tech industries. While we find many significant positive relationships between R&D activities and growth for high-tech industries, we find no significant relationships or even negative relationships between these characteristics in low-tech industries. Furthermore, the industries also differ in the time structure of the relationship between R&D and growth.

Hence, our analysis, first of all, suggests that the characteristics that are connected to high growth should be examined for each industry separately. Studies that aggregate over all industries provide information about the average behavior of firms, but ignore a lot of details and the result depends crucially on the mixture of firms in the data set. Our study also shows that still more research about the time structure of growth processes is needed. Both, the time structure of the effects of R&D as well as capital expenditures on growth, needs to be further examined on an industry-specific level, using longer time series than available for our study.

Furthermore, our study finds clear differences in the impact of tangible and intangible investments on firm growth. Both kinds of investments are supported by government programs. Our results suggest that one-time investments in capital as well as in R&D help firms to grow, at least, in a number of industries. However, the various industries differ in whether they benefit from these two kinds of investments. The separation of various industries is a first step. More detailed analyses might help to specify the relevant characteristics of firms and to give advice to policy makers about how respective programs could be focused adequately.

Further research is needed on the questions of how to measure the productivity of intangibles and how external intangibles can be internalised by firms. Our future work is to explore the reasons why firms that are engaged in R&D activities perform better than other firms and why particularly the high growth firms appear to be more engaged in R&D activities. In addition, future work could investigate different innovation indicators such as product and process R&D separately. Product and process innovations can be assumed to have very different impacts on firm growth. Furthermore, there is a need for qualitative research in this research area. It is important to learn more about the motives for innovation activities and how the impact on firm growth depends on these motives. Case studies could be a very helpful tool for this.

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3.7 Appendix

Table 3.8 Distribution of firms by country

Country	Code	Frequency	Percent [%]
Germany	1	164	16.6
UK	2	310	31.8
France	3	113	11.6
Finland	4	68	7.0
Sweden	5	74	7.6
The Netherlands	6	51	5.2
Italy	7	47	4.8
Denmark	8	37	3.8
Belgium	9	33	3.4
Spain	10	21	2.2
Ireland	11	11	1.1
Luxembourg	12	5	0.5
Austria	13	30	3.1
Hungary	14	3	0.3
Slovenia	15	2	0.2
Czech Republic	16	4	0.4
Greece	17	3	0.3
Portugal	18	1	0.1
Latvia	19	1	0.1
		978	**100.0**

Table 3.9 Type of sector (SECTOR)

Description*	**Code**	**Frequency**	**Percent [%]**
Agriculture, Forestry	1	8	0.8
Mining and Quarrying	2	24	2.5
Manufacturing	3	550	56.2
Electricity, gas, steam, hot water supply	4	31	3.2
Construction	5	8	0.8
Wholesale, retail trade	6	25	2.6
Transport, storage, communication	7	30	3.1
Financial intermediation	8	50	5.1
Real estate, renting, business activities	9	218	22.3
Public administration, defense	10	9	0.9
Other community, social/personal service activities	11	25	2.6
Total		**978**	**100.0**

Table 3.10: Technology classification

Description	**2-digit**	**Category**
Food and beverages	15	
Tabacco products	16	
Textiles	17	
Wearing apparel	18	
Lether articles	19	low-tech industries
Wood products	20	
Paper	21	
Publishing, printing	22	
Petroleum products, nuclear fuel	23	
Basic chemicals	24	high-tech industries
Rubber and plastic products	25	
Non-metallic mineral products	26	low-tech industries
Basic metals	27	
Fabricated metal products	28	
Energy machinery	29	
Office machinery and computers	30	
Electrical equipment	31	
Electronic components and telecommunication	32	high-tech industries
Medical equipment	33	
Motor vehicles	34	
Other transport equipment	35	
Furniture and consumer goods	36	low-tech industries
Recycling	37	

Table 3.11 Correlation matrix

	R&Dexp	R&Dexp05	R&Dexp04	R&Dexp03	R&Dcapex	R&Dcapex05	R&Dcapex04	R&Dcapex03
R&Dexp	1.0000							
R&Dexp05	0.8811 (0.0000)	1.0000						
R&Dexp04	0.7692 (0.0000)	0.6397 (0.0000)	1.0000					
R&Dexp03	0.9069 (0.0000)	0.7572 (0.0000)	0.7425 (0.0000)	1.0000				
R&Dcapex	0.4388 (0.0000)	0.3690 (0.0000)	0.1972 (0.0000)	0.2475 (0.0000)	1.0000			
R&Dcapex05	0.4869 (0.0000)	0.4914 (0.0000)	0.3046 (0.0000)	0.3194 (0.0000)	0.1692 (0.0000)	1.0000		
R&Dcapex04	0.6355 (0.0000)	0.4889 (0.0000)	0.6973 (0.0000)	0.5312 (0.0000)	0.2348 (0.0000)	0.6219 (0.0000)	1.0000	
R&Dcapex03	0.3393 (0.0000)	0.2322 (0.0000)	0.2070 (0.0000)	0.3355 (0.0000)	0.1033 (0.0014)	0.2087 (0.0000)	0.5080 (0.0000)	1.0000

Table 3.12 Descriptive statistics for individual variables (all firms)

Variable	Obs	Mean	Std. Dev.	Min	Max
TURN	977	1.1864	0.7238	0.3333	20
Turn04/05	974	1.1699	0.5756	0.1333	13
Turn03/04	973	1.1608	0.6092	0	10.5
R&Dexp	977	39.4526	224.1171	0.0063	4675
R&Dexp05	977	45.9412	261.3499	0	4675
R&Dexp04	974	46.7828	316.8017	0	5008
R&Dexp03	973	40.1677	228.0366	0	4675
R&Dcapex	965	8.2639	21.5889	0	500
R&Dcapex05	972	9.0299	28.8666	0	500
R&Dcapex04	969	8.6001	21.8306	0	300
R&Dcapex03	968	9.2619	38.0695	0	900
profit	978	302.9438	1219.4	-6608	15469

Table 3.13 Descriptive statistics for individual variables (SME)

Variable	Obs	Mean	Std. Dev.	Min	Max
TURN	143	1.4488	1.6756	0.3333	20
Turn04/05	140	1.3991	1.2879	0.1333	13
Turn03/04	139	1.3451	1.1884	0	10.5
R&Dexp	143	237.3358	546.4955	0.0063	4675
R&Dexp05	143	281.0219	635.443	0	4675
R&Dexp04	140	292.6213	794.36	0	5008
R&Dexp03	139	242.7948	562.4023	0	4675
R&Dcapex	141	25.7888	46.9934	0	500
R&Dcapex05	142	28.5177	65.9636	0	500
R&Dcapex04	139	27.0599	50.3216	0	30
R&Dcapex03	138	30.9783	96.6949	0	900
profit	144	12.9247	215.5082	-6608	15469

Table 3.14 Descriptive statistics for large firms

Variable	Obs	Mean	Std. Dev.	Min	Max
TURN	182	1.2035	0.5749	0.5419	7.3889
Turn04/05	182	1.1848	0.4021	0.3797	3.75
Turn03/04	182	1.2356	0.5431	0.0825	4.9231
R&Dexp	182	12.2245	12.1767	0.3282	69.8936
R&Dexp05	182	12.7915	14.7355	0.0698	86.8611
R&Dexp04	182	12.3281	13.6974	0	88.8333
R&Dexp03	182	15.3108	32.3641	0	401.2
R&Dcapex	181	5.0925	7.7672	0	58.3743
R&Dcapex05	181	6.7381	25.0981	0.1593	309.5694
R&Dcapex04	181	5.6664	14.6343	0	174.5536
R&Dcapex03	181	5.2396	7.5693	0	60
profit	182	3.8023	46.3133	-172	390.0402

Table 3.15 Descriptive statistics for very large firms

Variable	Obs	Mean	Std. Dev.	Min	Max
TURN	652	1.1208	0.2484	0.3861	3.8557
Turn04/05	652	1.1091	0.2811	0.2120	3.8997
Turn03/04	652	1.0947	0.3993	0.1040	8.4851
R&Dexp	652	3.4839	4.4237	0.0063	41.7388
R&Dexp05	652	3.4623	4.5444	0	54.7222
R&Dexp04	652	3.4615	4.6827	0	43.3906
R&Dexp03	652	3.7529	6.4411	0	102.6042
R&Dcapex	649	5.1239	5.0494	0.0029	48.0069
R&Dcapex05	651	5.4516	5.4286	0	60.8471
R&Dcapex04	651	5.5355	5.4176	0	49.4444
R&Dcapex03	651	5.8027	7.3021	0	93.7293
profit	652	455.5292	1476.428	-6608	15469

Table 3.16 Estimates for different firm size (excluding R&D activity variables)

VARIABLES	(all firms) TURN	(SME) TURN	(large) TURN	(very large) TURN
Turn04/05	0.0673***	0.00501	0.217***	0.234***
	(0.0140)	(0.0278)	(0.0538)	(0.0247)
Turn03/04	0.0586***	0.0171	-0.00216	0.0637***
	(0.0128)	(0.0296)	(0.0388)	(0.0171)
Size	-0.0155***	-0.151***	-0.135***	-0.00117
	(0.00418)	(0.0496)	(0.0405)	(0.00529)
Profit	2.61e-06	-2.69e-05	-0.000204	-1.27e-06
	(7.09e-06)	(0.000157)	(0.000439)	(5.19e-06)
IndDummy1	-0.0210	(0)	0.118	0.00977
	(0.0963)	(0)	(0.258)	(0.0769)
IndDummy2	0.0687	-0.0537	-0.104	0.0311
	(0.0700)	(0.451)	(0.261)	(0.0597)
IndDummy3	-0.0607	-0.286	-0.000286	-0.0385
	(0.0486)	(0.207)	(0.102)	(0.0463)
IndDummy4	-0.0226	0.477	0.171	-0.0912
	(0.0643)	(0.454)	(0.168)	(0.0560)
IndDummy5	0.0187	(0)	(0)	0.00413
	(0.0969)	(0)	(0)	(0.0741)
IndDummy6	-0.115*	(0)	-0.206	-0.0932
	(0.0677)	(0)	(0.170)	(0.0578)
IndDummy7	-0.0498	-1.107**	0.0214	-0.0438
	(0.0651)	(0.502)	(0.195)	(0.0562)
IndDummy8	-0.00379	-0.0788	0.00253	-0.00758
	(0.0586)	(0.350)	(0.135)	(0.0525)
IndDummy9	-0.0475	-0.210	0.0454	-0.0563
	(0.0501)	(0.207)	(0.104)	(0.0491)
IndDummy10	-0.0878	(0)	(0)	-0.0787
	(0.0923)	(0)	(0)	(0.0712)
Constant	0.144**	1.085***	0.690**	-0.181**
	(0.0628)	(0.312)	(0.316)	(0.0716)
Observations	978	144	182	652
R-squared	0.096	0.122	0.267	0.214

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.17 Estimates for all firms (excluding prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN	(5) TURN	(6) TURN	(7) TURN
R&Dexp	0.000383**	-0.000194	-8.82e-07	0.000192**			
	(0.000156)	(0.000160)	(0.000105)	(9.37e-05)			
Capex	-4.26e-08*				-9.13e-08***	-2.33e-08*	-2.73e-08**
	(2.58e-08)				(2.40e-08)	(1.30e-08)	(1.37e-08)
Capex05		0.00530***					
		(0.000944)					
Capex04			0.00186**				
			(0.000773)				
Capex03				0.000159			
				(0.000359)			
R&Dexp05					0.000996***		
					(0.000114)		
R&Dexp04						0.000162***	
						(4.68e-05)	
R&Dexp03							0.000308***
							(7.68e-05)
Size	-1.82e-07	-1.06e-07	-3.77e-08	-4.11e-08	-5.76e-08	-4.64e-08	-2.44e-08
	(6.07e-07)	(5.96e-07)	(3.32e-07)	(3.33e-07)	(5.86e-07)	(3.32e-07)	(3.32e-07)
Profit	-1.74e-05	-1.46e-05	-1.63e-05	-1.64e-05	-1.77e-05	-1.72e-05	-1.74e-05
	(2.29e-05)	(2.24e-05)	(1.25e-05)	(1.25e-05)	(2.21e-05)	(1.26e-05)	(1.25e-05)
IndDummy1	-0.0895	-0.0843	-0.0813	-0.0830	-0.0879	-0.0872	-0.0870
	(0.272)	(0.267)	(0.148)	(0.149)	(0.262)	(0.149)	(0.148)
IndDummy2	0.167	0.120	0.142	0.151	0.167	0.164*	0.165*
	(0.179)	(0.173)	(0.0961)	(0.0962)	(0.173)	(0.0981)	(0.0978)
IndDummy3	-0.0790	-0.0776	-0.104**	-0.105**	-0.0951	-0.108**	-0.112**
	(0.0917)	(0.0896)	(0.0499)	(0.0500)	(0.0885)	(0.0502)	(0.0501)
IndDummy4	-0.0476	-0.242	-0.0801	-0.0503	-0.0541	-0.0501	-0.0507
	(0.158)	(0.157)	(0.0864)	(0.0856)	(0.153)	(0.0867)	(0.0864)
IndDummy5	-0.0714	-0.0767	-0.0713	-0.0717	-0.0734	-0.0759	-0.0762
	(0.272)	(0.267)	(0.149)	(0.149)	(0.263)	(0.149)	(0.149)
IndDummy6	-0.200	-0.198	-0.202**	-0.204**	-0.204	-0.206**	-0.206**
	(0.174)	(0.168)	(0.0933)	(0.0935)	(0.168)	(0.0950)	(0.0948)
IndDummy7	-0.130	-0.168	-0.147	-0.137	-0.137	-0.139	-0.140
	(0.164)	(0.161)	(0.0899)	(0.0899)	(0.159)	(0.0900)	(0.0898)
IndDummy8	-0.0670	-0.07888	-0.0793	-0.0760	-0.0665	-0.0705	-0.070
	(0.181)	(0.177)	(0.0986)	(0.0988)	(0.175)	(0.0991)	(0.0988)
IndDummy9	-0.0349	-0.0224	-0.0222	-0.0200	-0.0957	-0.0252	-0.0274
	(0.100)	(0.0979)	(0.0545)	(0.0546)	(0.0968)	(0.0548)	(0.0547)
IndDummy10	-0.153	-0.137	-0.143	-0.148	-0.155	-0.152	-0.156
	(0.258)	(0.253)	(0.141)	(0.141)	(0.249)	(0.141)	(0.141)
Constant	1.248***	1.219***	1.233***	1.240***	1.244***	1.246***	1.245***
	(0.0868)	(0.0848)	(0.0473)	(0.0473)	(0.0837)	(0.0475)	(0.0474)
Observations	965	972	969	968	965	963	961
R-squared	0.012	0.041	0.032	0.029	0.080	0.036	0.041

Table 3.18 Estimates for all firms (including prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN	(5) TURN	(6) TURN	(7) TURN
Turn04/05	0.125***	0.136***	0.120***	0.124***	0.133***	0.122***	0.124***
	(0.0229)	(0.0225)	(0.0258)	(0.0228)	(0.0225)	(0.0277)	(0.0233)
Turn0304	0.108***	0.107***	0.110***	0.109***	0.107***	0.109***	0.101***
	(0.0206)	(0.0202)	(0.0209)	(0.0207)	(0.0206)	(0.0210)	(0.0209)
R&Dexp	0.000209**	-0.000138	0.000119	0.000139			
	(9.30e-05)	(9.67e-05)	(0.000115)	(9.25e-05)			
Capex	-2.87e-08**				-3.07e-08**	-1.96e-08	-2.29e-08*
	(1.39e-08)				(1.36e-08)	(1.33e-08)	(1.34e-08)
Capex05		0.00316***					
		(0.000514)					
Capex04			0.000267				
			(0.000868)				
Capex03				2.90e-05			
				(0.000348)			
R&Dexp05					0.000207***		
					(6.66e-05)		
R&Dexp04						3.97e-05	
						(5.59e-05)	
R&Dexp03							0.000126
							(7.86e-05)
Size	4.40e-08	8.57e-08	3.51e-08	3.47e-08	4.97e-08	1.87e-08	3.29e-08
	(3.22e-07)	(3.16e-07)	(3.22e-07)	(3.22e-07)	(3.21e-07)	(3.23e-07)	(3.23e-07)
Profit	-1.47e-05	-1.26e-05	-1.38e-05	-1.38e-05	-1.46e-05	-1.46e-05	-1.48e-05
	(1.22e-05)	(1.19e-05)	(1.21e-05)	(1.21e-05)	(1.21e-05)	(1.22e-05)	(1.22e-05)
IndDummy3	-0.0996**	-0.0956**	-0.0954**	-0.0950**	-0.0986**	-0.0959**	-0.0983**
	(0.0487)	(0.0474)	(0.0484)	(0.0484)	(0.0485)	(0.0488)	(0.0487)
IndDummy4	-0.0438	-0.158*	-0.0453	-0.0413	-0.0449	-0.0429	-0.0442
	(0.0840)	(0.0834)	(0.0840)	(0.0828)	(0.0838)	(0.0842)	(0.0841)
IndDummy6	-0.201**	-0.197**	-0.198**	-0.198**	-0.201**	-0.200**	-0.201**
	(0.0920)	(0.0886)	(0.0904)	(0.0904)	(0.0918)	(0.0922)	(0.0921)
Constant	0.967***	0.936***	0.966***	0.964***	0.958***	0.970***	0.976***
	(0.0573)	(0.0561)	(0.0574)	(0.0570)	(0.0571)	(0.0593)	(0.0583)
Observations	961	967	967	967	961	961	961
R-squared	0.097	0.127	0.093	0.093	0.102	0.093	0.095

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notice: Statistically non-significant industry dummy are not shown

Table 3.19 Estimates for SME (excluding prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN
R&Dexp	-0.000411			
	(0.000444)			
Capex	-2.96e-08	-8.83e-08	-3.25e-08	-2.99e-08
	(6.03e-08)	(5.70e-08)	(1.97e-08)	(2.07e-08)
R&Dexp05		0.000765**		
		(0.000321)		
R&Dexp04			8.02e-05	
			(7.44e-05)	
R&Dexp03				5.72e-05
				(0.000134)
Size	-0.00645**	-0.00269	-0.00170**	-0.00193**
	(0.00263)	(0.00256)	(0.000855)	(0.000905)
Profit	-0.000228	-7.06e-05	-8.90e-05	-0.000109
	(0.000661)	(0.000650)	(0.000231)	(0.000231)
IndDummy4	0.939	1.049	1.253*	1.235*
	(1.830)	(1.797)	(0.641)	(0.641)
Constant	2.592***	2.011**	1.875***	1.910***
	(0.794)	(0.779)	(0.273)	(0.277)
Observations	141	141	139	137
R-squared	0.056	0.089	0.118	0.117

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notice: Statistically non-significant industry dummy are not shown

Table 3.20 Estimates for SME (including prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN
Turn04/05	0.0486	0.0467	0.0266	0.0471
	(0.0412)	(0.0408)	(0.0550)	(0.0428)
Turn03/04	0.0287	0.0304	0.0358	0.0307
	(0.0436)	(0.0435)	(0.0442)	(0.0438)
R&Dexp	-5.02e-05			
	(0.000175)			
Capex	-2.72e-08	-2.89e-08	-3.05e-08	-2.90e-08
	(2.14e-08)	(2.10e-08)	(2.06e-08)	(2.07e-08)
R&Dexp05		-4.31e-06		
		(0.000121)		
R&Dexp04			5.58e-05	
			(0.000103)	
R&Dexp03				-3.71e-06
				(0.000143)
Size	-0.00217**	-0.00206**	-0.00189**	-0.00205**
	(0.000951)	(0.000935)	(0.000896)	(0.000914)
Profit	-0.000105	-0.000103	-9.75e-05	-0.000102
	(0.000232)	(0.000233)	(0.000232)	(0.000232)
IndDummy4	1.265*	1.267*	1.255*	1.267*
	(0.643)	(0.644)	(0.643)	(0.643)
Constant	1.852***	1.836***	1.828***	1.834***
	(0.291)	(0.292)	(0.284)	(0.285)
Observations	137	137	137	137
R-squared	0.129	0.128	0.130	0.128

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notice: Statistically non-significant industry dummy are not shown

Table 3.21 Estimates for large-sized firms (excluding prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN
R&Dexp	0.0107***			
	(0.00401)			
Capex	4.54e-05	-9.04e-05	-1.45e-05	-0.000148
	(0.000333)	(0.000308)	(0.000333)	(0.000319)
R&Dexp05		0.0174***		
		(0.00303)		
R&Dexp04			0.0109***	
			(0.00350)	
R&Dexp03				0.00671***
				(0.00134)
Size	-4.11e-05	8.11e-05	-7.10e-05	-0.000112
	(0.000218)	(0.000203)	(0.000213)	(0.000203)
Profit	-0.000291	-0.000289	-0.000301	-6.60e-05
	(0.00102)	(0.000944)	(0.00101)	(0.000969)
IndDummy3	-0.248	-0.291*	-0.252	-0.205
	(0.187)	(0.174)	(0.186)	(0.177)
Constant	1.288***	1.193***	1.313***	1.328***
	(0.217)	(0.201)	(0.213)	(0.202)
Observations	181	181	181	181
R-squared	0.070	0.190	0.083	0.155

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notice: Statistically non-significant industry dummy are not shown

Table 3.22 Estimates for large-sized firms (including prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN
Turn04/05	0.377***	0.430***	0.351***	0.351***
	(0.118)	(0.108)	(0.117)	(0.114)
Turn03/04	0.0632	0.0476	0.0645	-0.0466
	(0.0859)	(0.0787)	(0.0856)	(0.0877)
R&Dexp	0.0108***			
	(0.00386)			
Capex	3.27e-05	-0.000117	-2.63e-06	-0.000107
	(0.000321)	(0.000291)	(0.000323)	(0.000312)
R&Dexp05		0.0184***		
		(0.00288)		
R&Dexp04			0.00999***	
			(0.00340)	
R&Dexp03				0.00624***
				(0.00141)
Size	3.99e-05	0.000179	-2.87e-06	-6.98e-05
	(0.000211)	(0.000193)	(0.000207)	(0.000199)
Profit	-4.83e-05	-3.42e-05	-9.36e-05	-3.06e-05
	(0.000984)	(0.000899)	(0.000980)	(0.000950)
Constant	0.583**	0.421	0.656**	0.867***
	(0.278)	(0.255)	(0.274)	(0.268)
Observations	181	181	181	181
R-squared	0.149	0.284	0.153	0.203

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notice: Statistically non-significant industry dummy are not shown

Table 3.23 Estimates for very large-sized firms (excluding prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN
R&Dexp	-0.000957			
	(0.00206)			
Capex	4.53e-06	4.51e-06	4.66e-06	4.59e-06
	(1.16e-05)	(1.16e-05)	(1.16e-05)	(1.16e-05)
R&Dexp05		-0.000741		
		(0.00198)		
R&Dexp04			-0.000593	
			(0.00202)	
R&Dexp03				0.000323
				(0.00154)
Size	1.67e-07	1.68e-07	1.68e-07	1.72e-07
	(2.11e-07)	(2.11e-07)	(2.11e-07)	(2.11e-07)
Profit	-1.51e-05*	-1.51e-05*	-1.51e-05*	-1.52e-05*
	(7.89e-06)	(7.89e-06)	(7.89e-06)	(7.89e-06)
IndDummy2	0.218***	0.219***	0.219***	0.219***
	(0.0653)	(0.0653)	(0.0653)	(0.0653)
IndDummy3	-0.0658*	-0.0663*	-0.0666*	-0.0693*
	(0.0367)	(0.0367)	(0.0368)	(0.0366)
IndDummy6	-0.150**	-0.150**	-0.150**	-0.149**
	(0.0645)	(0.0645)	(0.0645)	(0.0645)
IndDummy7	-0.104*	-0.103*	-0.103*	-0.104*
	(0.0599)	(0.0599)	(0.0599)	(0.0599)
IndDummy9	-0.0822*	-0.0832*	-0.0841*	-0.0888**
	(0.0455)	(0.0455)	(0.0455)	(0.0450)
Constant	1.188***	1.188***	1.188***	1.187***
	(0.0346)	(0.0346)	(0.0345)	(0.0345)
Observations	643	643	643	643
R-squared	0.048	0.048	0.048	0.048

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notice: Statistically non-significant industry dummy are not shown

Table 3.24 Estimates for very large-sized firms (including prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN
Turn04/05	0.380***	0.378***	0.380***	0.378***
	(0.0318)	(0.0318)	(0.0319)	(0.0318)
Turn04/04	0.111***	0.111***	0.111***	0.115***
	(0.0222)	(0.0222)	(0.0222)	(0.0223)
R&Dexp	-0.00269			
	(0.00176)			
Capex	-1.90e-06	-1.90e-06	-1.50e-06	-1.17e-06
	(9.93e-06)	(9.95e-06)	(9.94e-06)	(9.94e-06)
R&Dexp05		-0.00188		
		(0.00169)		
R&Dexp04			-0.00231	
			(0.00173)	
R&Dexp03				-0.00193
				(0.00133)
Size	1.97e-07	1.99e-07	1.97e-07	1.98e-07
	(1.80e-07)	(1.81e-07)	(1.81e-07)	(1.80e-07)
Profit	-1.10e-05	-1.10e-05	-1.09e-05	-1.10e-05
	(6.75e-06)	(6.76e-06)	(6.76e-06)	(6.75e-06)
IndDummy4	-0.133***	-0.132***	-0.132***	-0.132***
	(0.0508)	(0.0508)	(0.0508)	(0.0508)
IndDummy6	-0.135**	-0.134**	-0.134**	-0.134**
	(0.0552)	(0.0552)	(0.0552)	(0.0552)
IndDummy9	-0.0635	-0.0675*	-0.0654*	-0.0675*
	(0.0390)	(0.0390)	(0.0390)	(0.0385)
Constant	0.636***	0.636***	0.635***	0.632***
	(0.0467)	(0.0467)	(0.0467)	(0.0468)
Observations	643	643	643	643
R-squared	0.306	0.305	0.306	0.306

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notice: Statistically non-significant industry dummy are not shown

Table 3.25 Estimates for high-tech firms (including prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN	(5) TURN	(6) TURN	(7) TURN
Turn04/05	0.480***	0.464***	0.477***	0.485***	0.471***	0.461***	0.496***
	(0.0372)	(0.0383)	(0.0384)	(0.0373)	(0.0370)	(0.0365)	(0.0392)
Turn03/04	-0.0225	-0.0179	-0.0217	-0.0229	-0.0200	-0.0160	-0.0263
	(0.0183)	(0.0185)	(0.0185)	(0.0184)	(0.0181)	(0.0179)	(0.0185)
R&Dexp	0.000291***	0.000109	0.000147	0.000225**			
	(9.49e-05)	(9.56e-05)	(0.000116)	(9.49e-05)			
Capex	-2.59e-07*				-3.58e-07**	-2.48e-07*	-3.77e-08
	(1.43e-07)				(1.45e-07)	(1.27e-07)	(1.41e-07)
Capex05		0.00127**					
		(0.000626)					
Capex04			0.000589				
			(0.000806)				
Capex03				-0.000162			
				(0.000413)			
R&Dexp05					0.000454***		
					(0.000110)		
R&Dexp04						0.000263***	
						(4.82e-05)	
R&Dexp03							-9.17e-06
							(7.87e-05)
Size	-1.24e-09	-1.18e-08	-4.44e-09	-5.38e-10	9.84e-09	5.28e-09	-3.33e-08
	(3.88e-07)	(3.87e-07)	(3.89e-07)	(3.89e-07)	(3.84e-07)	(3.78e-07)	(3.92e-07)
Profit	-3.96e-06	-3.53e-06	-3.64e-06	-3.92e-06	-3.52e-06	-3.32e-06	-5.11e-06
	(2.01e-05)	(2.00e-05)	(2.01e-05)	(2.01e-05)	(1.99e-05)	(1.96e-05)	(2.03e-05)
Constant	0.609***	0.615***	0.608***	0.605***	0.613***	0.620***	0.603***
	(0.0431)	(0.0432)	(0.0434)	(0.0432)	(0.0427)	(0.0421)	(0.0449)
Observations	401	401	401	401	401	401	401
R-squared	0.342	0.344	0.338	0.337	0.355	0.374	0.327

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.26 Estimates for low-tech firms (including prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN	(5) TURN	(6) TURN	(7) TURN
Turn04/05	0.317***	0.330***	0.324***	0.309***	0.316***	0.316***	0.316***
	(0.0734)	(0.0718)	(0.0713)	(0.0720)	(0.0733)	(0.0735)	(0.0733)
Turn03/04	0.320***	0.320***	0.322***	0.321***	0.321***	0.320***	0.320***
	(0.0463)	(0.0451)	(0.0449)	(0.0454)	(0.0463)	(0.0464)	(0.0463)
R&Dexp	-0.00187	-0.00328	-0.00268	-0.00284			
	(0.00789)	(0.00509)	(0.00506)	(0.00511)			
Capex	-1.04e-05				-2.29e-05	-8.87e-06	2.97e-05
	(7.40e-05)				(6.04e-05)	(0.000121)	(0.000177)
Capex05		-0.0104**					
		(0.00482)					
Capex04			-0.0123**				
			(0.00515)				
Capex03				-0.0103*			
				(0.00579)			
R&Dexp05					-0.000164		
					(0.00808)		
R/Dexp04						-0.00105	
						(0.00789)	
R&Dexp03							-0.00236
							(0.00753)
Size	-7.26e-07	-6.49e-07	-6.40e-07	-6.69e-07	-7.33e-07	-7.29e-07	-7.20e-07
	(5.88e-07)	(5.73e-07)	(5.71e-07)	(5.76e-07)	(5.88e-07)	(5.88e-07)	(5.88e-07)
Profit	3.42e-05	2.92e-05	2.80e-05	3.06e-05	3.47e-05	3.45e-05	3.41e-05
	(2.71e-05)	(2.65e-05)	(2.64e-05)	(2.66e-05)	(2.71e-05)	(2.71e-05)	(2.71e-05)
Constant	0.423***	0.465***	0.475***	0.479***	0.421***	0.422***	0.424***
	(0.0773)	(0.0754)	(0.0757)	(0.0794)	(0.0780)	(0.0772)	(0.0774)
Observations	123	124	124	124	123	123	123
R-squared	0.492	0.511	0.515	0.505	0.491	0.491	0.492

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.27 Estimates very large-sized firms in Food, beverages and tobacco (prior growth)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	TURN	TURN	TURN	TURN	TURN	TURN	TURN
Turn04/05	0.490***	0.477***	0.495***	0.499***	0.497***	0.488***	0.460***
	(0.0771)	(0.0792)	(0.0840)	(0.0833)	(0.0782)	(0.0770)	(0.0754)
Turn03/04	-0.312***	-0.295***	-0.255**	-0.248**	-0.310***	-0.324***	-0.309***
	(0.0985)	(0.0986)	(0.102)	(0.104)	(0.100)	(0.100)	(0.0934)
R&Dexp	-0.0209	-0.0123	-0.00740	-0.00793			
	(0.0132)	(0.0121)	(0.0126)	(0.0126)			
Capex	0.0198**				0.0184*	0.0195**	0.0209**
	(0.00921)				(0.00920)	(0.00908)	(0.00862)
Capex05		0.0110*					
		(0.00582)					
Capex04			0.00244				
			(0.00628)				
Capex03				-0.00123			
				(0.00673)			
R&Dexp05					-0.0161		
					(0.0120)		
R&Dexp04						-0.0237	
						(0.0146)	
R&Dexp03							-0.0318**
							(0.0142)
Size	-1.11e-06**	-1.21e-06**	-1.33e-06**	-1.31e-06**	-1.18e-06**	-1.04e-06*	-9.12e-07*
	(5.25e-07)	(5.27e-07)	(5.54e-07)	(5.55e-07)	(5.24e-07)	(5.35e-07)	(5.21e-07)
Profit	4.80e-05**	4.91e-05**	4.90e-05**	4.81e-05**	4.96e-05***	4.65e-05**	4.36e-05**
	(1.77e-05)	(1.79e-05)	(1.90e-05)	(1.90e-05)	(1.78e-05)	(1.77e-05)	(1.72e-05)
Constant	0.876***	0.820***	0.807***	0.812***	0.865***	0.890***	0.908***
	(0.0940)	(0.0903)	(0.0955)	(0.0970)	(0.0941)	(0.0968)	(0.0928)
Observations	36	36	36	36	36	36	36
R-squared	0.628	0.616	0.571	0.569	0.619	0.629	0.655

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.28 Estimates very large-sized firms in Chemicals (prior growth)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	TURN	TURN	TURN	TURN	TURN	TURN	TURN
Turn04/05	0.442***	0.417***	0.449***	0.462***	0.438***	0.411***	0.473***
	(0.0813)	(0.0851)	(0.0841)	(0.0814)	(0.0799)	(0.0745)	(0.0880)
Turn03/04	0.187*	0.212**	0.179*	0.172*	0.199**	0.250***	0.134
	(0.0996)	(0.103)	(0.102)	(0.0996)	(0.0982)	(0.0920)	(0.104)
R&Dexp	0.000332***	0.000128	0.000181	0.000304**			
	(0.000117)	(0.000122)	(0.000177)	(0.000118)			
Capex	-2.75e-07*				-3.43e-07**	-2.45e-07*	-4.43e-08
	(1.59e-07)				(1.62e-07)	(1.31e-07)	(1.71e-07)
Capex05		0.00210					
		(0.00143)					
Capex04			0.000703				
			(0.00209)				
Capex03				-0.00130			
				(0.00109)			
R&Dexp05					0.000461***		
					(0.000137)		
R&Dexp04						0.000292***	
						(5.49e-05)	
R&Dexp03							2.57e-07
							(0.000125)
Size	3.43e-07	3.77e-07	3.45e-07	1.51e-07	4.60e-07	4.73e-07	-1.56e-07
	(2.21e-06)	(2.20e-06)	(2.23e-06)	(2.22e-06)	(2.18e-06)	(2.02e-06)	(2.30e-06)
Profit	-1.23e-05	-1.11e-05	-1.15e-05	-1.06e-05	-1.31e-05	-1.28e-05	-9.32e-06
	(3.79e-05)	(3.77e-05)	(3.81e-05)	(3.79e-05)	(3.73e-05)	(3.46e-05)	(3.94e-05)
Constant	0.423***	0.409***	0.418***	0.429***	0.410***	0.384***	0.468***
	(0.0935)	(0.0940)	(0.0958)	(0.0939)	(0.0924)	(0.0857)	(0.0961)
Observations	101	102	102	102	101	101	101
R-squared	0.496	0.493	0.482	0.489	0.512	0.580	0.453

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3.29 Estimates very large-sized firms in Metal (prior growth)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	TURN	TURN	TURN	TURN	TURN	TURN	TURN
Turn04/05	0.353***	0.328***	0.335***	0.333***	0.371***	0.342***	0.343***
	(0.119)	(0.117)	(0.118)	(0.119)	(0.119)	(0.118)	(0.119)
Turn03/04	0.378***	0.357***	0.371***	0.382***	0.371***	0.380***	0.380***
	(0.0969)	(0.1000)	(0.0981)	(0.0992)	(0.0965)	(0.0971)	(0.0972)
R&Dexp	0.00757	-0.000130	-0.000312	-0.000158			
	(0.0120)	(0.00722)	(0.00725)	(0.00725)			
Capex	-0.00421				-0.00584	-0.00273	-0.00323
	(0.00533)				(0.00490)	(0.00488)	(0.00627)
Capex05		-0.00669					
		(0.00865)					
Capex04			-0.00326				
			(0.00790)				
Capex03				0.00108			
				(0.00980)			
R&Dexp05					0.0130		
					(0.0112)		
R&Dexp04						0.00394	
						(0.0119)	
R&Dexp03							0.00331
							(0.0104)
Size	-8.47e-08	-6.96e-07	-3.07e-07	1.24e-08	-1.04e-07	-6.78e-08	-7.21e-08
	(1.88e-06)	(2.05e-06)	(1.97e-06)	(2.03e-06)	(1.87e-06)	(1.89e-06)	(1.89e-06)
Profit	-4.81e-05	6.36e-06	-3.06e-05	-6.01e-05	-3.95e-05	-5.17e-05	-5.31e-05
	(0.000154)	(0.000172)	(0.000164)	(0.000169)	(0.000154)	(0.000154)	(0.000154)
Constant	0.325*	0.408**	0.377**	0.353**	0.300*	0.342**	0.342**
	(0.168)	(0.168)	(0.162)	(0.175)	(0.166)	(0.167)	(0.167)
Observations	79	78	78	78	79	79	79
R-squared	0.410	0.417	0.414	0.413	0.417	0.407	0.407

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3.30 Estimates very large-sized firms in Electrical/optical equipment (prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN	(5) TURN	(6) TURN	(7) TURN
TURN04/05	0.445***	0.447***	0.455***	0.419***	0.399***	0.371***	0.446***
	(0.0545)	(0.0549)	(0.0548)	(0.0551)	(0.0533)	(0.0539)	(0.0536)
TURN03/04	-0.0402*	-0.0410**	-0.0436**	-0.0329	-0.0341*	-0.0225	-0.0497**
	(0.0205)	(0.0208)	(0.0208)	(0.0206)	(0.0196)	(0.0197)	(0.0205)
R&Dexp	0.000490*	0.000537*	0.000855*	0.000889***			
	(0.000249)	(0.000287)	(0.000467)	(0.000339)			
Capex	-6.90e-07				-7.38e-06**	-1.87e-05***	-3.76e-07
	(3.43e-06)				(3.61e-06)	(5.13e-06)	(3.08e-06)
Capex05		-0.000291					
		(0.000817)					
Capex04			-0.00133				
			(0.00143)				
Capex03				-0.000929			
				(0.000592)			
R&Dexp05					0.00130***		
					(0.000294)		
R&Dexp04						0.00111***	
						(0.000223)	
R&Dexp03							0.000543***
							(0.000193)
Size	2.33e-07	2.46e-07	2.65e-07	2.40e-07	2.36e-07	2.23e-07	2.38e-07
	(6.17e-07)	(6.18e-07)	(6.17e-07)	(6.13e-07)	(5.90e-07)	(5.82e-07)	(6.10e-07)
Profit	1.51e-05	1.49e-05	1.35e-05	1.55e-05	1.84e-05	1.82e-05	1.55e-05
	(4.67e-05)	(4.68e-05)	(4.67e-05)	(4.64e-05)	(4.47e-05)	(4.40e-05)	(4.62e-05)
Constant	0.652***	0.649***	0.646***	0.671***	0.682***	0.704***	0.658***
	(0.0607)	(0.0602)	(0.0600)	(0.0605)	(0.0585)	(0.0583)	(0.0600)
Observations	170	171	171	171	170	170	170
R-squared	0.363	0.362	0.364	0.371	0.418	0.434	0.378

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.31 Estimates very large-sized firms in Transport equipment (prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN	(5) TURN	(6) TURN	(7) TURN
Turn04/05	0.443***	0.289***	0.514***	0.369***	0.677***	0.198**	0.218**
	(0.124)	(0.0895)	(0.136)	(0.115)	(0.150)	(0.0784)	(0.102)
Turn03/04	-0.00389	-0.00519	-0.0204	0.0154	-0.00360	-0.00482	-0.0402
	(0.0360)	(0.0252)	(0.0400)	(0.0328)	(0.0462)	(0.0217)	(0.0280)
R&Dexp	0.0430***	-0.00181**	-0.00669***	-0.0125***			
	(0.00699)	(0.000685)	(0.00144)	(0.00158)			
Capex	-0.000351***				-8.77e-05	-0.000305***	-0.000547***
	(5.38e-05)				(7.78e-05)	(2.01e-05)	(5.21e-05)
Capex05		0.0429***					
		(0.00357)					
Capex04			0.0509***				
			(0.0105)				
Capex03				0.0429***			
				(0.00541)			
R&Dexp05					0.0117		
					(0.0139)		
R&Dexp04						0.0183***	
						(0.00127)	
R&Dexp03							0.0116***
							(0.00115)
Size	-1.77e-07	5.69e-07	-3.36e-07	4.48e-07	-3.11e-07	-1.34e-07	-2.35e-07
	(7.39e-07)	(5.23e-07)	(8.19e-07)	(6.78e-07)	(9.46e-07)	(4.45e-07)	(5.71e-07)
Profit	-3.12e-05	-0.000149***	-6.78e-05	-0.000139**	-9.60e-06	-2.65e-05	-2.33e-05
	(6.59e-05)	(4.76e-05)	(7.41e-05)	(6.21e-05)	(8.46e-05)	(3.96e-05)	(5.08e-05)
Constant	0.464***	0.611***	0.395**	0.546***	0.347*	0.839***	0.896***
	(0.139)	(0.0994)	(0.157)	(0.128)	(0.187)	(0.0890)	(0.118)
Observations	65	64	64	64	65	65	65
R-squared	0.566	0.787	0.468	0.643	0.292	0.843	0.741

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.32 Estimates for all firms in Real estate sector (prior growth)

VARIABLES	(1) TURN	(2) TURN	(3) TURN	(4) TURN	(5) TURN	(6) TURN	(7) TURN
Turn04/05	0.0264	0.0465	0.0140	0.0299	0.0302	0.0215	0.0269
	(0.0446)	(0.0494)	(0.0716)	(0.0443)	(0.0424)	(0.0972)	(0.0476)
Turn03/04	0.235***	0.234***	0.242***	0.238***	0.236***	0.237***	0.230***
	(0.0689)	(0.0688)	(0.0705)	(0.0687)	(0.0687)	(0.0693)	(0.0811)
R&Dexp	6.93e-05	-0.000300	-0.000102	-3.54e-05			
	(0.000280)	(0.000418)	(0.000322)	(0.000239)			
Capex	-1.72e-08				-1.73e-08	-1.48e-08	-1.52e-08
	(2.41e-08)				(2.14e-08)	(2.18e-08)	(2.21e-08)
Capex05		0.00243					
		(0.00323)					
Capex04			0.000884				
			(0.00312)				
Capex03				-6.24e-05			
				(0.000668)			
R&Dexp05					5.72e-05		
					(0.000123)		
R&Dexp04						2.16e-05	
						(0.000226)	
R&Dexp03							3.38e-05
							(0.000251)
Size	-1.28e-06	-1.33e-06	-1.30e-06	-1.32e-06	-1.26e-06	-1.30e-06	-1.30e-06
	(1.99e-06)	(1.99e-06)	(1.99e-06)	(1.99e-06)	(1.99e-06)	(1.99e-06)	(1.99e-06)
Profit	4.86e-06	1.27e-05	7.89e-06	6.19e-06	6.83e-06	4.86e-06	3.84e-06
	(0.000146)	(0.000145)	(0.000145)	(0.000145)	(0.000146)	(0.000146)	(0.000146)
Constant	0.935***	0.911***	0.940***	0.931***	0.928***	0.940***	0.941***
	(0.107)	(0.109)	(0.111)	(0.106)	(0.107)	(0.130)	(0.122)
Observations	215	216	216	216	215	215	215
R-squared	0.060	0.060	0.058	0.058	0.061	0.060	0.060

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4 Complementary effects and embeddedness into cooperation networks

The effects of cooperative R&D subsidies and subsidized cooperation on employment growth

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Abstract

The paper investigates the contribution of cooperative and non-cooperative R&D subsidies to firm growth. Of particular interest is hereby firms' embeddedness into subsidized cooperation networks. For the empirical analysis we utilize an unbalanced panel of 2.199 German manufacturing firms covering the time period from 1999 to 2009. A dynamic panel estimation technique is employed to control for growth autocorrelation as well as endogeneity. Our findings show that non-cooperative R&D subsidies have a stimulating impact on large firms' employment growth. In contrast being engaged in many subsidized cooperation is related to significant growth-reducing effects. In the case of large firms, exceptions are subsidized cooperation with geographically distant firms, which can positively influence employment growth. For small firms, rather interactions with research organizations are found to facilitate their development.

Keywords R&D subsidies, cooperation network, firm growth, serial correlation

4.1 Introduction

Firm growth and its determining factors have received considerable attention in the literature (see for a review Coad, 2009). Amongst these factors are R&D (research and development) subsidies, which are argued to support innovation activities and thereby (indirectly) facilitate their economic development (Busom, 2000). Rich empirical evidence exists that confirms such positive effects of R&D subsidies (cf. Czarnitzki et al., 2007). The adaption of knowledge from firm external sources is another growth stimulating factor that is particularly emphasized in endogenous growth theories (Romer, 1990). The absorption and utilization of such knowledge is achieved via various mechanisms including firms' engagement in inter-organizational cooperation. The contribution of cooperation to firm' economic performance has also been subject to many theoretical and empirical studies (cf. Powell et al., 1996; Powell et al., 1999). In this literature it is widely accepted that firms' generally benefit from cooperating with other organizations. While significant empirical evidence exist for cooperation and R&D subsidies facilitating firms' development (cf. Brouwer et al., 1993; Czarnitzki et al., 2007), it is rarely considered that firms frequently (and to an increasing extent) engage into inter-organizational cooperation in order for being rewarded with R&D subsidies. By participating in such programs firms become embedded into (subsidized) cooperation networks (Broekel and Graf, 2011), which can have significant effects on firms' innovation and patenting activities as Fornahl et al. (2011) recently highlighted in their study on the German biotech industry. The present paper contributes to these literature streams with an empirical study on the relevance of non-cooperative and cooperative R&D subsidies for firms' employment growth. We are evaluating their relative importance and, in case of cooperative subsidies, also explicitly take into account their function of embedding firms into (subsidized) cooperation networks. More precise, we particularly investigate the impact of a firms' position in these networks and whether it matters with what types of organizations they cooperate with. Our study is based on a panel of 2,199 German manufacturing firms covering the time period from 2004 to 2009. A Systems-GMM approach is applied to deal with endogeneity and growth autocorrelation. The empirical analysis provides empirical evidence for non-cooperative R&D subsidies positively influencing the employment growth of large firms. This contrasts the results for cooperative R&D subsidies for which no direct effects are identified. It matters however that firms engage in subsidized cooperation. For instance, we find a growth-stimulating effect of cooperating with public research organizations. In case of large firms rather interacting with geographically distant firms seem to be of larger importance. We also observe negative effects being associated to cooperating, which are primarily related to extensive participation in subsidized cooperation.

The structure of the paper is as follows. Section 4.2 reviews the literature on the empirical evaluation of subsidies and cooperation as well as their relevance for firm growth. Hypotheses are subsequently developed in the same section. Section 4.3 focuses on the methodology, the employed data, and the construction of the empirical variables. The findings are presented and discussed in Section 4.4. Section 4.5 concludes the paper.

4.2 Theoretical background and hypotheses

A substantial literature studies the determinants of firm growth. McKelvie and Wiklund (2010) summarize the main research streams within this literature. The first of these streams focuses on growth as the outcome of economic processes and firm characteristics. The second stream concentrates on the results and effects of firm growth and the third stream studies the growth process itself. The present paper fits into the first stream by focusing on the role subsidies play for the economic success of firms. Subsidies and the evaluation of their impact on the economic success of firms have received substantial empirical attention in the literature. It has, for example, been shown that subsidies impact firms' R&D efforts (cf. Busom 2000, Gorg and Strobl 2007) and employment growth (cf. Brouwer et al. 1993, Girma et al. 2008). In other words, subsidies are shown to be very relevant for firms' economic development. In the following, we focus on one particular type of subsidies, namely R&D subsidies. There are multiple reasons for R&D subsidies being granted. For instance, they are used to stimulate private research in fields that are politically desirable. In Germany this applies to new technologies and so-called key technologies that are foremost supported (Fier 2002). Subsidies for R&D are also argued to be necessary because private investments into R&D activities are perceived to be below a social optimum. The uncertainty and risks involved in innovation activities are particularly important amongst the reasons for insufficient investments (Cantwell 1999). Financial constraints further reduce the amounts invested in R&D and strongly hamper innovation. R&D subsidies can remove these obstacles by providing additional financial resources for innovation-oriented activities. As for subsidies in general, the financial aspects of R&D subsidies have therefore received most attention in their scientific evaluation (cf. Czarnitzki and Hussinger 2004, Czarnitzki et al. 2007). The empirical relation between R&D subsidies and employment growth is likely to be different from that between employment growth and other types of subsidies. First of all, R&D subsidies are predominantly aimed at expanding firms' R&D capacities and impact their ability to grow in the middle run and long run. Their effects on employment are thereby indirect in nature contrasting the rather direct effects of many other subsidies types. Secondly, R&D subsidies generally tend to be relative small in terms of granted monetary amounts. For the empirical investigation it implies that the empirical detection of an impact on employment growth is less likely. Thirdly, firms participating in R&D subsidy programs are probably structurally different from those that apply for non-R&D related subsidies. Foremost, the latter firms do not necessarily conduct R&D, which is however a requirement for firms' to obtain R&D subsidies. This may impact the empirical findings insofar as firms active in R&D show different (more positive) growth patterns than those that do not invest in R&D (Brower et al. 1993). Despite these unique characteristics of R&D subsidies they are expected to stimulate firms' employment growth, which is supported by already existing empirical evidence (Czarnitzki et al. 2007). Our first hypothesis emphasizes these potentially positive effects of R&D subsidies.

H1: R&D subsidies facilitate firms' employment growth.

Another growth-stimulating factor that has received considerable attention in the recent literature is a firm's capability to invent and use new knowledge (Zahra et. al. 2006). Cohen and Levinthal (1990) famously pointed out that a firms' competence in absorbing external information and knowledge is crucial in this respect (absorptive capacity). O'Regon et al. (2006) argue similarly that firms are unlikely to sustain their competitive advantage without access to greater (and potentially external) research and development resources. It is therefore particularly important for firms to interact with external knowledge sources to continuously innovate and generate growth momentum (cf. Powell et al. 1996). One way for firms to access external knowledge is to engage in formal and informal cooperation with other organizations.[1] Such inter-organizational cooperation in R&D is an important supplement to internal R&D activities as it generally increases the probability of innovative success (Oerleman and Meeus

[1] Other mechanisms are for instance labor mobility and the exchange of embodied knowledge via the trading of good and tools.

2000). Cooperating organizations benefit from the sharing of risks and costs (Cassiman and Veugelers 2002), access to complementary knowledge and assets (Teece 1986), and their transfer into the organization (Eisenhardt and Schoonhoven 1996). Accordingly, it can be argued (and it is empirically shown) that firms, which are well embedded into a wide range of cooperation are likely to be in superior positions for achieving above average innovation performance and eventually employment growth (cf. Powell et al. 1996). However, cooperation might not always be beneficial. The establishment and maintenance of cooperation agreements require efforts. Cooperation might fail, which implies a wasting of these efforts (Bleeke and Ernst 1993). Another reason for potential negative effects of cooperation is free-riding on partners' R&D efforts (Kesteloot and Veugelers 1995). "[L]earning races between the partners [...], diverging opinions on intended benefits [...] and a lack of flexibility and adaptability" (Faems et al. 2005 p. 240) can additionally induce negative effects. Another danger inherent to cooperative activities is the potential "leakage" of crucial knowledge to competitors (De Bondt et al. 1992).[2] Nevertheless, cooperation is generally perceived to enhance firms' economic performance (cf. Li and Vanhaverbeke 2009). This has also been noticed by policy. An increasing number of programs aiming at the stimulation of growth are characterized by strong cooperative elements. In addition to the previous arguments, policy intervention is motivated by the fact that some projects are too big to be realized by a single organization, which makes cooperation a necessity. Policy also frequently tries to stimulate technology transfer from public to private organizations. Universities and research organizations are encouraged to participate in the respective funding programs and to engage in cooperation with private firms. Prominent examples for such policies are the framework programs by the EU, which provide strong incentives for firms and research organizations to engage in joint projects (cf. Scherngell and Barber 2011). In a similar fashion, the German federal government is increasingly supporting cooperative (i.e. joint) projects with R&D subsidies. Broekel and Graf (2011) estimate that about 30 percent of all R&D subsidy grants (by the German federal government) are given to consortia of organizations realizing joint research projects. These authors as well as Fornahl et al. (2011) argue that such cooperative subsidies might take effect on firms' performance beyond the "simple" monetary effects because they also imply active engagements in cooperative activities. In contrast to unsubsidized cooperation, which are frequently approximated by patents (Ejermo and Karlsson 2006), venture capital syndication (Sorenson and Stuart 2001), director inter-locks (Mizruchi 1996), joint publication (Ponds et al., 2010), or interview data on inter-organizational interaction (Uzzi 1996), little is known about the relationship between such subsidized cooperation and firm performance. While most of the literature agrees that (unsubsidized) cooperation generally enhances innovative and economic performance it is still unclear whether the same can be said about subsidized cooperation. Differences in the structure and effects of subsidized and unsubsidized cooperation can be expected to exist, though, because policy heavily interferes in the establishment and process of (subsidized) cooperation. For instance, it defines the general conditions of cooperating in subsidies programs and selects those proposals that are granted, which might not be the ones that are economically most beneficial. Moreover, the pool of potential cooperation partners is likely to differ between unsubsidized and subsidized cooperation as in the latter case it will include only those organizations that (for whatever reasons) seek and apply for R&D subsidies. Despite these differences to unsubsidized cooperation, subsidized cooperation is also shown to impact firms' economic success. Fornahl et al. (2011) provide empirical evidence for the existence of differences in the effects of cooperative and non-cooperative subsidies for the German biotech industry. These authors show that a firm's innovation performance is not

[2] See also Broekel et al. (2011) for a discussion of these issues.

enhanced by non-cooperative subsidies but by firms being engaged in subsidized cooperation. This motivates our second hypothesis.

H2: Cooperative R&D subsidies are more conducive for employment growth than non-cooperative R&D subsidies.

Broekel and Graf (2011) as well as Fornahl et al. (2011) argue further that by participating in joint projects, organizations become embedded into inter-organizational cooperation networks. These cooperation networks are likely to represent effective channels of knowledge diffusion, i.e. knowledge networks, because participating organizations agree to substantial knowledge sharing regulations. Accordingly, knowledge network effects might also be present when firms engage in subsidized joint projects. Such effects imply that knowledge can diffuse beyond directly linked organizations. It means further that a partner's partners become relevant for a cooperating firm. Fornahl et al. (2011) find that firms' with many direct links do not experience above average innovation performance. Rather those firms benefit from being embedded in subsidized cooperation networks that have easy access to knowledge located at very different areas in the networks. On this basis we formulate the third hypothesis as follows.

H3: Firms profit from holding central network positions with easy access to knowledge located elsewhere in the network.

Partnering organizations need to "fit" to each other in order to profit from cooperating. This involves a common understanding of the joint project's aims and the willingness to share knowledge, resources, as well as capabilities (cf. Cantner and Meder 2007). Moreover, different forms of proximity between the partners (geographic, institutional, social, organizational, and cognitive) impact the effectiveness of interacting (Boschma 2005). As in the case of unsubsidized cooperation, it matters with whom organizations cooperate. The empirical literature suggests that linkages to research organizations and universities might be especially knowledge rich and valuable (cf. Beise and Stahl 1999, Raspe and van Oort 2011). The fourth hypothesis takes these findings up.

H4: Subsidized linkages to research organizations and universities enable firms to outgrow firms that primarily cooperate with other firms.

Another aspect that has frequently been investigated is the relevance of the geographical dimension of firms' cooperative links. Geographic proximity to partners is frequently argued to enhance the effectiveness of inter-organizational knowledge exchange (see for a discussion Boschma 2005). Accordingly, organizations that frequently cooperate with organizations located within small geographic distance are more likely to benefit from cooperating (Oerlemans and Meeus 2005). Our fifth hypothesis highlights such effects of geographic proximity.

H5: Geographic proximity to cooperation partners enhances the effectiveness of knowledge transfer and thereby is conducive for firm growth.

So far, we treated all firms as being homogenous. However, there are good reasons to believe that some of the previously outlined relationships vary in their importance for different types of firms. For instance, research on SMEs reveals that these firms especially obtain a great share of knowledge from external advisors, universities, and other firms (cf. Beise and Stahl 1999, O'Regan et al. 2005, Raspe and van Oort 2008). Accordingly, we expect cooperation and in particular cooperation with research organizations (including universities) to be more important for small than for larger firms. This leads to the sixth hypothesis, which highlights these differences related to firm size.

H6: Differences exist in the importance of subsidized cooperation between small and large firms. Links to research institutes and universities are particularly more conducive to small firms' growth.

In the following, we present the employed database before the approach is discussed with which the six hypotheses are empirically tested.

4.3 Data source and empirical variables

4.3.1 Data sources

We use the MARKUS database provided by the Bureau van Dijk as data source. It contains 1.3 million German, Austrian, and Luxembourgian firms. For this paper we focus only on German manufacturing companies with information on their names, industry affiliation, zip code, sales/turnover, and their total employment numbers. Sales/turnover and employment data are available for the time period from 2001 to 2010, however with many missing values. In an initial step, a firm population is selected consisting of 14,018 firms for which sales/turnover and employment information is available at least for the time period 2004 to 2009. This information is matched to data on R&D projects that were subsidized by the following German federal ministries: Ministry of Education and Research (BMBF), Ministry of Economics and Technology (BMWi), and the Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU). Accordingly, the data covers the most important sources of R&D subsidies on the federal level. It is recorded in the so-called "Förderkatalog" (subsidies catalogue), which is accessible via the website www.foerderkatalog.de. The database offers very detailed information on more than 110,000 projects that were supported between 1960 and 2009 including information on the name and location of the receiving organization. It is important to point out that the data does not provide complete information on all types of R&D subsidies a firm can potentially receive. Only R&D related subsidies granted by the German federal government are covered leaving aside all non-R&D related subsidies and all subsidies from other political levels (e.g. the German federal states ("Länder"), districts, and EU). The R&D subsidies data allows for differentiating between subsidies granted to joined projects (i.e. cooperative subsidies) and those that are granted to single organizations (i.e. non-cooperative projects). Organizations that participate in such joint projects agree to a number of regulations that guarantee significant knowledge exchange between the partners. Accordingly, two organizations are defined to cooperate if they participate in the same joint project (see for more details Broekel and Graf, 2011). Of the 14,018 firms in the sample from the MARKUS database 733 firms are identified to have received subsidies in at least one year between 2001 and 2008.[3] With just 733 of 13,285 being subsidized any subsidies based variable will be heavily inflated with zero values, which might be problematic in the empirical assessment. We therefore create a smaller control group of unsubsidized firms. More precisely, we first consider all firms that did not receive subsidies between 2001 and 2008, for which we have complete information concerning their industry classification, employment (2004-2009), and turnover (2004-2009). Second, for each of the

[3] In the empirical estimation we consider a time lag between employment growth and subsidies. The smallest considered lag is one year.

733 subsidized firms we chose two unsubsidized firms from this sample that belong to the same 6-digit NACE industry and that are most similar in terms of their employment number. Each of these “control” firms is considered only once. In the rare instance that a 6-digit NACE industry is too small to offer a sufficiently large number of control firms, we consider firms of the same 5-digit and 4-digit industry, respectively. Accordingly, subsidized firms represent one third of the final sample, which amounts to 2.199 firms.

4.3.2 Descriptive statistics and correlations

The final unbalanced panel consists of 2.199 firms and 24.189 observations. Figure 4.1 shows the firm size distribution in 2008. Given the way the sample is constructed it closely resamples the size distribution of the 733 firms that received subsidies.

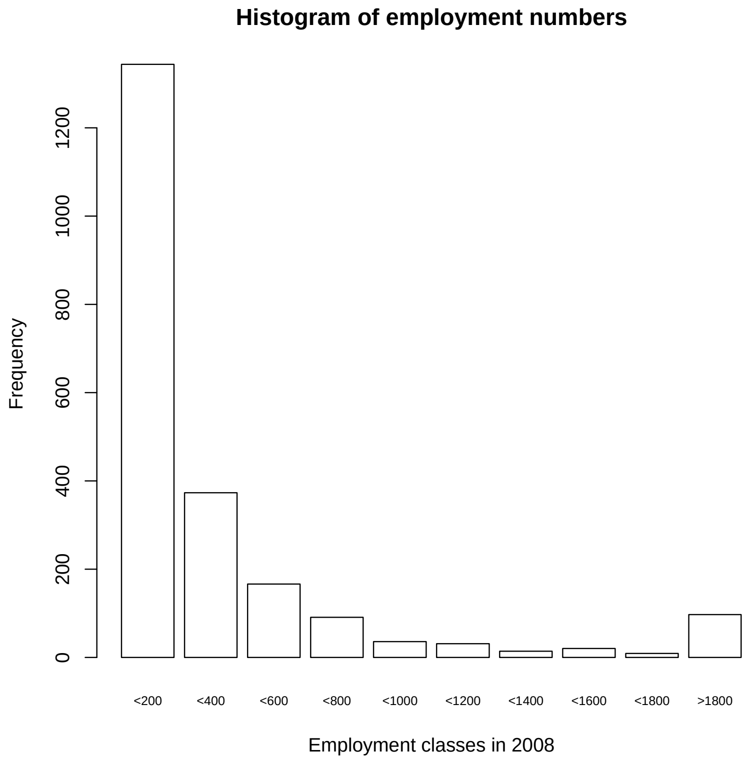

Figure 4.1 Distribution of employment

The figure shows that firms with less than 200 employees dominate our data base. However, compared to the overall distribution of firm sizes in Germany, the larger firms with more than 200 employees, which account for less than 1% of all German firms, are overrepresented in our sample. This reflects the overall bias of the MARKUS database towards larger firms and is further increased by the better data availability for larger firms and by larger firms being more likely to receive subsidies. In addition to the two main characteristics of firms (employment, turnover), we construct a number of variables on the basis of the subsidies data. They are presented in the following.

The first variable of interest is the total amount of yearly R&D subsidies a firm receives from the German federal government (SUBS). For the estimation of the yearly monetary amounts we take into account each project's exact starting and ending data and distributed the total

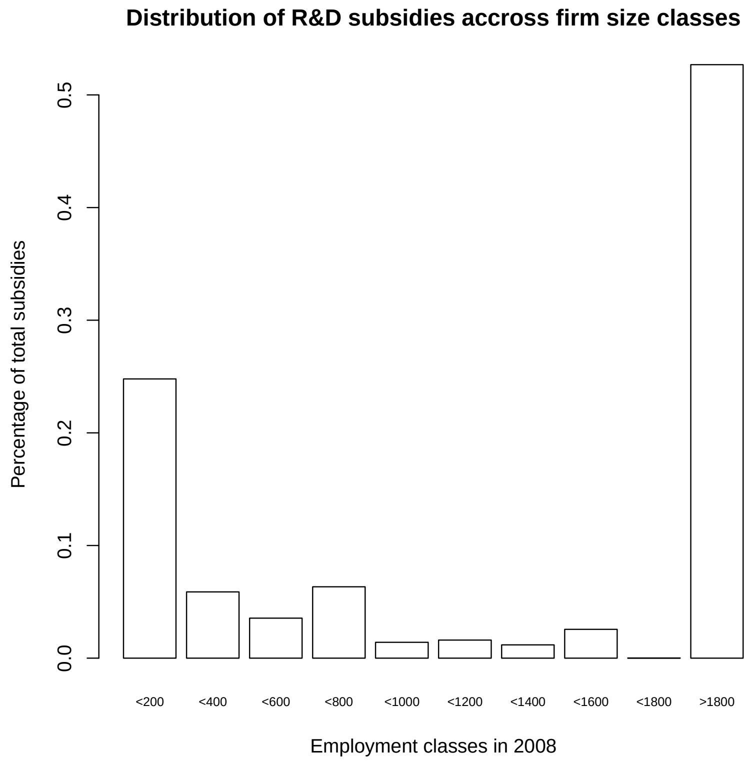

Figure 4.2 Distribution of subsidies across firm size classes

sum uniformly in time. Figure 4.2 pictures the distribution of granted subsidies across firm size classes. This means, for instance, that firms with less than 200 employees receive about 26 percent of the total amount of granted subsidies. Firms with more than 1,800 employees obtain the largest share of subsidies with more than 50 percent. To get more insights into the impact of subsidies, we split the variable SUBS into the number of granted projects (PROJ) and the average amount of subsidies per project (SUBSP). This allows for assessing whether the effects of subsidies are related to the size of projects (SUPS) or to the total number of projects a firm is involved (PROJ). The amount of subsidies is alternatively divided into the amounts coming from a firm's participation in joint projects, i.e. cooperative R&D subsidies (CSUM), and the non-cooperative R&D subsidies (SUM) that are acquired as subsidies granted to the individual firm. In a similar manner as for SUBS both numbers are also split into the average amount of subsidies per joint project (CSUMP), the number of joint projects (CPROJ), the amount of subsidies per non-cooperative project (SUMP), and the number of non-cooperative subsidized projects (SPROJ). Using the information on firms' participation in joint projects we can draw the complete inter-organizational networks of subsidized cooperation in Germany. For these networks we consider ALL organizations (firms, universities, associations) that receive subsidies from the respective German federal ministries in a particular year. Moreover, all subsidized research organizations; universities, associations, and other sorts of organizations are included in the network (see for more details Broekel and Graf, 2011). Some network descriptive can be found in Table 4.1. Interestingly, the number of organizations in the network (including isolates) increases until 2002 before it declines in the subsequent years. We can only speculate about this finding, which might be a result of changes in the support policies or the burst of the ".com bubble" in 2001. By and large, the density of the network remains stable since the number of links ("edges") drops simultaneously, though.

Network characteristic	Year 1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Density	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Nodes	4.069	4.333	4.807	5.263	4.972	4.541	4.414	4.414	3.949	3.331
Edges	11.309	12.161	14.539	15.159	14.118	12.274	12.047	12.571	10.170	7.543

Table 4.1 Network characteristics

In a common fashion, we approximate potential effects caused by firms' embeddedness into these networks through a firm's degree (DEGREE) and betweenness centrality (BETWEEN) (cf. Boschma and ter Wal, 2007). Degree centralization is straightforwardly defined as the number of links an organization has to other organizations. Or in the context of this paper, the number of unique partners a firm is cooperating with in joint projects in a particular year. Betweenness centrality is a more complex measure. It measures if a firm holds a 'brokerage' position in a network implying that it captures the extent to which shortest paths linking other organizations 'run' through this firm (Wasserman and Faust, 1994). Firm *i*'s betweenness centrality is estimated by:

$$BETW_i = \sum_{j<k} g_{jk}(n_i) / g_{jk} \quad (2)$$

with g_{ik} being the geodesic distance (DISTANCE) between organization *j* and *k* that are part of the network. The following variables provide information on the composition of firms' ego-networks (their direct partners) with respect to the organizational and institutional background of their partners. We consider the share of universities in a firm's partnering organizations (UNI), the share of research organizations (RESEARCH)[4], and the share of firms (FIRMS). The remaining share of miscellaneous organizations (associations, local authorities, and other governmental entities) is not considered to avoid perfect collinearity. As pointed out above, we are also interested in the geographical reach of a firm's ego network. For this reason we estimate the average geographic distance to all its partnering organizations, which can be seen as a measure of a firms' embeddedness into local knowledge networks (Broekel and Boschma, 2011). The descriptive statistics of all variables are presented in Table 4.2. Table 4.3 (in the appendix) presents the correlation structure of the variables. Some interesting observations can be made in the correlation table. Most subsidies variables are notably highly correlated. For instance, the numbers of projects (PROJ, CPROJ, SPROJ) are always (and not surprisingly) correlated to the absolute monetary amounts (SUBS, SUM, CSUM). More interestingly, the numbers of cooperative projects (CPROJ) and non-cooperative projects (SPROJ) are also highly correlated with r=0.778***. Accordingly, firms that receive subsidies apply for cooperative as well as non-cooperative subsidies. However, this correlation is likely being impacted by the size of organizations, which is not taken into account in this simple bivariate analysis. Another observation regards the two network centrality measures (DEGREE and BETWEEN), which are highly correlated with each other and with the number of cooperative projects (CPROJ). This has to be considered in the later empirical analysis.

[4] This particularly regards institutes belonging to the "big four" research organizations in Germany: the Max-Planck Society, the Fraunhofer Society, the Helmholtz Association, and the Leibniz Association.

Variable	Description	Mean	S.D.	Min	Max
EMP	Number of employees	920.83	11.618.38	1	439.000
PROD	Labour productivity (turnover in thousand EURO per employee)	305.91	3.874.21	5.92	249.000
SUBS	Amount of received subsidies	36.140.22	428.000.00	0	25.300.000
SUBSP	Amount of subsidies per project	12.855.80	47.101.84	0	1.060.000
PROJ	Number of granted projects	0.32	2.13	0	96
SUM	Subsidies granted to individual firm (non-cooperative R&D subs)	14.422.07	191.000.00	0	10.500.000
CSUM	Firm's participation in joint projects (cooperative R&D subsidies)	21.718.16	260.000.00	0	15.500.000
SUMP	Amount of subsidies per non-cooperative project	6.651.35	40.930.78	0	1.060.000
CSUMP	Average amount of subsidies per joint project	8.633.66	35.829.08	0	779.000
SPROJ	Number of non-cooperative subsidized projects	0.10	0.63	0	24
CPROJ	Number of joint granted projects	0.22	1.60	0	74
DEGREE	Number of links an organization has to other organizations	1.31	10.64	0	551
BETW	Measures if a firm holds a central position in this network	192.25	3.989.49	0	227.000
UNI	Share of universities in a firm's partnering organizations	0.02	0.10	0	1
RESEARCH	Share of research organizations	0.02	0.08	0	1
FIRM	Share of firms	0.08	0.23	0	1
DIST	Geodesic distance between organization and network	35.62	106.61	0	844

Table 4.2 Descriptive statistics of variables

4.4 Empirical approach

For the investigation of the relationship between subsidies and employment growth we follow the approach (and notation) by Girma et al. (2008). These authors specify a dynamic labour demand function that has been put forward by Nickell (1987):

$$\log(EMPL_{i,t}) = \alpha + \beta_1 \log(EMPL_{i,t-1}) + \beta_2 \log(TURN_{i,t}) + \beta_3 \log(WAGE_{i,t}) + \beta_4 \log(SUBS)_{i,t} + \tau_t + \eta_i + \varepsilon_{i,t}$$

whereby $EMPL_{i,t}$ represents the employment, $TURN_{i,t}$ the output (in terms of turnover), $WAGE_{i,t}$ the average wage, and $SUBS_{i,t}$ the amount of received subsidies of firm *i* in *t*. In contrast to Girma et al. (2008), we unfortunately don't have information on the wage per head and moreover find turnover to be highly correlated with employment (r=0.91***).[5] For this reason we rather use the turnover per employee, i.e. labour productivity (*PROD*), which on the one hand allows distinguishing between highly productive and less productive firms and on the other should be highly correlated to the wage per head. As Girma et al. (2008) we take the logarithm of employment and labour productivity, which yields more robust results. The subsidies variables are not logged as they involve many zero values that prevent a proper application of the log-transformation. Another difference between Girma et al. (2008) and our study is the more differentiated view on subsidies, which are considered as variable *g* in the above equation. We specify a multitude of variables approximating the extent to which firms receive non-cooperative and cooperative subsidies as well as a wide range of variables capturing their embeddedness into the subsidized cooperation networks. The adapted dynamic labour demand function looks the following:

$$\log(EMPL_{i,t}) = \alpha + \beta_1 \log(EMPL_{i,t-1}) + \beta_2 \log(PROD_{i,t}) + B * SUBS_{i,t} + \tau_t + \eta_i + \varepsilon_{i,t}$$

[5] "***" indicates a significance level of 0.01, "**" significance at 0.05, and "*" significance at 0.01.

In contrast to the above, PROD represents the labour productivity measure and SUBS the matrix of variables based on the subsidies data. τ_t represents time specific effects, η_i time invariant firm level ("fixed") effects, and $\varepsilon_{i,t}$ finally stands for the error term summarizing all other (stochastic) effects in both models. As common in this type of research, we consider a lagged version of the dependent variable in the estimation because of the dynamic nature of labour demand that is caused by a "non-smooth adjustment process" in firms' employment policy (Girma et al. 2008, p. 1187). The consideration of the lagged version of the dependent variable as independent variables requires the use of dynamic panel analysis (Arrelano and Bond 1991). In addition, when investigating the impact of subsidies on employment growth the most challenging issue is how to deal with potential endogeneity between the empirical variables. Endogeneity may be introduced to the econometric model primarily for two reasons. First, there might be certain unobserved firm characteristics impacting the probability with which firms receive subsidies and which simultaneously influence their employment growth. Such factors might be either unobservable or at least empirically hard to approximate. Second, while subsidies may influence employment growth the opposite can be the case as well. For instance, there might be policy programs specifically aiming at supporting declining or fast growing firms. For firms in declining markets it might also be a highly beneficial strategy to lobby and apply for subsidies. Accordingly, the relationship between subsidies and employment growth is not necessarily mono-directional violating a fundamental assumption of standard empirical models. In a similar fashion as Girma et al. (2008), we overcome these issues by using the Systems-GMM estimator developed by Blundell and Bond (1998). This estimator is widely used in current literature and therefore we refrain from introducing it at great length.[6] For instance, Lachenmaier and Rottmann (2011) make use of it to investigate the effects of innovation on employment. The idea behind the Systems-GMM estimator is that potentially endogenous variables are instrumented with their own lags. More precisely, the lags of their first difference as well as the lags of their values are used for the instrumentation. A crucial issue is hereby the validity of the lagged variables as instruments, which is related to the question of whether they can be considered to be exogenous and whether they conflict with over-identification restrictions. In a usual manner these issues are checked with a Sargan/Hansen statistic. In addition, the errors are required to be free of second-order autocorrelation, which is assessed with the Arrelano - Bond test (Arrelano and Bond 1991). The final model that is employed for the empirical analysis is a two-step Systems-GMM in the spirit of Arrelano and Bover (1995) with Windmeijer-corrected cluster robust-errors (Windmeijer 2005).[7] As pointed out above, R&D subsidies are unlikely to result in immediate employment expansion. However, it also seems to be impossible to define a reliable time lag between granting and the effect on employment, which is particularly the case for network effects. We therefore follow Girma et al. (2008) and simultaneously include a range of lags (1, 2, and 3 years) in the empirical analysis.

4.5 Empirical results

4.5.1 R&D subsidies and employment growth

The regression results for various models are reported in Tables 4.4, 4.4a, 4.4b and 4.5 (in the appendix). We specify the lagged employment ($EMPL_{t-1}$), labour productivity ($PROD_t$), and the subsidies variables to be potentially endogenous. Only the included year dummies (2004 to 2008 with 2009 being the reference) are considered to be purely exogenous. In all models

[6] Roodman (2009) provides an excellent introduction to this topic.
[7] See Roodman (2009) for a detailed discussion of these specifications.

the lagged dependent variable ($EMPL_{t-1}$) is instrumented with the sixths lag of its level and first difference. The level and first difference of the third and fifth lag proved to provide robust results for labour productivity ($PROD_t$). With the exception of **Model 1** all subsidies based variables are instrumented with the sixth lag of their levels and first differences. In the first model, also the fifths lag of SUBS's level and difference are considered. The requirements of no overidentification restrictions (as tested with the Sargan and Hansen statistics) and exogeneity of the instruments (evaluated with a difference-in-Hansen test) are fulfilled in all models. In all but two models, further requirements of significant first-order autocorrelation and insignificant second order-autocorrelation (as indicated by the Arellano-Bond test) are met by considering the first lag of the dependent variable ($EMPL_{t-1}$). In one models (**model 8**) the second lag of the dependent variable needs to be included as well. This will later be discussed in more detail. The lagged employment level turns out to be significantly positive and close to one in all models, which is in line with comparable findings in the literature (e.g., Bottazzi and Secchi, 2003; Coad, 2009; Girma et al., 2008). Labour productivity is found to be positively associated to employment growth (PROD). It means that highly productive firms outgrow less productive firms. The variable PROD loses its significance when including variables that account for the type of organizations firms' cooperate with (see **Models 7** and **8**). This observation suggests that a significant portion of this effect is related to highly productive firms cooperating with different types of organizations than less productive firms. The year dummies remain insignificant with few exceptions (y2004, y2005, and y2007 in Models **7** and **8**. In all cases they obtain negative coefficients suggesting that firms' employment was lower in most years before 2009 (reference year). In other words, firms' generally increased their size in the considered time period. In the first model we test **hypothesis 1** "*R&D subsidies stimulate the employment growth of firms"*. The significant negative coefficient of (the second lag of) SUBS clearly rejects this hypothesis and rather indicates that R&D subsidies show a negative relation with employment growth. Moreover, this finding contrasts previous results in the literature showing that non-R&D related subsidies induce higher employment growth (Girma et al. 2008). Accordingly, there are significant differences in the effects of the two types of subsidies. The second model gives a clearer picture on the source of the negative effects. While the variables SUBSP (amount of subsidies per supported project) remains insignificant PROJ (number of projects) gains negative significance in the third lag. It implies that firms experience lower employment growth when they engage in a large number of subsidized projects. In contrast, the size of the individual project (as approximated by the amount of received subsidies per project) is not relevant for growth. A major contribution of the present paper to the literature is the differentiated view on cooperative and non-cooperative subsidies. According to **hypothesis 2** the first ones are more likely to generate positive employment effects. The splitting of SUBS into SUMP (amount of non-cooperative subsidies) and CSUM (amount of cooperative subsidies) does not yield any significant coefficients (Model 3), though. We further differentiate between the numbers of subsidized projects (cooperative and non-cooperative) and the respective amounts of subsidies per project in **Model 4**. In this case the number of subsidized cooperative projects (CPROJ) gains significance in the first lag with a negative coefficient. In contrast, the other variables - number of non-cooperative subsidies (SPROJ), amount of cooperative subsidies per project (CSUMP), and amount of non-cooperative subsidies per project (SUMP) – remain insignificant. The high correlation between CPROJ and the total number of subsidized projects (PROJ) of r=0.982*** implies that the previously observed negative coefficient of PROJ has its cause in the negative impact of CPROJ. Accordingly, it is not the extensive engagement in subsidized projects in general that yields negative effects but rather the engagement in many subsidized cooperative projects. In light of this we have to reject hypothesis 2, which suggested a positive relationship between cooperative subsidies and employment growth. Before the implications are discussed in more detail it is worthwhile to take **Models 5** and **6** into consideration as well. They deal with **hypothesis 3** according to which firms that are central in the cooperation network should experience additional employment growth. When considering the two network measures, degree and betweenness centrality (DEGREE and BETWEEN) CPROJ loses its significance with these two variables also being insignificant. Each of the three variables is however negative significant when being separately considered, which suggests that they all explain the same effect. This is also visible in the high correlation (r>0.9***) among the three variables, see Table 4.3 in the appendix. It means that firms engaging in many cooperative projects are also very central in the cooperation network. We estimated a number of alternative models but failed to disentangle the effects of these three variables. Nevertheless, the negative relation between the number of cooperative projects (or degree and betweenness centrality) implies that we have to reject **hypothesis 3** as well, as we don't find positive effects caused by a strong embeddedness of firms in the subsidized cooperation network. The rejection of the two **hypotheses 2** and **3** is surprising as the theoretical arguments as well as empirical evidence strongly support these hypotheses (cf. Becker and Dietz, 2004). Moreover, negative effects related to too extensive cooperation activities are rarely reported in empirical studies. Most prominently, Uzzi (1996) highlights negative performance effects related to "overembeddedness" into networks. His argument and empirical evidence alludes to a strong reliance on few but very intensive relations, though. Brouwer et al. (1993) do not find a relationship between firms' R&D cooperation and employment growth. In the context of subsidized cooperation Fornahl et al. (2011) show that intensive engagement in cooperative subsidies does not increase firms' patenting performance. As pointed out before, negative effects related to cooperation can have different causes including free-riding on partners' R&D efforts (Kesteloot and Veugelers 1995) and knowledge "leakages" (De Bondt et al. 1992). It is also important that cooperating partners fit to each other implying complementary resources and capabilities as well as a shared understanding of the project's aims (Faems et al. 2005). The choice of the right cooperation partner is central in this respect (Fornahl et al. 2011). We pointed out before that non-subsidized cooperation might be quite different from subsidized cooperation as firms' are less free in choosing the most appropriate partner in the latter case. One might therefore speculate that it is a problematic selection / combination of firms' cooperation partners that explains the observed negative effects. We further explore this issue in **model 7** that includes variables approximating the share of universities (UNI), the share of research organizations (RESEARCH), and the share of firms (FIRMS) in firms' ego-networks, i.e. their direct links in subsidized cooperation projects. The first thing to notice is the positive significance of CPROJ in the second lag while the variable is still negative in the first lag. This is however a statistical artifact that relates to some incorrectly modeled autocorrelation dynamics in the original model. When including the second lag of the dependent variable ($LOGEMP_{t-2}$) the significance of CPROJ's second lag disappears. This will be discussed in more detail in the next subsection. In addition to CPROJ, also the share of research organizations (RESEARCH) becomes significant. The variable's coefficient is positive and indicates that firms' benefit from intensive cooperation with (public) research organizations. Most notably, this includes institutes of the Max-Planck and Fraunhofer Society that represent the majority of links in this category. The finding extents previous studies in the literature that find firms to benefit from unsubsidized cooperation with research organizations (cf. Beise and Stahl 1999, Ponds et al. 2010, Veugelers and Cassiman 2005) to the case of subsidized relations. The positive effect of RESEARCH partly confirms our **hypothesis 4** according to which relations to universities and research organizations are most beneficial. The confirmation is only partly as we do not find any statistical evidence for a growth promoting role of links to universities, for which rich empirical evidence exists (Jaffe 1989, Cassia et al. 2009).

We have to reject **hypothesis 5** as we do not observe a significant coefficient for DIST approximating the average distance of firms' direct links. It means that geographic proximity does not influence the effectiveness of subsidized R&D cooperation for employment growth. Although we now control for the institutional and geographic composition of firms' ego-networks CPROJ remains significant. Accordingly, the negative effects related to extensive cooperation are independent of these two aspects. Surely, this is an interesting issue for future research.

4.5.2 Size differences

In **hypothesis 6** we put forward that subsidies and subsidized cooperation are likely to be of varying importance for firms with different sizes. We particularly expect differences to exist between small and large firms. To test this, the sample of 2.199 firms is split into a sample of small firms with less than 100 and those with more than 100 employees (splitting our sample into two parts of similar size). As in particular very small firms might be quite different, we alternatively consider a third subsample consisting of firms with less than 50 employees. The previous empirical analysis (**model 8**) is repeated separately for the three subsamples. The results are presented in Table 4.5 in the appendix. All estimated models are similar to **model 8** in terms of coefficients and significance of non-subsidies based variables. We therefore refrain from discussing these. The estimation of models for the sample of firms with at least 100 employees requires the inclusion of the second lag of the dependent variable ($LOGEMP_{t-2}$) to avoid significant second-order autocorrelation. We pointed out above that the antipodal coefficient of CPROJ's second lag disappears when considering the second lag of the dependent variable in the model for the full population (see **model 7** and **8**). Accordingly, this observation seems to be driven by differences between the autocorrelation structure of large and small firms' employment growth. This provides support for **model 8** being empirically more reliable than **model 7**. Concerning the two subsidies variables that gained significance in **model 8** (complete firm population), CPROJ and RESEARCH, we find that the latter one does not obtain a significant coefficient in any of the models for the above subsamples implying that its influence is not particularly related to these firm size class. In addition, to RESEARCH's significance in the model for the complete firm population (**model 8**) it also becomes positive significant in a (not reported) model that restrict the sample of firms to those with at least 50 employees. The variable however looses its significance again when considering only firms with 100 employees implying that there is no systematic relationship with firm size. In the model for firms with at least 100 employees, FIRM is positively significant in the third lag. The positive coefficient suggests that FIRM is not simply picking up the effect of RESEARCH as both are strongly negatively correlated when restricting the sample to firms that receive cooperative subsidies (r=-0.47***). The finding means that larger firms tend to benefit from collaborating with other firms. However, there might be an alternative explanation. FIRM is highly positively correlated with DIST (r=0.854***). Therefore, we suspect that FIRM captures negative effects related to intensive cooperation with organizations in spatial proximity. It is often argued that particularly cooperation with local and regional organization can yield benefits (see for a discussion Boschma 2005; Broekel et al. 2010). We test this alternative explanation by excluding FIRM from the regressions for firms with at least 100 employees. DIST becomes positive significant in the third lag implying that there seems to be some relevance to this explanation.[8] For firms with at least 100 employees, we again observe the negative effect related to the number of cooperative projects (CPROJ), which is also visible in the models for the complete firm population. Similar is not observed in the models for small firms (less than 50 and less than

[8] To economize on space these results are not reported but can be obtained from the authors upon request.

100 employees). The negative relation between CPROJ and employment growth is therefore primarily relevant for larger firms. There are many reasons for why extensive cooperation can yield negative effects on firm growth, e.g., free-riding, learning races, lack of flexibility and adaptability (see Section 2). However, these do not seem to be particularly more relevant for large than for small firms. We furthermore only explore the effects of subsidized R&D cooperation implying that the relationships might be very different for non-subsidized cooperation. In light of this, we argue that the negative effects large firms experience when being extensively engaged in subsidized R&D cooperation are more likely to be caused by a suboptimal choice of cooperation partners and knowledge leakages. Starting with the latter, some large firms engage in a huge number of (subsidized) cooperation projects. One firm in our sample (a very large one) simultaneously cooperates with 551 organizations. These cooperative projects are distributed among different business units and technologies. It might very well be the case that the firm is cooperating in one field with a firm that is its direct competitor in another field. Given the convoluted structure of many large firms such may result in unintended knowledge spillovers and knowledge leakages that can reduce firm growth (cf. De Bondt et al. 1992). Another potential reason for negative effects associated to extensive cooperation activities is the choice of partners. In contrast to non-subsidized cooperation, firms are not completely free in choosing their partnering organizations when applying for a joint project grant. In many instances, subsidies programs are precisely designed to stimulating cooperation between particular types of organizations. Just to name one example, the German BioRegio program provides subsidies for cooperation in R&D projects that are formed between organizations located within the same geographical region (cf. Dohse 2000). It could therefore be argued that such and similar interference on firms' cooperation behaviour reduce the benefits of cooperation or even results in negative effects.[9] However, this remains speculative at the moment as this is beyond the present study. It clearly asks for future research. One more variable gains significance in the model for firms larger than 100 employees, namely SPROJ. The variable represents the number of non-cooperative projects. Its first lag becomes positive significant only in the model for firms with at least 100 employees. It suggests that large firms' growth can be facilitated with non-cooperative subsidies. This is interesting as in the same model the number of cooperative projects is negative significant (see above), which clearly highlights differences in the effects of the two forms of R&D subsidies. The finding supports the positive evaluation of subsidies for firm performance in the literature (cf. Girma et al. 2008, Czarnitzki et al. 2007). All the above results clearly confirm **hypothesis 6** according to which the relationship between R&D subsidies, cooperation networks, and firm growth differs significantly between firm size classes. This particularly concerns the importance of cooperation with different types of organizations (universities, research organizations, firms), which we find to vary strongly between small and large firms.

4.6 Conclusion

The present paper investigated the relevance of R&D subsidies for firm growth. It particularly contributed to the existing literature by differentiating between cooperative and non-cooperative R&D subsidies, which are shown to have distinct effects. Moreover, firms' embeddedness into subsidized cooperation networks was evaluated with respect to its importance for employment growth. Concerning the empirical results, we did not find any indication that the granted (monetary) amounts of R&D subsidies matter. All observed

[9] Another prominent interference is the preference of links between organizations located in different member states of the EU in the fifth Framework program (Cf. Scherngell and Barber, 2011).

significant effects relate to the number of subsidized projects a firm is engaged in. Neither the total amounts of received subsidies, nor the size of subsidized projects (as approximated by the average monetary amount of an individual grant) were found to impact firm growth. For policy evaluation, our findings imply that the effectiveness of programs is less related to the invested resources as to the actual specification of the program in terms of the number of supported projects, their cooperative character, as well as the particular type of cooperation that are supported. Evidence was provided that the number of subsidized non-cooperative projects a firm is involved in can stimulate its growth, at least in case of large firms with more than 100 employees. This implies that policy should rather initiate a great number of small projects instead of focusing the monetary support on few large-scale projects. Interestingly, we found the number of subsidized cooperative projects a firm is engaged in being related to significant negative effects on firms' (and in particular large firms') employment growth. This finding contrasts the growing importance of this type of subsidies in recent years (see Broekel and Graf 2011). Our findings however provide some evidence that if subsidies for cooperation aim at supporting interactions between firms and research organizations they can yield positive effects. The same is true when subsidized joint projects connect large firms to other firms located at larger geographical distances. Accordingly, our study highlights the importance of the particular design of R&D support policies. Clearly a "one size fits all" approach to R&D subsidies programs will yield suboptimal results. The presented study has a number of shortcomings that need to be pointed out. Amongst these is its focus on the *direct* relationship between R&D subsidies and employment growth. It can very well be argued that R&D subsidies primarily aim at enhancing firms' innovative capacities, which do not necessarily influence firms' employment growth. This implies that we probably underestimated the effects of R&D subsidies. For the empirical analysis we pooled the data for firms active in a wide range of industries. It seems to be more than likely that significant inter-industrial differences exist in the effectiveness and relevance of such subsidies. For instance, R&D subsidies are likely to be of larger importance in research-intensive industries. The employed data also covers only support programs by the German federal government. Support from inter-national organizations (e.g. EU) might have very distinct effects that are not considered in this study. The same might hold for programs initiated at sub-national levels (regions, districts, cities). These issues clearly lay the path for future research.

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4.8 Appendix

No.	EMP	PROD	SUBS	SUBSP	PROJ	SUM	CSUM	SUMP	CSUMP	SPROJ	CPROJ	DEGREE	BETW	UNI	RESEARCH	FIRM
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PROD	0.000 (0.966)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SUBS	0.768 (0.000)	-0.001 (0.913)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SUBSP	0.126 (0.000)	-0.001 (0.865)	0.339 (0.000)	-	-	-	-	-	-	-	-	-	-	-	-	-
PROJ	0.861 (0.000)	-0.002 (0.826)	0.925 (0.000)	0.319 (0.000)	-	-	-	-	-	-	-	-	-	-	-	-
SUM	0.628 (0.000)	-0.001 (0.926)	0.928 (0.000)	0.355 (0.000)	0.812 (0.000)	-	-	-	-	-	-	-	-	-	-	-
CSUM	0.789 (0.000)	-0.001 (0.914)	0.962 (0.000)	0.297 (0.000)	0.923 (0.000)	0.790 (0.000)	-	-	-	-	-	-	-	-	-	-
SUMP	0.169 (0.000)	-0.001 (0.930)	0.407 (0.000)	0.739 (0.000)	0.354 (0.000)	0.538 (0.000)	0.274 (0.000)	-	-	-	-	-	-	-	-	-
CSUMP	0.164 (0.000)	-0.002 (0.793)	0.326 (0.000)	0.720 (0.000)	0.331 (0.000)	0.210 (0.000)	0.380 (0.000)	0.205 (0.000)	-	-	-	-	-	-	-	-
SPROJ	0.714 (0.000)	-0.001 (0.881)	0.853 (0.000)	0.374 (0.000)	0.882 (0.000)	0.860 (0.000)	0.770 (0.000)	0.531 (0.000)	0.243 (0.000)	-	-	-	-	-	-	-
CPROJ	0.859 (0.000)	-0.002 (0.816)	0.894 (0.000)	0.277 (0.000)	0.982 (0.000)	0.740 (0.000)	0.925 (0.000)	0.261 (0.000)	0.345 (0.000)	0.778 (0.000)	-	-	-	-	-	-
DEGREE	0.873 (0.000)	-0.001 (0.874)	0.872 (0.000)	0.238 (0.000)	0.971 (0.000)	0.730 (0.000)	0.898 (0.000)	0.254 (0.000)	0.283 (0.000)	0.792 (0.000)	0.980 (0.000)	-	-	-	-	-
BETW	0.865 (0.000)	-0.001 (0.925)	0.836 (0.000)	0.135 (0.000)	0.922 (0.000)	0.700 (0.000)	0.860 (0.000)	0.207 (0.000)	0.153 (0.000)	0.757 (0.000)	0.928 (0.000)	0.943 (0.000)	-	-	-	-
UNI	0.084 (0.000)	-0.001 (0.895)	0.119 (0.000)	0.305 (0.000)	0.202 (0.000)	0.096 (0.000)	0.126 (0.000)	0.128 (0.000)	0.347 (0.000)	0.166 (0.000)	0.203 (0.000)	0.164 (0.000)	0.070 (0.000)	-	-	-
RESEARCH	0.072 (0.000)	-0.006 (0.472)	0.124 (0.000)	0.353 (0.000)	0.201 (0.000)	0.081 (0.000)	0.145 (0.000)	0.107 (0.000)	0.462 (0.000)	0.104 (0.000)	0.226 (0.000)	0.179 (0.000)	0.070 (0.000)	0.162 (0.000)	-	-
FIRM	0.122 (0.000)	-0.003 (0.727)	0.176 (0.000)	0.428 (0.000)	0.316 (0.000)	0.115 (0.000)	0.205 (0.000)	0.134 (0.000)	0.579 (0.000)	0.169 (0.000)	0.354 (0.000)	0.305 (0.000)	0.124 (0.000)	0.331 (0.000)	0.448 (0.000)	-
DIST	0.134 (0.000)	-0.001 (0.953)	0.189 (0.000)	0.448 (0.000)	0.316 (0.000)	0.131 (0.000)	0.215 (0.000)	0.154 (0.000)	0.602 (0.000)	0.183 (0.000)	0.348 (0.000)	0.295 (0.000)	0.123 (0.000)	0.421 (0.000)	0.592 (0.000)	0.854 (0.000)
Standard errors in parentheses		*** p<0.01, ** p<0.05, * p<0.1														

Table 4.3 Correlation matrix

Full Models	1	2	3	4	5	6	7	8
VARIABLES	logEMP	logEMP	logEMP	logEMP	logEMP	logEMP	logEMP	logEMP
Log(EMP)t-1	1.050*** (0.0334)	1.112*** (0.0672)	1.066*** (0.0545)	1.054*** (0.0365)	1.000*** (0.023)	1.017*** (0.0312)	1.014*** (0.0213)	1.125*** (0.101)
Log(EMP)t-2	-	-	-	-	-	-	-	-0.134 (0.0979)
Log(PROD)t	0.113** (0.0531)	0.143** (0.0643)	0.122* (0.0649)	0.0968* (0.0532)	0.0899* (0.0509)	0.0889* (0.048)	0.0719 (0.0443)	0.0598 (0.0696)
2004	-0.0223* (0.0136)	-0.0205 (0.0154)	-0.0208 (0.0147)	-0.0223* (0.0135)	-0.0220* (0.0132)	-0.0254* (0.0139)	-0.0317** (0.013)	-0.0382** (0.0152)
2005	-0.0773 (0.0652)	-0.0655 (0.0718)	-0.062 (0.0699)	-0.0751 (0.0649)	-0.0813 (0.0642)	-0.0921 (0.0653)	-0.130** (0.0602)	-
2006	-0.0312 (0.0503)	-0.0175 (0.0553)	-0.0208 (0.0541)	-0.0296 (0.0495)	-0.037 (0.0484)	-0.0462 (0.0501)	-0.0681 (0.0463)	-0.0949* (0.0543)
2007	-0.0469 (0.0334)	-0.0362 (0.0374)	-0.0393 (0.0358)	-0.039 (0.034)	-0.0448 (0.0334)	-0.0482 (0.0343)	-0.0648** (0.0322)	-0.0862** (0.0364)
2008	-0.0015 (0.0199)	0.0004 (0.0217)	0.0037 (0.0212)	-0.0002 (0.0199)	-0.0041 (0.0198)	-0.0068 (0.0201)	-0.0195 (0.0184)	-0.0212 (0.0203)
SUBSt-1	-2.80e-08 (2.56e-08)	-	-	-	-	-	-	-
SUBSt-2	-7.65e-08* (4.23e-08)	-	-	-	-	-	-	-
SUBSt-3	4.26e-08 (4.08e-08)	-	-	-	-	-	-	-
SUBSPt-1	-	5.76e-07 (7.48e-07)	-	-	-	-	-	-
SUBSPt-2	-	-9.18e-07 (8.72e-07)	-	-	-	-	-	-
SUBSPt-3	-	-3.06e-07 (4.85e-07)	-	-	-	-	-	-
PROJt-1	-	-0.0076 (0.0174)	-	-	-	-	-	-
PROJt-2	-	0.0176 (0.0174)	-	-	-	-	-	-
PROJt-3	-	-0.0253* (0.0142)	-	-	-	-	-	-
SUMt-1	-	-	-4.83e-08 (6.37e-08)	-	-	-	-	-
SUMt-2	-	-	-1.01e-07 (7.07e-08)	-	-	-	-	-
SUMt-3	-	-	2.02e-08 (1.27e-07)	-	-	-	-	-
CSUMt-1	-	-	-6.11e-09 (2.00e-07)	-	-	-	-	-
CSUMt-2	-	-	-1.26e-08 (2.43e-07)	-	-	-	-	-
CSUMt-3	-	-	-4.41e-08 (9.57e-08)	-	-	-	-	-
SUMP_Pt-1	-	-	-	4.80e-07 (5.67e-07)	-2.42e-08 (7.14e-07)	1.06e-07 (5.64e-07)	-7.09e-08 (3.42e-07)	-7.19e-07 (7.61e-07)
SUMP_Pt-2	-	-	-	-2.78e-07 (5.07e-07)	2.59e-07 (5.09e-07)	1.91e-07 (4.08e-07)	3.39e-07 (3.67e-07)	3.35e-07 (3.94e-07)
SUMP_Pt-3	-	-	-	-2.26e-08 (3.48e-07)	-3.81e-07 (3.02e-07)	-2.54e-07 (2.63e-07)	-4.34e-07 (3.81e-07)	-1.12e-07 (3.44e-07)
CSUMP_Pt-1	-	-	-	-2.39e-07 (5.87e-07)	5.62e-07 (5.04e-07)	7.35e-08 (4.50e-07)	2.75e-07 (6.15e-07)	9.15e-07 (1.24e-06)
CSUMP_Pt-2	-	-	-	1.35e-09 (5.02e-07)	1.43e-07 (3.73e-07)	-2.26e-08 (3.67e-07)	-4.70e-07 (7.18e-07)	-8.03e-07 (9.78e-07)
CSUMP_Pt-3	-	-	-	-2.05e-07 (4.18e-07)	-2.64e-07 (3.18e-07)	-1.16e-07 (3.82e-07)	2.17e-07 (4.64e-07)	2.41e-07 (4.42e-07)

Table 4.4 R&D subsidies and employment growth - all time lags

SPROJt-1	-	-	-	0.0231 (0.0527)	0.0326 (0.055)	0.0534 (0.0437)	0.039 (0.0385)	0.0589 (0.0416)
SPROJt-2	-	-	-	-0.0156 (0.0219)	-0.030 (0.0297)	-0.0241 (0.0309)	-0.0178 (0.0155)	-0.0164 (0.0224)
SPROJt-3	-	-	-	-0.0384 (0.0365)	0.0012 (0.0359)	-0.021 (0.0404)	-0.0166 (0.0261)	-0.0365 (0.0352)
CPROJt-1	-	-	-	-0.0266** (0.0123)	-0.0169 (0.0646)	-0.0251 (0.024)	-0.0193** (0.0092)	-0.0272** (0.0128)
CPROJt-2	-	-	-	0.0386 (0.024)	0.0138 (0.0472)	0.023 (0.0191)	0.0361* (0.0204)	0.0459 (0.0317)
CPROJt-3	-	-	-	-0.0142 (0.0184)	-0.0123 (0.0277)	-0.0177 (0.0254)	-0.0222 (0.0147)	-0.0207 (0.0264)
DEGREEt-1	-	-	-	-	0.0005 (0.0075)	-	-	-
DEGREEt-2	-	-	-	-	0.0016 (0.0043)	-	-	-
DEGREEt-3	-	-	-	-	-0.0004 (0.0033)	-	-	-
BETWt-1	-	-	-	-	-	3.75e-06 (9.52e-06)	-	-
BETWt-2	-	-	-	-	-	1.01e-06 (3.07e-06)	-	-
BETWt-3	-	-	-	-	-	6.35e-07 (4.10e-06)	-	-
UNIt-1	-	-	-	-	-	-	-0.0308 (0.369)	0.149 (0.343)
UNIt-2	-	-	-	-	-	-	-0.196 (0.212)	-0.476 (0.382)
UNIt-3	-	-	-	-	-	-	0.161 (0.151)	0.347 (0.317)
RESEARCHt-1	-	-	-	-	-	-	-0.0699 (0.410)	0.212 (0.511)
RESEARCHt-2	-	-	-	-	-	-	-0.486 (0.383)	-0.632 (0.408)
RESEARCHt-3	-	-	-	-	-	-	0.400** (0.186)	0.407* (0.221)
FIRMt-1	-	-	-	-	-	-	0.111 (0.175)	-0.0249 (0.190)
FIRMt-2	-	-	-	-	-	-	-0.123 (0.154)	-0.141 (0.211)
FIRMt-3	-	-	-	-	-	-	0.118 (0.118)	0.147 (0.157)
DISTt-1	-	-	-	-	-	-	0.0002 (0.0004)	-0.0001 (0.0006)
DISTt-2	-	-	-	-	-	-	0.0003 (0.0004)	0.0006 (0.0006)
DISTt-3	-	-	-	-	-	-	-0.0004 (0.0003)	-0.0005 (0.0004)
Constant	44.01 (27.4)	39.83 (31.12)	40.85 (29.71)	44.06 (27.28)	43.76 (26.67)	50.50* (27.99)	63.23** (26.19)	76.48** (30.72)

Table 4.4a R&D subsidies and employment growth - all time lags

Observations	11101	11101	11101	11101	11101	11101	11101	11101
Number of firms	2189	2189	2189	2189	2189	2189	2189	2189
No.instruments	47	48	46	66	76	76	106	95
AR (1)	-3.964	-3.862	-3.934	-3.939	-3.961	-3.967	-4.025	-3.1
AR (1) p-value	7.36E-05	0.000112	8.35E-05	8.18E-05	7.47E-05	7.28E-05	5.69E-05	2.00E-03
AR (2)	1.585	1.59	1.579	1.541	1.55	1.544	1.624	1.61
AR (2) p-value	0.113	0.112	0.114	0.123	0.121	0.123	0.104	0.108
Obs/group avg	5.071	5.071	5.071	5.071	5.071	5.071	5.071	4.08
Obs/group max	6	6	6	6	6	6	6	5
Obs/group min	1	1	1	1	1	1	1	1
Wald chi2	4145	2840	2546	22482	74004	68627	98541	70054.33
Wald chi2 p-value	0	0	0	0	0	0	0	0
Hansen	31.06	20.5	24.22	26.66	41.34	40.08	54.32	52.16
Hansen p-value	0.703	0.967	0.836	0.99	0.877	0.905	0.958	0.833
Sargan	32.3	25.08	27.04	39.4	45.9	46.76	70.99	45.06
Sargan p-value	0.645	0.867	0.716	0.743	0.745	0.714	0.578	0.957

St.errors in parenth. *** p<0.01, ** p<0.05, * p<0.1

Table 4.4b R&D subsidies and employment growth - all time lags

	<50	<100	>100
VARIABLES	logEMP	logEMP	logEMP
Log(EMP)t-1	0.8300*** (0.0748)	0.8700*** (0.0703)	1.0540*** (0.0770)
Log(EMP)t-2	0.0114 (0.0573)	0.0440 (0.0462)	-0.0039 (0.0788)
Log(PROD)t	-	-	-0.0829 (0.0617)
2004	0.0002 (0.0002)	0.0101 (0.0256)	-0.0705*** (0.0189)
2005	-0.0353* (0.0197)	0.0114 (0.1210)	-
2006	0.0013 (0.0277)	0.0441 (0.0955)	-0.2160*** (0.0658)
2007	-0.0013 (0.0189)	0.0101 (0.0666)	-0.1670*** (0.0418)
2008	0.0098 (0.0173)	0.0141 (0.0397)	-0.0603*** (0.0225)
SUMPt-1	6.26e-07 (2.74e-06)	-8.28e-08 (2.38e-07)	-9.96e-07 (7.18e-07)
SUMPt-2	-3.72e-07 (7.07e-07)	8.63e-08 (2.91e-07)	2.02e-07 (4.47e-07)
SUMPt-3	-2.60e-07 (3.57e-07)	6.19e-08 (3.73e-07)	7.79e-08 (3.43e-07)
CSUMt-1	3.66e-07 (2.12e-06)	1.22e-06 (1.45e-06)	7.40e-07 (7.12e-07)
CSUMt-2	6.33e-07 (8.64e-07)	6.48e-08 (1.05e-06)	-3.77e-07 (8.29e-07)
CSUMt-3	2.26e-07 (1.05e-06)	-4.37e-07 (6.56e-07)	1.33e-07 (5.62e-07)
SPROJt-1	-0.0538 (0.1440)	0.1030 (0.1140)	0.0612* (0.0372)
SPROJt-2	0.1060 (0.0885)	-0.0351 (0.1070)	-0.0226 (0.0232)
SPROJt-3	-0.0367 (0.0523)	-0.0687 (0.0586)	-0.0223 (0.0406)
CPROJt-1	-0.0013 (0.0597)	0.0660 (0.0628)	-0.0240* (0.0130)
CPROJt-2	0.0129 (0.0261)	-0.0051 (0.0433)	0.0262 (0.0245)
CPROJt-3	-0.0175 (0.0281)	-0.0688 (0.0589)	-0.0038 (0.0186)
UNIt-1	-0.1360 (0.5230)	0.0868 (0.4250)	0.0672 (0.1720)
UNIt-2	-0.3980 (0.3270)	-0.4700 (0.3380)	-0.2270 (0.1890)
UNIt-3	0.1040 (0.2450)	0.2950 (0.3060)	0.1440 (0.1510)
RESEARCHt-1	-0.0738 (0.3090)	-0.0316 (0.3680)	0.0775 (0.4020)
RESEARCHt-2	-0.4100 (0.4290)	0.0247 (0.3910)	-0.1310 (0.3010)
RESEARCHt-3	0.1650 (0.2670)	-0.0696 (0.3070)	0.2040 (0.1680)
FIRMt-1	0.1490 (0.4340)	-0.0471 (0.2300)	-0.1840 (0.1550)
FIRMt-2	-0.0179 (0.1620)	-0.0582 (0.1400)	-0.2730 (0.1770)
FIRMt-3	-0.0180 (0.1540)	0.0600 (0.1580)	0.2310** (0.1120)
DISTt-1	-0.0002 (0.0004)	3.94e-05 (0.0005)	0.0003 (0.0004)
DISTt-2	0.0004 (0.0004)	0.0003 (0.0004)	0.0004 (0.0005)
DISTt-3	-9.41e-05 (0.0004)	0.0002 (0.0004)	-0.0004 (0.0003)
Constant	0.0000 (0.0000)	-20.0300 (51.6400)	141.9000*** (38.3300)
Observations	2.552	4.46	5.288
Number of firms	500	879	1209
No. instruments	97	103	93
AR (1)	-2494	-2906	-2143
AR (1) p-value	0.0126	0.00366	0.0321
AR (2)	0.520	0.539	1428
AR (2) p-value	0.603	0.590	0.153
Obs/group avg	5104	5074	4099
Obs/group max	6	6	5
Obs/group min	1	1	1
Wald chi2	309265	987.8	70161
Wald(chi2p-v.)	0	0	0
Hansen	70.10	67.58	48.71
Hansen p-value	0.311	0.593	0.872
Sargan	62.87	58.02	36.65
Sargan p-value	0.552	0.866	0.994
St.errors in pare	*** p<0.01, ** p<0.05, * p<0.1		

Table 4.5 R&D subsidies and employment growth -size disaggregation

5 Spatial relatedness to other actors and internalisation

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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

The growth of firms not only depends on internal firm-specific factors but also on factors external to the firm. In this paper the relationship between firm growth and various 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. Furthermore, we disentangle different degrees of relatedness and major functional roles of universities, namely education and research. Applied on a large sample of German manufacturing firms, we show that the impact of external factors substantially differ along the firms' organizational dimensions size. Using quantile regression techniques, we confirm our expectation that highly expanding and shrinking firms, which are a prominent feature in growth dynamics of firms, rely differently on external knowledge sources. Finally, knowledge spillovers from universities transcend traditional regional boundaries, whereas for spillovers from other related plants clear threshold distances emerge, which in some cases remain constrained to a narrow local range of a few minutes.

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

5.1 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 and 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 and 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 and 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.[1] The respective studies suffer from a missing or superficial conceptualisation 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-

[1] 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 and 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.

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 5.2 we start by discussing the theoretical framework of firm growth before we review and discuss some spatial issues related to external growth factors. Chapter 5.3 analyses the stochastic properties of a sample on German manufacturing firms and describes the construction of the variables, whereas chapter 5.4 presents the model and introduces into quantile regression as an adequate estimation technique. In chapter 5.5 the empirical results are discussed. Chapter 5.6 concludes.

5.2 Theoretical framework and hypotheses

5.2.1 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 (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).[2] 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 and 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 and 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 and 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 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 specialisation 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 specialisation versus diversification at the regional level (Beaudry and 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 and 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 and Lissoni 2009, Eriksson and Lindgren 2009) and the exchange of intermediate goods (Döring and 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.[3] Hence we get:

[2] 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 and Iammarino 2009).

[3] Empirical studies focusing on the impact of agglomeration on firm performance are necessarily confronted by an endogeneity problem (Pinske and 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 and Okubo 2006).

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 and Dohse 2007, Eriksson 2011, Raspe and 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 and van Oort 2011) reveals significant relationships between firm growth and university presence. Generally speaking, universities' role is to perform education and research (Schlump and 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 and 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).

5.2.2 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 and Karlsson 2007: 131). Despite recent improvements in ICT (Sonn and 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 and 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 and 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 conceptualisation. 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 p: 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 and Slade 2010 p: 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 and 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 and 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 and Karlsson 2007 p: 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 and Karlsson 2007 p: 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 and 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 and 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 and 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):

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

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.[4] In doing so, we not only obtain information regarding the magnitude of that impact, but also regarding its spatial range and functional form.

5.3 Data and variables

5.3.1 Dependent variable: employment and turnover growth

A sample of German manufacturing firms was extracted from the Creditreform MARKUS database.[5] 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*:

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

Since no universally best size indicator exists, we employ and compare two alternatives: turnover as well as employment number.[6] Due to data availability, growth rates are calculated

[4] 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.

[5] 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.

[6] 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.

for the years 2005, 2006 and 2007 and pooled together.[7] 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 and 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 5.1.

Table 5.1 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

[7] 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.

slightly, but not significantly higher.[8] The most relevant observation here, however, is 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 and Rao 2008).

Table 5.2 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)

5.3.2 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*).[9] 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).[10] 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

[8] 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 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.

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

[10] 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.

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 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 5.3 recapitulates the independent variables of this study, whereas descriptive statistics are reported in Table 5.8 (in the appendix).

Table 5.3 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

5.3.3 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[11] 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 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.

[11] 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.

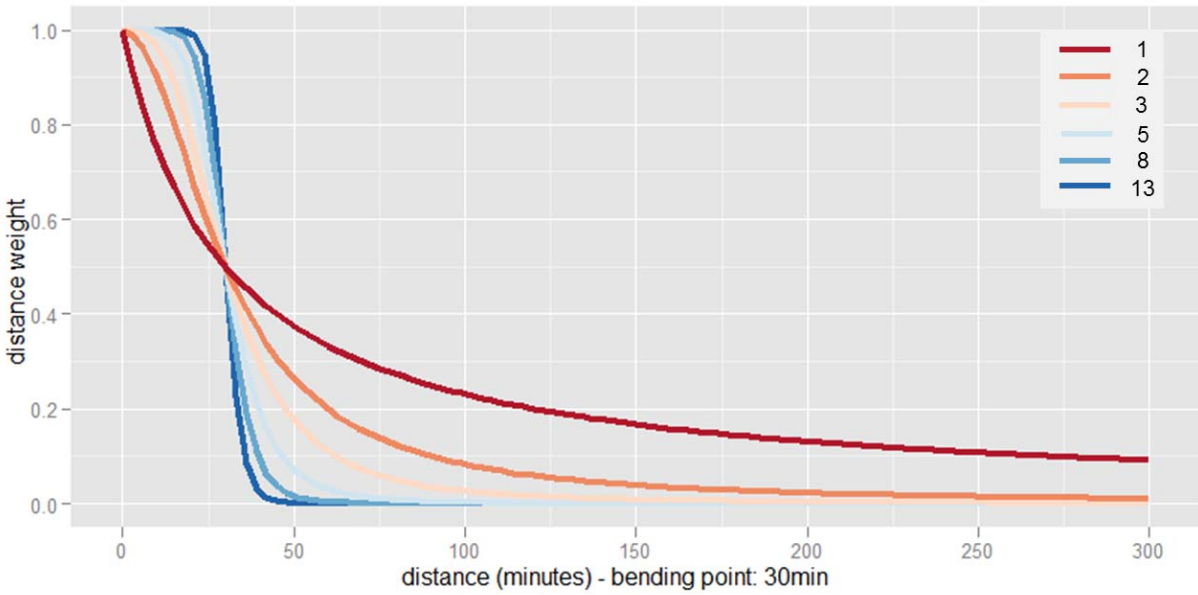
5.4 Model and estimation

An identification of the best fitting model allows on the one hand quantifying 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.

5.4.1 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 5.1 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:

with , , , and , representing the parameters to be estimated, the above defined log-logistic distance decay function, the travel distance between the units and , the various firm- and region-specific control variables, and as well as the distance weighted impact of other firms and universities, respectively. The error term is denoted by .

5.4.2 Quantile regression

Koenker (2005 p: 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 and 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 and Hölzl 2009). Technical details are well described amongst others in Koenker and Bassett (1978), Koenker and Hallock (2001), and Buchinsky (1998).[12] 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 and 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.

5.5 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 5.2 and present within each section only the relevant parts of the results. The complete regression results are reported in Tables 5.9 and 5.10 (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.

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

5.5.1 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 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.

5.5.2 The impact of other related firms

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 5.4 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 specialisation* 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.

5.5.3 The impact of universities

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 5.5 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 specialisation 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.

5.5.4 Spatial range and functional form of impact

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 5.6 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 5.6 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 5.7). 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 5.7 Frequency of range parameter *r* in cases of *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.

5.6 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 alternatives of 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.

5.7 References

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5.8 Appendix

Table 5.8 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 5.9 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 5.10 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)*

6 Impact of regional specialisation and industrial variety on firm growth

Localisation economies and Jacobian variety: impact on firms' employment growth

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Preliminary Draft

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Abstract
The paper investigates the contribution of localisation economies and Jacobian diversification to firms' employment growth. Of particular interest is hereby firms' embeddedness into a surrounding that is characterised by much knowledge of the same industries or knowledge that is very different from the industry. For the empirical analysis we utilize an unbalanced panel of 244.000 German manufacturing and services firms covering the time period from 2003 to 2011. Cross-sectional time series estimation is employed to control for yearly changes in the growth rates. Our findings show that Jacob's externalities in terms of unrelated variety are likely to dampen average employment growth in SME but this effect disappears and even becomes a positive outcome as we control for year-to-year employment growth, while related variety strongly stimulates employment growth in SME. Furthermore, we find that the probability to detect a positive effect of localization economies (Marshall's externalities) increases as the level of industrial classification becomes narrower (3-digit and 4-digit). Otherwise, the probability to perceive a negative impact of Marshall's externalities increases as the industry aggregation gets more broadly defined. Finally, employment growth of larger firms is positively influenced by being well connected to KIBS, while the positive effect of being well embedded into high population density does only hold for SME.

Keywords Regional specialisation, industrial variety, firm growth

6.1 Introduction

Employment growth and its growth enhancing factors have received considerable attention in the previous and current literature (Coad 2009). Amongst these factors are regional characteristics and spatial conditions, which are argued to stimulate performance activities and thereby (indirectly and directly) facilitate the growth and innovativeness of firms (e.g., Boschma and Iammarino 2009, Frenken et al. 2007). Some empirical evidence exists that confirms the positive effects of growth enhancing factors (for an overview see Storey 1994). The adaption of knowledge from regional knowledge base (external sources) is another growth enhancing variable that is particularly emphasised in the resource-based view of firm growth (Penrose 1959). It is therefore closely related to the capability perspective (e.g. Williamson 1975, 1985, 1991), i.e. a firm is an organization of capabilities that combine a bundle of resources and activities to grow and innovate (Penrose 1959, Schumpeter 1942). More precisely, a firm operates to manage complexities and idiosyncrasy of transaction and tries to ensure collective learning processes by utilizing organisational processes and structures. Capabilities of a firm are parts of a firm's inimitable resource (Penrose 1959) and can be seen as competitive advantages in terms of activities to actors in the market such as knowledge intensive business services. The absorption and utilization of additional knowledge is achieved via various mechanisms and channels including firms' engagement in inter-organisational linkages (Brökel et al. 2011) and knowledge endowment (e.g. Audretsch and Dohse 2007). The contribution of regional knowledge base to employment growth has also been subject to many theoretical and empirical studies. The literature points out that firm generally benefit from regional knowledge endowment (e.g. Audretsch and Dohse 2007, Beaudry and Schiffauerova 2009). More precisely, the notion of related variety describes the effect that "knowledge will spill over effectively only when complementarities exist among sectors in terms of shared competences" (Boschma and Iammarino 2009: p. 290). Thus, the region has many industries that are related and specialised (i.e. Marshall's externalities). This kind of "knowledge spillover effect should be distinguished from another variety effect, that is, unrelated variety" (Boschma and Iammarino 2009: p. 290). This in turn means the region has many industries that are unrelated and diversified (i.e. Jacobs's externalities). It has been partially discussed whether "Jacobs externalities are best measured by related variety (within sectors) […] or it is better captured by unrelated variety (between sectors)" (Frenken et. al 2007: p. 685). They find that Jacob externalities contribute to growth, while Marshall's externalities dampen unemployment growth (Frenken et.al 2007). It can be argued that both issues (i.e. related or unrelated variety) have advantages and drawbacks from an economic point of view. The present paper contributes to these literature streams with an empirical study on the relevance of the choice of the industry aggregation for firms' employment growth. More precise, we particularly investigate the effect whether too much knowledge of the same industries might engender regional (e.g. Bathelt et al. 2004) and firm-level lock-in or knowledge that is very different from the industry obviously become harmful. Our study is based on a panel of 244.000 German manufacturing and service firms covering the time period from 2003 to 2011. A cross-sectional time series approach is applied. The empirical analysis provides empirical evidence for that fact that Jacob's externalities in terms of unrelated variety are likely to dampen average employment growth in SME but this effect disappears and even becomes a positive outcome as we control for year-to-year employment growth, while related variety strongly stimulates employment growth in SME. Furthermore, we find that the probability to detect a positive effect of localization economies (Marshall's externalities) increases as the level of industrial classification becomes narrower (3-digit and 4-digit). Otherwise, the probability to perceive a negative impact of Marshall's externalities increases as the industry aggregation gets more broadly defined. Finally, we suggest that employment growth of larger firms is positively influenced by being well connected to KIBS, while the positive effect of being well embedded into high population density does only hold for SME. The remainder of the paper is as follows: In Section 2 we derivate the theoretical background and supply our main hypotheses. Section 3 introduces our methodology, data and methodology. In section 4 we present our results and interpretations and section 5 briefly concludes.

6.2 Theoretical derivation and hypotheses

The theoretical discussion according firm growth relies on a complex construct consisting of various components that influence the growth process itself. Predominantly, the conceptual part has mainly focussed on internal and external growth related factors contributing to the growth in firms. In this vain, related theories dedicate this issue from very different perceptions ranging from evolutionary growth concepts, in which the fitness of firms undertakes the central role (e.g. Metcalfe 1993) to neoclassical theories of ‘optimal size’ (e.g. Coase 1937). In respect to our empirical study, theories like endogenous growth (Romer 1990), the resource-based approach (e.g. Penrose 1959) as well as the sociological concept (e.g. Hannan and Freeman 1977) become apparent. Since the end of the 20th century, the endogenous growth model is an initial trigger for economists to deal with technological progress and growth in firms. Thereby, the growth process itself is understood as a development that is primarily based on endogenous force instead of external growth factors. One central issue of the endogenous growth theory is the production of endogenous knowledge (e.g., Griliches 1979). Decisive sources of knowledge production in firms are internal growth related factors (such as R&D-division). In endogenous growth theory, several internal growth related factors exist that can be seen as influential factors that generate new knowledge. It has been continuously discussed that the stock of human capital, workforce qualities and the regional knowledge base determine the rate of growth (e.g. Romer 1986, 1990). Moreover, Lucas (1988) extends the statements made by Romer (1990) and concludes that knowledge is regionally consolidated and highlights the impact of human capital in agglomeration areas. He pointed to the fact, that urban shaped areas consolidate human capital and knowledge that contribute to positive external effects (i.e. spillovers) that, in turns, might lead to growth. “But knowledge will spill over effectively” (Boschma and Iammarino 2009 p: 290) when complementarities exist among sectors in terms of shared competences (Boschma and Iammarino 2009). There is also the opinion that “when a region has many industries that are unrelated, it can more easily absorb sector-specific shocks” (Boschma and Iammarino 2009 p: 209). In the light of this, knowledge diffusion will occur when firms are embedded in more specialised environment (Marshalls externalities) or in regions that are more diversified (Jacobs externalities). In this specific case, the term spillover describes the certain interrelation between different market participants and their knowledge transfer. Knowledge spillovers are partially unmarketable factors through which firms can benefit in terms of innovation activities, productivity and profitability. Additionally, the new economic geography (e.g. Krugman 1991) constitutes that certain regions and urban areas grow fundamentally faster if the area is characterised by knowledge flows through spillovers. The question through which channel knowledge transfer can be captured is still a challenging task. Krugman (1991) states that “knowledge flows are invisible they leave no paper trail by which they may be measured and tracked” (Audretsch and Feldman 2004 p: 2718). In regard to the sociological concept, our study agrees with the assumption that the availability of resources and the competition of these resources are core forces of growth in firms. This approach does strongly correspond to the generally accepted concept of the resource-based viewpoint (Penrose 1959) of growth. Finally, all conceptual models share the certain idea of economists that the market participants (in our case: firms) compete with each other to gain competitive advantages that, in turns, might lead to growth in these firms. Growth in firms is not entirely dependent on single determinants; it is rather a result of an interaction mechanism of different channels and transmitter. Simultaneously, it is safe to say that there is a superior distinction between two categories of growth related determinants: firm-internal growth determinants and firm-external growth determinants. On the one hand, it has been repeatedly studied that firm-internal factors such as size, age and industry affiliation do have a direct impact on the rate of growth (e.g. Bottazzi and Secchi 2006). In contrast, Gibrat's Law states that firm growth originally follows a random walk and is completely independent from internal determinants such as the size (Gibrat 1931). Nevertheless, empirical investigations on the impact of age on firms' growth have been largely neglected by scientific research. On the other hand, not too much emphasis is placed on the impact of firm-external growth factors. More precisely, this study deals with two major issues. First, we investigate the external channel and transmitter, which might be very well in position to generate positive knowledge flows, through which firms becomes growing. Second, we stress the fact whether regional specialisation and industrial variety engender differences in the way firms grow.

As we already stated, regional specialisation and industrial variety do also engender differences in the way firms grow. The basic paper by Boschma and Iammarino (2009) clearly discusses the terms related and unrelated variety. Therefore, the notion of related variety describes the effect that "knowledge will spill over effectively only when complementarities exist among sectors in terms of shared competences" (Boschma and Iammarino 2009 p: 290). Thus, the region has many industries that are related and specialized (i.e. generate relatively more Marshall's externalities). Simultaneously, this kind of "knowledge spillover effect should be distinguished from another variety effect, that is, unrelated variety" (Boschma and Iammarino 2009 p: 290). This in turn means the region has many industries that are unrelated and diversified (i.e. generate relatively more Jacobs's externalities). It has been partially discussed whether "Jacobs externalities are best measured by related variety (within sectors) […] or it is better captured by unrelated variety (between sectors)" (Frenken et al. 2007 p: 685). They find that Jacob externalities contribute to employment growth, while Marshall externalities dampen unemployment growth. It can be argued that both issues (i.e. related or unrelated variety) have advantages and drawbacks from an economic point of view. While too much embedded knowledge of the same industries in the specialized region might engender regional lock-in (e.g. Bathelt et al. 2004), knowledge that is very different from the industry that a region is specialized in might be inefficient. Furthermore, the regional knowledge cannot be easily absorbed and it much harder to learn and benefit from it (e.g., Boschma and Iammarino 2009). Some literature discusses the effect of traditional factors of new firm formation (i.e. agglomeration economies) compared to measures of regional knowledge base and find that agglomeration effects do have a much stronger impact on new firm formation (e.g., Knoben et al. 2011). In this case, the discussion of agglomeration economies and cluster formation becomes apparent. Porter (2003) pointed to the fact that cluster and spatial agglomeration such as enterprises and (higher) education and research institutes of related and unrelated industries do promote economic growth in the certain industry. Thereby, the performance of regional economies is strongly influenced by the strength of local cluster (Porter 2003). Pecuniary agglomeration economies in terms of knowledge externalities enable both gains and losses associated with the impact on regional growth (e.g. Antonelli 2011). On the one hand, the concentration of related industries benefits the knowledge spillovers between firms and yields to growth within the certain industry (Marshall's externalities). On the other hand, firms do not necessarily benefit from knowledge transfer from related industries but rather from industries that are unrelated (Jacobs's externalities). Both issues are two sides of the same coin. Nevertheless the distinction is still made between effects of

Jacobs's externalities and localization economies (Marshall's externalities). The discussion whether interindustry spillovers are more important than intraindustry spillovers is still a challenging task in economic and regional research community. Some studies support the Marshall's claim about the importance of knowledge spillovers within industries rather than between them (e.g. Baldwin et al. 2010, Mukkala 2004). Hence, knowledge spillover seems to be highly localized that in turn means that agglomeration of related industries yields to increasing net positive effects. Mukkala (2004) also supports the hypothesis that regional specialisation (Marshall's externalities) is more effective than diversification (Jacobs's externalities). In contrast, some studies point to the fact that growth is enhanced by industrial diversity (e.g., Lasagni 2011; Bun et al. 2010). Already Glaeser et.al (1992) investigates that knowledge spillover may occur between rather than within industries. They point to the importance of industrial variety rather than specialisation. Industrial variety is more conducive to growth, because in diversified agglomerations there is a higher exchange of different and new ideas (e.g. Glaeser et al. 1992). However, estimating the impact of localisation and urbanization economies supports the fact that the outcome of these effects vary across industry affiliation, age and size (e.g. Bun et al. 2010). For instance, "establishments in relatively young industries rely more on diversified environments, while establishments in relatively old industries receive greater external benefits in the same industry cluster" (Bun et al. 2010 p: 3131). Nevertheless, the impact of age and size has been largely neglected in previous studies. Thus, we also take care of this issue and distinguish between different types of industries, firm size classes and age groups. Additionally, we know that it is highly important to distinguish between different forms of regional specialisation and industrial variety (i.e. this also goes in line with the interpretation by Frenken et al. 2007). Hence, we understand *regional specialisation* in two different ways, as sectors that are localized in terms of shared (i) primary and shared (ii) secondary industry classification (i.e. German classification of economic activities). Simultaneously, we interpret *industrial variety* (i.e. can bee understand as diversification measures) as related industrial variety and unrelated industrial variety. For our point of view, *related industrial variety* is defined as the average variety *within* the 2-digit-industries. Contrarily to this measure, *unrelated industrial variety* stands for the average variety *between* the 2-digit-industries. We therefore suggest our first hypothesis:

H1: While Marshall's externalities are negatively related to employment growth in SME, Jacob's externalities are more positively related to employment growth of SME.

Most important in the context of our investigation is the impact of the different aggregates representing specialisation in terms of the narrower consideration of specialisation to a more broadly defined consideration of specialisation. Already Frenken et al. (2007 p: 689) pointed to the fact that "the choice of sector aggregation is not trivial". We therefore want to focus on the level of industry aggregation. Specialisation has indeed an impact on firm growth as is expressed by different industry classification (e.g. 2-digit, 3-digit or 4-digit). This effect might be, however, limited by the choice of the industry aggregation. Put another way, this indicates that specialisation might be conducive, but diversity may be needed nevertheless, at least to certain extent. If this diversity, as expressed here in within-class diversity on the 2-digit NACE level, is suppressed, specialisation obviously becomes harmful. We hence suggest:

H2: Marshall's externalities do influence employment growth but the choice of industry aggregation matters hereby.

Mainly the regional knowledge base itself and the regional knowledge base as a source of positive external effects (i.e. spillover) is a main constituent of many growth related investigations. Research interests in this area go back to Lucas (1988) and Romer (1990) who focus on the benefits of human capital and workforce qualities. Their work is the immediate stimulus for further research studies in the topic of the impact of regional knowledge base. Obviously, the individual know-how and the abilities of each employee are important input factors for the success of the enterprise. Correspondingly, employees' qualities and their educational level are not independent of the growth performance of firms. To say it in the words of Jovanovic and Rob (1989 p: 569): "Spillovers of knowledge depend not only on how hard people are trying, but also on the differences in what they know: if all of us know the same thing, we cannot learn from each other." Besides the ability of creating new knowledge, the individual qualities of the employees are substantial for the absorption of new knowledge (e.g., Cohen and Levinthal 1989, Acs and Armington 2004). The knowledge transfer of tacit knowledge (coded and embodied) strongly depends on the distance to the source of knowledge (e.g. Feldman 1999). In contrast to explicit knowledge (encoded) is tacit knowledge regionally embedded and personally embodied and, hence, needs to transmit personally. Glaeser et al. (1992 p: 1127) concludes that "intellectual breakthroughs must cross hallways and streets more easily than oceans and continents". The implicit knowledge transfer increases when employees change their jobs or move to another place (e.g., Powers 2003, Audretsch and Lehmann 2005). Hence, firms mostly benefit from the availability of qualified workforce. The absorption of new knowledge (i.e. from universities and other higher education institutes) offers at the same time new market potential to the firm if this has not yet been commercialized (e.g. Audretsch 1995). Therefore, one of the determining factors for growth of firms is local knowledge endowment. Another important trend also goes to the complementary effect between internal and external business activities "to renew and reconfigure existing capabilities and knowledge to enable them to meet environmental demands and to innovate" (Fores and Camison 2011: p. 56). In recent years, there is also an economic focus on the existence, development and impact of *knowledge intensive business services* (i.e. KIBS). Mainly "it is argued that changing competitiveness conditions are heightening the requirements for firms in most sectors to innovate and take advantages of their core competences and knowledge" (Huggins 2011 p: 1459). As a result, many firms outsource their knowledge intensive business services. Huggins (2011) points to the fact that regions continue to be key knowledge bases and constitute an important source of knowledge transfer. A study by Raspe and Oort (2011) shows that agglomeration knowledge relates to firms employment growth, but this effect is captured by various features of the firm population and knowledge externalities that comes from industries-more in services than in manufacturing (i.e. KIBS). Some studies point to the fact that KIBS undertake functional linkages to cooperation partners, customers and knowledge providers (e.g. Koch and Strotmann 2006). Knowledge intensive business services as innovation agents for other firms have been studied by Aslesen and Isaksen (2007). They find that the presence of KIBS may stimulate innovation and growth. This means, "KIBS mainly provide products and services tailored to individual clients" (Aslesen and Isaksen 2007 p: 321) and to other firms and have face-to-face relationships that might contribute to the growth in firms. Thereby, the findings suggest that agglomerated firms are more frequent users of business services than firms located outside the agglomeration (e.g. Aslesen and Isaksen 2007). Already Marshall (1890) concludes that firms are more efficient and perform much better when located within high-density areas or agglomerations. Empirical studies show "that firms located in strong clusters create more jobs" (Wennberg and Lindqvist 2010 p: 221). They also find that a high *population density* positively affects the survival of firms. Hoogstra and van Dijk (2004) show in their investigation that firms located in regions with high population density are more likely to grow stronger. For our understanding, this effect is also captured by the industry affiliation and this, in turns; engender differences in the way firms grow. Thus, the positive effect of population density disappears if the analysis is restricted to young and knowledge intensive firms (e.g. Audretsch and Dohse 2007). With regard to the last issue, Fingleton et.al (2004) finds no significant relationship between population density and the employment growth in high-tech firms, knowledge intensive firms or services. Moreover, we control for *KIBS* and *population density* that might affect employment growth. We hence hypothesize:

H3: Employment growth is affected by being well connected to KIBS, and by being well embedded into high population density. The size of the firm matters hereby.

6.3 Data source, variables and methods

6.3.1 Data source

We employ a panel of German firms (including manufacturing firms: NACE 2-digit classification 15 - 40) that derives from the Creditreform Markus database[1]. The database provides information on the number of employees, turnover, and industry affiliation (i.e. primary and secondary digit-industry classification of the German classification of economic activities) and year of foundation. The data (especially employment data) are available for the time period from 2003 to 2011. Hence, a firm population is selected consisting of approximately 244.000 German firms at least for the time period from 2003 to 2011[2]. An appropriate replacement of the missing values is a neighbouring nonmissing value (i.e. [_n-1] or [_n+1])[3] for each individual firm in the panel. Nevertheless, in some cases the values of the number of employees are completely missing for all years. Hence, we are not able to replace these missing values. Thus, manufacturing firms clearly dominates our firm sample (80.5 percent). To perform on different firm size classes, we split our sample into three different size categories based on the average annual firm size. This categorisation is set by the European Commission (2003)[4]: small-sized enterprises (10-50 employees), medium-sized enterprises (51-250 employees) and large-sized enterprises (251-1000 employees). The distribution of the number of firms within the different firm size classes is shown in Table 6.1.

Table 6.1 Firm size distribution

	manufacturing			services		
year	small	medium	large	small	medium	large
2003	9,785	4,305	19,908	86,602	8,212	114,693
2004	12,359	4,336	17,303	106,956	8,267	94,284
2005	12,271	4,421	17,306	106,681	8,536	94,290
2006	12,312	4,371	17,315	106,858	8,339	94,310
2007	12,183	4,469	17,346	106,463	8,628	94,416
2008	12,195	4,426	17,377	106,494	8,516	94,497
2009	12,154	4,464	17,380	106,153	8,825	94,529
2010	12,182	4,441	17,375	106,341	8,646	94,520
2011	12,312	4,516	17,170	108,148	9,053	92,306
pool	107,753	39,749	158,480	940,696	77,022	867,845

[1] The sample was extracted from the Creditreform MARKUS DVD on 11/2010.
[2] We are aware of the fact that the financial crisis (in 2008) represents a special case and offers different stochastic properties of the growth rates. Therefore, we replace the values of 2008 with the mean values.
[3] by id (year), sort: replace employment = employment [_n-1] if employment >= . / by id (year), sort: replace employment = employment[_n+1] if employment >= .
[4] See http://ec.europa.eu/enterprise/policies/sme/facts-figures-analysis/sme-definition/index_en.htm.

More precisely, we shortly discuss the stochastic properties within the different firm size classes and the different sectors (see Table 2). We therefore create a sample of 10% of our current data set and run the query (based on the stochastic properties of the growth rates $\text{EMP}_{i,t}$, the Subbotin distribution family was introduced into economics by Bottazzi et al. 2002). Table 6.2 shows the distribution parameters and the standard errors.

Table 6.2 Stochastic properties

	Manufacturing growth						Service growth					
	b		a		m		b		a		m	
size	Par.	Std err	Par.	Std err	Par.	Std err	Par.	Std err	Par.	Std err	Par.	Std err
small	1.053	.244	.223	.019	.003	.002	1.356	.029	.036	.008	.001	.001
medium	.316	.024	.013	.007	.001	.000	.234	.022	.012	.004	.005	.000
large	.220	.020	.002	.001	.001	.000	.175	.017	.002	.005	.001	.000

The shape parameter b is the crucial one for our analyses, because it gives information about the fatness of the tails. This means once again the larger b, the thinner are the tails (i.e. if b decreases the tails of the density become fatter). As you already know if b < 1 the distribution reduces to a Laplace, whereas for b > 1 we recover a Gaussian distribution. For employment growth in manufacturing sector, the parameter b gets smaller with increasing firm size. Estimates for smaller firms in the manufacturing sector indicate that employment growth rates seem to distribute according to a Laplace: the shape parameter b is equal to 1. The most important result, however, is that the underlying drivers in the growth process can be accounted for Laplace distribution. This finding contradicts the fact that (super-) Laplace distribution is a better fit for larger firms (e.g. Fu et.al 2005) while the growth rate distribution of smaller firms has even thinner tails. Irrespective of the sector affiliation, the scale parameter a decreases with increasing size that also goes in line with the common literature (e.g., Bottazzi et.al 2011) on firm growth. This means larger firms display lower variability in their growth dynamics. In contrast, estimates for smaller firms in the service sector indicate that employment growth rates seem to distribute according to a Gaussian distribution: the shape parameter b is > 1.

6.3.2 Variables and descriptive statistics

For the investigation of the relationship between the independent variables and employment growth rates $\text{EMP}_{i,t}$ we define our dependent variable as the differences of the natural logarithms of the size of firm *i* between two successive years *t*:

$$\text{EMP}_{i,t} = \log\,(size_{i,t+1}) - \log\,(size_{i,t})$$

As we know firms' growth can be measured in different ways[5] (e.g., turnover, employees, profit and asset). The discussion on an appropriate measure of firm growth is still a controversial task; nevertheless, we employ the growth measure: Number of employees (*EMP*). To control for autocorrelation in firms' growth rates, we include the term revenue (*REVENUE*), which allows us to analyze firms revenue that have an impact on subsequent employment growth or not (e.g. Coad 2009). As Girma et al. (2008) we take the logarithm of revenue, which yields to more robust results. The firms' potential to benefit from specialisation and variety measures is not independent on firm size. Therefore, we control for relevant firm-specific properties. Based on the literature on firm growth, we control for

[5] For an overview see Garnsey and Heffernan (2006): pp.11.

critical firm-specific variables: the logarithm of firm size (*SIZE*) and autocorrelation dynamics (*REVENUE*). Additionally, we entirely know that firms' specific properties differ across the various sectors and industries. Hence, we distinguish between manufacturing firms and service firms (see Table 2). To assess the impact of being located or diversified as well as industrial related or unrelated variety, we measure regional specialisation in terms of primary industry classification (*PRIM_LQ*) and secondary industry classification (*SEC_LQ*). Additionally we control for different digit industry classification such as primary 2-digit/3-digit/4-digit industry classification (*PRIM_LQ_2d/ PRIM_LQ_3d/ PRIM_LQ_4d*) and secondary 2-digit/3-digit/4-digit industry classification (*SEC_LQ_2d/ SEC_LQ_3d/ SEC_LQ_4d*). Let us start with the term regional specialisation (*LQ*) it hence is measured as:

$$LQ_{ij} = \frac{e_{ij}/E_i}{E_j/E} = \frac{e_{ij}/E_j}{E_i/E} \qquad (1)$$

LQ is constructed by using employment data and corresponds to the primary or the secondary industry in which the firm operates. The location measure (*LQ*) is calculated by the ratio of the share of employees (*e*) of a region (*i*) in this certain industry (*j*), divided by the total share of employees (*E*) in this very field in the whole country.

Besides we measure diversification or industrial variety (*VAR*) in terms of related variety (*REL_VAR*) and unrelated variety (*UNREL_VAR*). As explained by Frenken et al. (2007), the concept of related variety holds that some sectors are more or less related than other. The issue of industrial relatedness (*VAR*) is fed by a simple hierarchical approach. Firms which belong to the same 2-digit industry are taken into account. For our point of view, related industrial variety (*REL_VAR*) is defined as the average variety within the 2-digit-industries (i.e. Marshall's externalities and localization economies). Following Frenken et al. (2007) the term industrial related variety is measured as the weighted sum of entropy within each two-digit sector as:

$$REL\_VAR = \sum_{g=1}^{G} P_g H_g \qquad (2),$$

$$H_g = \sum_{i e S_g} \frac{p_i}{P_g} \log_2 \left(\frac{1}{\frac{p_i}{P_g}} \right) \qquad (3)$$

Contrarily to this measure, unrelated industrial variety stands for the average variety between the 2-digit-industries (i.e. Jacobs's externalities). Following Frenken et.al (2007) the term industrial unrelated variety (*UNREL_VAR*) is measured as follows:

$$UNREL\_VAR = \sum_{g=1}^{G} P_g \log_2 \left(\frac{1}{P_g} \right) (4),$$

With *knowledge intensive business services* (*KIBS*), we introduce a variable referring to whether a region exhibits a certain share of knowledge intensive business services to the firms. As we already know, *KIBS* undertake functional linkages to different cooperation partners, customers and knowledge providers (e.g. Koch and Strotmann 2006) that might lead to growth in firms. This means we ask whether the presence of *KIBS* may stimulate innovation and growth in firms. *POPDENS* is constructed by measuring *population density* and hence catching effects of agglomeration that refer to firm growth. Table 6.3 depicts the list of the dependent variable and the various explanatory variables and shortly describes their characteristics and definitions.

Table 6.3 List of variables

Variable	**Description**
EMP	Logarithm of number of employees
REVENUE	Autocorrelation dynamics, i.e. logarithm of revenue
PRIM_LQ	Regional specialization of primary 1-digit industry classification (broadly defined)
PRIM_LQ_2d	Regional specialization of primary 2-digit industry classification (broadly defined)
PRIM_LQ_3d	Regional specialization of primary 3-digit industry classification (medium defined)
PRIM_LQ_4d	Regional specialization of primary 4-digit industry classification (narrow defined)
SEC_LQ	Regional specialization of secondary 1-digit industry classification (broadly defined)
SEC_LQ_2d	Regional specialization of secondary 2-digit industry classification (broadly defined)
SEC_LQ_3d	Regional specialization of secondary 3-digit industry classification (medium defined)
SEC_LQ_4d	Regional specialization of secondary 4-digit industry classification (narrow defined)
REL_VAR	Related variety within each 2-digit sector
UNREL_VAR	Unrelated variety, i.e. average variety between 2-digit sectors
KIBS	Share of knowledge intensive business sectors in the region
SIZE	Size of the firm; classified as: small-sized (<=50), medium-sized (>50 and <=250) and large-sized enterprises (>250)

The final database consists of approximately 244.000 firms (33.988 manufacturing firms and 209.507 service firms). The descriptive statistics for the dependent and independent variables of the entire population are given in Table 6.4.

Table 6.4 Descriptive statistics of the variables

Variable	Obs	Mean	Std. Dev.	Min	Max
EMP	1142442	2.3223615	1.7672795	0	13.19254
REVENUE	1720905	7.101518	1.85317	0	18.71725
PRIM_LQ	2180604	1.706885	4.941289	0	419.647
PRIM_LQ_2d	2186169	1.266414	1.5164109	0	69.6147
PRIM_LQ_3d	2182397	1.5117275	3.0575042	0	142.762
PRIM_LQ_4d	2180604	1.689264	4.812497	0	419.647
SEC_LQ	1445939	1.332498	2.065589	0	139.305
SEC_LQ_2d	1447854	1.15725	0.7739717	0	68.119
SEC_LQ_3d	1446557	1.2449685	1.460695	0	139.305
SEC_LQ_4d	1445939	1.3182615	1.928873	0	129.042
UNREL_VAR	2191545	3.3879585	0.22910325	1.92683	3.8251
REL_VAR	2191545	1.5670065	0.1913076	0.700719	2.04529
KIBS	2191545	0.08323175	0.0511543	0.0045908	0.190384
POPDENS	2191545	0.3793465	0.29196845	0.0536599	2.58903

6.4 Growth model

In a first step we estimate firm growth (i.e. *EMP*) using the OLS estimation on the basis of pooled panel data and cross-sectional time series estimations (i.e. Fixed-effects). Thereby, we investigate the relationship between employment growth rates and the several independent variables (as discussed in section 3.2). Table 6.5 (in the appendix) present the correlation matrix of the variables. Some interesting observations can be made in the correlation Table 6.5 (in the appendix). We do not see a problem with multicollinearity. For instance, the items of *VAR* (i.e. *REL_VAR* and *UNREL_VAR*) are slightly (and not surprisingly) correlated to each other (r=-0.4343***). This effect is captured by the fact that we are, in general, dealing with industrial variety (*VAR*). Thus, we measure the average variety *within* and *between* the 2-digit industries. Obviously, the term revenue growth (*REVENUE*) is highly correlated with the dependent variables of EMP (r=0.8833***). Already Coad (2009 p: 71) pointed to the fact that “sales/revenue growth is positively associated with subsequent growth of employment, and vice versa”. However, this strong correlation is likely being impacted by the industry affiliation of the firm (i.e. manufacturing or services) which is taken into account in following analyses (i.e. industry-specific analyses). Furthermore, the independent variable knowledge intensive business services (*KIBS*) is weakly correlated with the variety measures (*UNREL_VAR*: r=-0.5013***; *REL_VAR*: r=0.7191***). Accordingly, related variety confirms the general concept that some sectors are more related to KIBS than others (i.e. for unrelated variety it is precisely the other way around). As it is clear from Table 6.5, specialisation (*LQ*) at higher levels of aggregation shows resemblance with specialisation of lower level of aggregation (see Frenken et al. 2007). The emergence of strong positive correlation between the different digit-industry aggregations (i.e. 2/3/4-digit industries) supports the fact (e.g., correlation coefficient between *PRIM_LQ_4d* and *PRIM_LQ_3d*: r=0.6731***). More precisely, this strong correlation between the different aggregates is assumed to be caused by the hierarchical system of NACE classes that is due to the narrower consideration of specialisation of the respectively 4-digit industry classes in comparison to the more broadly defined consideration of specialisation of 1-digit industry classification. Then, we analyse the level of industrial aggregation, where we distinguish between more broadly defined specialisation (1-digit and 2-digit), medium (3-digit) and narrow (4-digit) levels of industry classification (for an overview see Beaudry and Schiffauerova 2009).

Furthermore, to estimate the impact of the independent variables on employment growth of firms we set up two different growth models. First, we set up cross-sectional analyses in terms of OLS estimations with pooled panel data to analyse the average employment growth effect of firms. Comparing the simple OLS estimation (i.e. for only one wave) and the OLS estimation with pooled panel data we can obviously increase the number of observation. It is likely that the OLS estimation will under estimate (i.e. in the case of zero) or over estimate (i.e. in the case of missing values) the growth rates of firms in the sample. As a second step, we hence estimate employment growth using cross-sectional time series estimation regarded as fixed effects model. Put differently, we change the perspective from average employment growth to a more dynamic point of view (i.e. year-to-year consideration of employment growth). In particular, we run the model to gain a more detailed insight on individual characteristics that may contribute to the predictor variable and to control for unknown heterogeneity. To decide whether the fixed effects model is suitable (probably using random effects model), we perform the Hausman test. We do not fail to reject the null hypothesis and conclude that fixed effect model is appropriate (i.e. Prob>chi2 = significant). Finally, we set up our basic econometric model as:

$$\log(\mathrm{EMP})_{it} = \alpha + \beta_1 REVENUE_j + \sum_{k=2}^{8} \beta_k LQ_{kj} + \sum_{k=3}^{9} \beta_k VAR_{kj} + \beta_{11} KIBS_j + \beta 12 POPDENSj + \varepsilon it$$

where *growth* stands for the dependent variable of *EMP* with *i* = firms and *t* = time. The parameters β_i represent the estimated coefficients for the several independent variables as discussed in section 3.2 (i.e. *REVENUE, LQ, VAR, KIBS,* and *POPDENS*). So the term $\boldsymbol{\alpha}$ stands for the unknown intercept for each firm and ε finally stands for the error term.

6.5 Results and interpretation

In the following section 4 we discuss the main findings of the regression analyses and present the interpretation. The estimates are reported in Tables 6.6 (pooled OLS) – 6.7 (panel).

6.5.1 Localization economies versus Jacobs's externalities

This subsections starts with the theoretical discussion and explanation of our first hypothesis that states *while Marshall's externalities are negatively related to employment growth in SME, Jacob's externalities are more positively related to employment growth of SME.* It highlights therefore the controversial discussion about Marshallian externalities (i.e. specialisation) versus Jacobian externalities (i.e. diversification). Usually the impacts of regional factors on regional aggregates are studied without explicitly considering firm-level. We therefore focus on the following independent variables: overall aggregates (i.e. broadly defined) of localization economies (i.e. LQ: *LQ_PRIM* and *LQ_SEC*) as well as Jacobian measures (i.e. VAR: *UNREL_VAR* and *REL_VAR*). Let us start with the OLS estimations with pooled panel data to analyse the average employment growth effect (see Table 6.6). As a main control variable, we include *REVENUE* to control for positive growth feedback loops (e.g. Coad 2009). The Table 6.6 shows that revenue growth is always positively associated with subsequent growth of employment. This finding goes in line with findings by Coad (2009). Obviously, the coefficient for *LQ_PRIM* only becomes weakly significant in terms of medium-sized firms in manufacturing sector, with a negative sign. Furthermore, we find a negative coefficient for small-sized firms in the service sector. The negative coefficients indicate that average employment growth tends to decline with high share of local firms within the same primary or secondary sector. If we change the perspective from Marshall's externalities to Jacob's externalities, we find interesting results for the independent variables of *UNREL_VAR* and *REL_VAR*. Put differently, the negative coefficients of *UNREL_VAR* for SME in manufacturing and service sectors suggest that employment growth tends to decline when local firms having a high unrelated variety of knowledge flowing into the firm. Otherwise, the negative coefficients turn into strong positive coefficients of *REL_VAR* referring that firms that are "well endowed with sectors that are complementary in terms of competencies perform" on average better (e.g. Boschma and Iammarino 2009 p: 289). This especially holds for small-sized firms irrespective of the industry affiliation. In the case of larger firms in the manufacturing sector, the positive impact of related variety disappears. This might lead to the fact that larger firms do not benefit from local firms that are well endowed with sectors that are complementary. If we look at the estimates for the cross-sectional time series regression (see Table 6.7) we receive predominantly consistent results. In the case of medium-sized firms in manufacturing and service sector, we find negative coefficients for *LQ_SEC* pointing to the fact employment growth tends to decrease with high share of local firms within the same secondary sector. Put differently, too much knowledge from the same industry might dampen fruitful knowledge spillover and employment growth in

SMEs. For large-sized firms in the service sector we also find a negative significant coefficient for *LQ_SEC.* We interpret this as a statistically support for the fact that even in larger firms too much knowledge of the same secondary sector hampers firm to grow in terms of employment. Now let us come to the Jacob's externalities of *UNREL_VAR* and *REL_VAR* (see table 6.7). Not surprisingly, the estimates show strong positive and statistically significant coefficients for both measures of diversification. In the case of *UNREL_VAR*, we suggest for all cohorts (except larger firm in the service sector) to be more growing with diversified sectoral structure that is unrelated. In terms of *REL_VAR* we especially find this important effect for SME irrespective of the sector affiliation. It can therefore be expected that knowledge within sectors might experience growth-enhancing effects in terms of employment growth. Our findings go in line with the impact of related variety on regional economic growth by Boschma and Iammarino (2009).

To sum up, we can entirely confirm our hypothesis 1 meaning that localization economies are negatively related to employment growth in SME, while Jacobian diversification is more likely to positively influence employment growth in SME. We are also able to deepen our expectation that *Jacob's externalities in terms of unrelated variety are likely to dampen average employment growth in SME but this effect disappears and even becomes a positive outcome as we control for year-to-year employment growth, while related variety strongly stimulates employment growth in SME.* To put it differently, it can be argued that both issues (i.e. related or unrelated variety) have advantages and drawbacks from an economic point of view. While too much embedded knowledge of the same industries might engender regional lock-in (e.g. Bathelt et.al 2004), knowledge that is very different from the industry that a firm is specialised in might be inefficient. An overall explanation for our result might be that "Jacob's externalities necessarily result in knowledge spillover" (Boschma and Iammarino 2009 p: 290) that, in turn, is highly important for SME. To put it differently, industrial variety is responsible for employment growth and job creation.

6.5.2 Level of industry aggregation

As already stated in the study by Frenken et al. (2007 p: 689), "variety at high level of aggregation shows little resemblance with variety at low level, which strongly suggests that the choice of sector aggregation is not trivial". Likewise, Beaudry and Schiffauerova (2009 p: 323) suggest that the probability to detect Jacob's externalities increases with the level of narrow and detailed industry classification, whereas it does not have such tendency for localization economies. "For specialisation externalities, the highest probability of detection of positive (and the lowest for negative) results is for the medium level of industrial classification, but is somewhat lower for broad or detailed industrial classification schemes" (see Beaudry and Schiffauerova 2009 p: 232/324). We therefore are highly interested in the patterns of localization economies (i.e. specialisation) measured by different digit-industries classifications. We hence suggest that *Marshall's externalities do influence employment growth but the choice of industry aggregation strongly matters hereby*. We already know from the discussion above (see section 6.5.1) that localization economies (i.e. overall aggregation) are negatively related to employment growth in SME. But the question whether the negative trend does also hold for the different measures of industry aggregation is still unclear. Let us start with estimations of the OLS regression (pool) (see Table 6.6) and the different variables of the industry aggregation (i.e. *LQ_PRIM_2d/3d/4d* and *LQ_SECOND_2d/3d/4d*). In the case of medium-sized manufacturing firms, we find a negative and statistically significant coefficient for *LQ_PRIM_3d* and a significant coefficient for *LQ_PRIM_4d*, but with a positive sign. This interesting result points to the fact that localization economies in terms of higher level of industry aggregation (i.e.. *LQ_PRIM* and *LQ_PRIM_3d*) do have a negative impact on average employment growth. This effect is expressed by a positive sign of the coefficient of the lowest level of aggregation *LQ_PRIM_4d*. To put it differently, this result indicates that broadly defined specialisation influences average employment growth negatively. In contrast, the positive coefficient for *LQ_PRIM_4d* suggests that narrow specialisation impacts average employment growth of medium-sized manufacturing firms positively. This change of sign is assumed to be caused by the constraint of NACE industry classes that is due to the narrower consideration of the 4-digit classes in comparison to the next higher level of industry aggregation (e.g. 2/3-digit). In terms of localisation economies in terms of secondary industry classification the results show that only *LQ_SEC_2d* presents positive and significant evidence on average employment growth. While overall aggregation of secondary industry classification does not show any effect on average employment growth, the positive and statistically significant effect of *LQ_SEC_2d* suggests that a more narrow consideration of specialisation is more likely to be conducive for the outcome variable. In terms of large-sized and manufacturing firms we exclusively find positive and statistically significant results. More precisely, irrespective of the industry aggregation specialisation obviously becomes beneficial. For small-sized firms in the manufacturing sector we do not find any evidence for the impact of Marshall's externalities on firm growth. This non-significance is, however, limited to the manufacturing sector. Consequently, positive and statistically significant coefficients for *LQ_PRIM_2d* and *LQ_SEC_2d/3d* assume that specialisation at a narrow consideration of the industry classification does really impact the average employment growth of small-sized firms in the service sector. As previously discussed, we find that more broadly defined specialisation impacts medium-sized firms in the manufacturing sector in a negative way. This is exactly the opposite to the situation of medium-sized firms in the service sector. Here we find a positive and significant coefficient for *LQ_PRIM_3d* and a negative coefficient for *LQ_PRIM_4d.* Put another way, this indicates that specialisation is conducive for average employment growth, but diversity is needed nevertheless, at least to certain extent. If this diversity, as expressed here in within-class diversity on the 3-digit NACE level, is suppressed, specialisation obviously becomes harmful. For large-sized firms in the service sector, we find a negative and statistically significant coefficient for *LQ_PRIM_4d*, meaning that narrow consideration of specialisation might hamper firms to evolve in terms of average employment growth. Contrarily, for secondary industry classification it is true that very narrow defined specialisation has a positive impact on average employment growth as is expressed by the positive sign of the coefficient of the 4-digit LQ. But this effect is, again, limited by the negative sign of the coefficient of the 3-digit and the 2-digit LQ (pooled OLS and time series). This change of sign is assumed to be caused by the constraint of NACE classes that is due to the broader defined consideration of the 2/3-digit classes in comparison to the 4-digit ones. Put another way, this indicates that specialisation is no longer conducive, but specialisation at a narrow consideration of aggregation is needed nevertheless, at least to certain extent. Now let us discuss the estimates for the cross-sectional time series regressions (see Table 6.7 in the appendix). If we change the perspective from average growth to the year-to-year consideration of employment growth we find slightly different results. As discussed above, there is no evidence that specialisation at certain extent has an impact on average employment growth of smaller firms in manufacturing sector. For the year-to-year consideration of job creation we find the results that a negative coefficient of *LQ_PRIM_2d* turns into a positive sign of the coefficient of the 3-digit LQ indicating that year-to-year employment growth is affected by the more narrow consideration of specialisation (i.e. *LQ_PRIM_3d*) but gets even negative as specialisation becomes more broadly defined (i.e. *LQ_PRIM_2d*). The same effect holds for medium-sized firms in the service sector. While we actually found a negative effect for broadly defined specialisation *LQ_SEC* (1-digit industrial class) in the case of medium-sized and manufacturing firms this impact turns into a positive force as the secondary industry aggregation becomes more narrow (e.g., *LQ_SEC_2d/4d*). Put differently, this indicates that specialisation is conducive, but at the narrower consideration of at least 2-digit classes. For the large-sized enterprises in the manufacturing sector we receive similar results for the different temporal estimates. We therefore suggest that narrow specialisation has a positive impact on year-to-year employment growth as is expressed by the positive sign of the coefficient of the primary 2-digit and 3-digit LQ. This also is true in the case primary 2-digit industry classification of large-sized firms in the services sector. This effect is, however, limited by the negative sign of the coefficient of the secondary 2-digit LQ. Put another way, this indicates that specialisation is conducive, but diversity is needed nevertheless, at least to certain extent. If this diversity, as expressed here in within-class diversity on the 2-digit NACE level, is suppressed, specialisation obviously becomes harmful.

To best of our knowledge, we suggest that Marshall's externalities do influence employment growth but the choice of industry aggregation matters hereby. More precisely, the probability to detect a positive effect of localization economies (Marshall's externalities) increases as the level of industrial classification becomes more narrow (3-digit and 4-digit). Otherwise, the probability to perceive a negative impact of Marshall's externalities increases as the industry aggregation gets more broadly defined. We therefore confirm our hypothesis 2 and additionally conclude that the impact of the level of industry aggregation on employment growth does not independently operate on the time period considered.

6.5.3 Linkages and embeddedness

Furthermore, we discuss the fact that firms are embedded somewhere in space. Space provides certain spatial conditions that could be beneficial (i.e. spatial embeddedness) or even harmful (i.e. spatial isolation) to firms located in. We understand the surrounding of firms as a potential pool consisting of growth enhancing factors (as well as growth reducing variables) that might engender firms to grow and evolve. We hence control for the existence of knowledge intensive business services (*KIBS*) and population density (*POPDENS*) to elaborate the direct impact of external growth related factors on employment growth. Some studies already point to the fact that external conditions of the surrounding undertake functional linkages to, for instance, cooperation partners, customers and knowledge providers and qualified workforce that might be a key stimulus for firms to grow and innovate (e.g. Koch and Strotmann 2006, Aslesen and Isaksen 2007). We therefore hypothesise that e*mployment growth of firms is affected by being well connected to KIBS, and by being well embedded into high population density. The size of the firm matters hereby.* We again start with the estimations of the OLS regression (see Table 6.6). For SME, we find negative and statistically significant coefficients for *KIBS* reflecting that a high share of knowledge intensive business services in the region do not necessarily engender SME to grow and innovate. This result might contradict the findings in previous empirical studies that especially *KIBS* might be beneficial for firms in terms of average employment growth (e.g. Aslesen and Isaksen 2007). We interpret this result as a statistical support for the suggestion that smaller firms are less likely to outsource some of their competencies and knowledge (i.e. Huggins 2011) by focussing on their key competencies. We therefore assume that especially SME try to undertake all corporate divisions of their company. This finding holds for SME in the manufacturing and service sector. Thereby, the finding suggests that a high share of knowledge intensive business services in the labour market region is counterproductive for job creation in SME. In respect to the large-sized firms in our sample, we find significant coefficients with a positive sign, indicating that *KIBS* enable larger firms in the manufacturing and service sector to evolve in terms of average employment growth and in terms of year-to-year consideration. An explanation for that might be that larger firms do actually outsource their knowledge intensive business services to external players (e.g. Huggins 2011). But now let us come to the cross-sectional time series regression where we find similar results (see Table 6.7). For small-sized-firms, we again find negative coefficients for *KIBS*. By the way, this result can be seen as robust finding because it also holds for the year-to-year consideration of employment growth. Medium-sized enterprises now present a positive coefficient for *KIBS* meaning that a higher share of business services in the region does positively contribute to employment growth. Let us now look at the results for the independent variable of *POPDENS*. In the case of manufacturing and service sector, Table 6.6 (in the appendix) shows exclusively positive and statistically significant coefficients for *POPDENS* in the case of SME. We suggest that a high population density of the respective region engender SME to grow in terms of average employment growth. This finding goes in line with common understanding of the fact that a high *population density* positively affects the survival of firms (e.g., Wennberg and Lindqvist 2010, Hoogstra and van Dijk 2004). For our understanding, this effect is also captured by the open access to qualified workforce and knowledge.

To briefly sum up, we can partially confirm our hypothesis 3. We therefore set up an alternative hypothesis 3 that e*mployment growth of larger firms is positively influenced by being well connected to KIBS, while the positive effect of being well embedded into high population density does only hold for SME.* As such, SME do not necessarily perform better when they are located within regions with high share if *KIBS*. We also find that the positive effect of *POPDENS* disappears if the analysis is restricted to only large-sized firms.

6.6 Conclusion

The paper investigates the contribution of regional specialisation and industrial variety to employment growth and highlights therefore the controversial debate about Marshallian specialisation versus Jacobian diversification. Usually the impacts of regional factors on regional aggregates are studied without explicitly considering firm-level, level of industry aggregation and growth related external factors. Moreover, our study focuses on the direct impact of regional characteristics on employment growth, especially the impact of specialisation (i.e. localization economies) and industrial variety (Jacob's externalities). The study presents three major empirical issues. First, we find that localization economies (more broadly defined: 1-digit industrial class) are negatively related to employment growth in SME, while Jacobian diversification (more narrow 3-digit industrial class) is more likely to positively influence employment growth in SME. We are also able to deepen our expectation that Jacob's externalities in terms of unrelated variety are likely to dampen average employment growth in SME but this effect disappears and even becomes a positive outcome as we control for year-to-year employment growth, while related variety strongly stimulates employment growth in SME. To put it differently, it can be argued that "Jacob's externalities necessarily result in knowledge spillover" (Boschma and Iammarino 2009 p: 290) that, in turn, is highly important for SME. Then, industrial variety is responsible for employment growth and job creation. Second, we suggest that Marshall's externalities do influence employment growth but the choice of industry aggregation entirely matters hereby. More precisely, the probability to detect a positive effect of localization economies (Marshall's externalities) increases as the level of industrial classification becomes more narrow (3-digit and 4-digit). Otherwise, the probability to perceive a negative impact of Marshall's externalities increases as the industry aggregation gets more broadly defined. Third, we analyse that employment growth of larger firms is positively influenced by being well connected to KIBS, while the positive effect of being well embedded into high population density does only hold for SME. As such, SME do not necessarily perform better when they are located within regions with high share if *KIBS*. We also find that the positive effect of population density disappears if the analysis is restricted to only large-sized firms.

The presented study has a number of shortcomings that need to be pointed out. Amongst these is its focus on the direct relationship between localisation economies as well as Jacobian diversification and firms' employment growth. It can very well be argued that these spatial conditions primarily aim at enhancing firms' growth capacities. But they differ across firm size, level of industrial class and time period. This implies that we probably underestimated the effects of localisation economies and Jacob's externalities. For the empirical analysis we pooled the panel data for firms active in manufacturing and service sector. It seems to be more than likely that significant inter-industrial differences exist in the linkages and relevance of such externalities. For instance, different indicators may need to be selected to identify the MAR externalities precisely (e.g. Rigby and Essletzbichler 2002, Duranton and Puga 2004). These empirical issues clearly lay the path for future research.

6.7 References

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6.8 Appendix

Table 6.5 Correlation matrix

	EMP	REVENUE	PRIM_LQ	PRIM_LQ_2d	PRIM_LQ_3d	PRIM_LQ_4d	SEC_LQ	SEC_LQ_2d	SEC_LQ_3d	SEC_LQ_4d	UNREL_VAR	REL_VAR	KIBS	POPDENS
EMP	1.0000													
REVENUE	0.8833 (0.000)	1.0000												
PRIM_LQ	0.0651 (0.000)	0.0522 (0.000)	1.0000											
PRIM_LQ_2d	0.0929 (0.000)	0.0641 (0.000)	0.4777 (0.000)	1.0000										
PRIM_LQ_3d	0.0685 (0.000)	0.0618 (0.000)	0.6749 (0.000)	0.7171 (0.000)	1.0000									
PRIM_LQ_4d	0.0645 (0.000)	0.0521 (0.000)	0.9932 (0.000)	0.4673 (0.000)	0.6731 (0.000)	1.0000								
SEC_LQ	0.0665 (0.000)	0.0625 (0.000)	0.2107 (0.000)	0.3169 (0.000)	0.2970 (0.000)	0.2092 (0.000)	1.0000							
SEC_LQ_2d	0.0809 (0.000)	0.0637 (0.000)	0.1355 (0.000)	0.3006 (0.000)	0.1983 (0.000)	0.1356 (0.000)	0.5606 (0.000)	1.0000						
SEC_LQ_3d	0.0753 (0.000)	0.0695 (0.000)	0.1718 (0.000)	0.2398 (0.000)	0.2202 (0.000)	0.1714 (0.000)	0.7354 (0.000)	0.7352 (0.000)	1.0000					
SEC_LQ_4d	0.0710 (0.000)	0.0668 (0.000)	0.1975 (0.000)	0.2812 (0.000)	0.2696 (0.000)	0.1955 (0.000)	0.9345 (0.000)	0.6066 (0.000)	0.7926 (0.000)	1.0000				
UNREL/VAR	-0.0043 (0.108)	0.0120 (0.000)	-0.0802 (0.000)	-0.1117 (0.000)	-0.0971 (0.000)	-0.0801 (0.000)	-0.0917 (0.000)	-0.1186 (0.000)	-0.1077 (0.000)	-0.1032 (0.000)	1.0000			
REL/VAR	-0.0081 (0.002)	-0.0047 (0.023)	-0.0555 (0.000)	-0.0866 (0.000)	-0.0670 (0.000)	-0.0512 (0.000)	-0.0700 (0.000)	-0.0454 (0.000)	-0.0488 (0.000)	-0.0644 (0.000)	-0.4343 (0.000)	1.0000		
KIBS	-0.0298 (0.000)	-0.0251 (0.000)	-0.0924 (0.000)	-0.1380 (0.000)	-0.1099 (0.000)	-0.0897 (0.000)	-0.1244 (0.000)	-0.1532 (0.000)	-0.1202 (0.000)	-0.1230 (0.000)	-0.5013 (0.000)	0.7191 (0.000)	1.0000	
POPDENS	-0.0335 (0.000)	-0.0211 (0.000)	0.0382 (0.000)	0.0364 (0.000)	0.0355 (0.000)	0.0379 (0.000)	0.0146 (0.000)	-0.0161 (0.000)	-0.0024 (0.261)	0.0114 (0.000)	-0.1712 (0.000)	-0.2964 (0.000)	-0.3467 (0.000)	1.0000

Table 6.6 OLS estimations (pooled panel data) for manufacturing and service firms

	manufacturing			services		
VARIABLES	(I) (EMP) small	(II) (EMP) medium	(III) (EMP) large	(IV) (EMP) small	(V) (EMP) medium	(VI) (EMP) large
REVENUE	0.482***	0.199***	0.576***	0.410***	0.102***	0.396***
	(0.00248)	(0.00264)	(0.00496)	(0.000945)	(0.00155)	(0.00364)
LQ_PRIM	-0.00446	-0.00372*	0.00108	-0.00223	-0.00222	0.00303
	(0.00429)	(0.00210)	(0.00453)	(0.00239)	(0.00233)	(0.00461)
LQ_PRIM_2d	0.00148	5.52e-05	0.0146***	0.00757*	0.00208	-0.0229
	(0.00274)	(0.00186)	(0.00344)	(0.00452)	(0.00466)	(0.0150)
LQ_PRIM_3d	-0.00140	-0.00468***	-0.00169	-0.00174	0.0110***	0.0143
	(0.000965)	(0.00110)	(0.00151)	(0.00353)	(0.00373)	(0.00930)
LQ_PRIM_4d	0.00430	0.00682***	0.00221	-0.000998	-0.00994***	-0.0192**
	(0.00431)	(0.00220)	(0.00457)	(0.00321)	(0.00362)	(0.00847)
LQ_SEC	-0.00782	-0.000844	-0.0104	-0.00756*	0.00270	-0.00937
	(0.00503)	(0.00218)	(0.00653)	(0.00440)	(0.00517)	(0.0105)
LQ_SEC_2d	0.00328	0.0188***	0.0183*	0.00768*	-0.000272	-0.0241*
	(0.00569)	(0.00407)	(0.00961)	(0.00426)	(0.00444)	(0.0140)
LQ_SEC_3d	0.000636	-0.000391	0.00291	0.00632**	0.00142	-0.0378***
	(0.00332)	(0.00278)	(0.00608)	(0.00294)	(0.00225)	(0.0130)
LQ_SEC_4d	0.00591	-0.00139	0.0166**	-0.000627	-0.00114	0.0321**
	(0.00542)	(0.00286)	(0.00756)	(0.00494)	(0.00560)	(0.0146)
UNREL_VAR	-0.139***	-0.107***	0.0168	-0.108***	-0.0286**	-0.0583
	(0.0220)	(0.0181)	(0.0429)	(0.00956)	(0.0139)	(0.0410)
REL_VAR	0.215***	0.00595	-0.262***	0.0531***	-0.00805	-0.0271
	(0.0361)	(0.0281)	(0.0634)	(0.0149)	(0.0204)	(0.0581)
KIBS	-0.990***	-0.486***	1.489***	-0.392***	-0.174**	0.341*
	(0.136)	(0.107)	(0.241)	(0.0544)	(0.0779)	(0.207)
POPDENS	0.0792***	0.0342***	0.0105	0.182***	-0.00138	-0.0230
	(0.0150)	(0.0119)	(0.0295)	(0.00637)	(0.00916)	(0.0267)
Constant	-1.086***	3.076***	-0.171	-0.793***	3.743***	2.381***
	(0.103)	(0.0884)	(0.204)	(0.0448)	(0.0649)	(0.194)
Obs.	46223	20406	9744	315917	42003	19765
R-squared	0.451	0.223	0.606	0.375	0.095	0.378

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6.7 Cross-sectional time series regression results

	manufacturing			service		
	(I)	(II)	(III)	(IV)	(V)	(VI)
	(EMP)	(EMP)	(EMP)	(EMP)	(EMP)	(EMP)
VARIABLES	small	medium	large	small	medium	large
REVENUE	0.126***	0.0559***	0.0524***	0.149***	0.0411***	0.0901***
	(0.00450)	(0.00231)	(0.00365)	(0.00198)	(0.00155)	(0.00322)
LQ_PRIM	0.00299	0.000328	0.000196	-0.00125	-0.00147	0.000955
	(0.00206)	(0.000778)	(0.00132)	(0.00118)	(0.00105)	(0.00113)
LQ_PRIM_2d	-0.0162***	-0.00228	0.00569**	-0.000463	-0.0129***	0.0203***
	(0.00387)	(0.00199)	(0.00279)	(0.00409)	(0.00356)	(0.00664)
LQ_PRIM_3d	0.00613***	0.00404***	0.00388***	-0.00377	0.00583***	-0.00123
	(0.00172)	(0.00113)	(0.000845)	(0.00279)	(0.00216)	(0.00331)
LQ_PRIM_4d	-0.00189	0.000262	0.000831	0.00198	0.00466***	0.00249
	(0.00211)	(0.00117)	(0.00136)	(0.00199)	(0.00171)	(0.00331)
LQ_SEC	0.00427	-0.00204***	0.000132	0.000536	-0.00393**	-0.00545*
	(0.00239)	(0.000749)	(0.00182)	(0.00221)	(0.00188)	(0.00316)
LQ_SEC_2d	2.27e-05	0.0118***	0.00544	0.00560	0.00389	-0.0181***
	(0.00589)	(0.00375)	(0.00593)	(0.00431)	(0.00340)	(0.00588)
LQ_SEC_3d	0.000747	-0.00114	-0.00365	0.00481	0.00123	0.00469
	(0.00210)	(0.00226)	(0.00330)	(0.00304)	(0.00272)	(0.00577)
LQ_SEC_4d	-0.00408	0.00670***	0.00297	-0.00236	0.00452*	0.00765
	(0.00277)	(0.00157)	(0.00240)	(0.00294)	(0.00244)	(0.00611)
UNREL_VAR	0.467***	0.292***	0.163**	0.520***	0.0676**	0.0872
	(0.0691)	(0.0400)	(0.0672)	(0.0304)	(0.0317)	(0.0631)
REL_VAR	0.999***	0.108*	0.0694	1.067***	0.0756*	-0.0834
	(0.0976)	(0.0563)	(0.0939)	(0.0430)	(0.0447)	(0.0886)
KIBS	-0.269*	0.805***	0.314**	-0.274***	0.110*	0.119
	(0.145)	(0.0864)	(0.144)	(0.0598)	(0.0629)	(0.126)
POPDENS	0.489***	-0.0195	-0.0808	0.571***	0.123***	0.0334
	(0.0507)	(0.0301)	(0.0550)	(0.0222)	(0.0233)	(0.0513)
Constant	-2.074***	2.898***	5.186***	-2.923***	4.041***	5.381***
	(0.374)	(0.216)	(0.364)	(0.166)	(0.173)	(0.346)
Obs.	46223	20406	9744	315917	42003	19765
R-squared	0.027	0.061	0.041	0.026	0.060	0.082

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

7 Local knowledge endowment and specialisation

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Impact of Local Knowledge Endowment on Employment Growth in Nanotechnology

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Abstract

This paper investigates the contribution of local knowledge endowment to employment growth in nanotechnology firms. We exploit a unique data set focusing on firms operating in fields that apply nanotechnology. Our findings suggest that regions that offer knowledge can stimulate employment growth in smaller and younger firms. By contrast, being embedded into specialised regions might be counterproductive, especially for firms belonging to a particularly knowledge intensive sector and older firms.

Keywords Employment growth, local knowledge endowment, general purpose technology, specialisation, nanotechnology, spillover

JEL codes: D83, L25, O31, R11

7.1 Introduction

All over the world nanotechnologies are seen as the most promising future technology with a great economic potential for growth and employment. The term nanotechnology thereby refers to most different types of analysis and processing of materials which have one thing in common: Their small size (1-100nm). Nanotechnology makes use of the special characteristics that many nanostructures do not only depend on the original material but very much also on their size and shape. It is widely accepted as being the next general purpose technology (e.g. Youtie et al. 2008). Nanotechnology is still a young and dynamic technology, there is large scope for improvement, and innovation activities are essential firm activities. In Germany, small and medium-sized enterprises (SME) account for more than 80 percent of all nanotechnology firms (Schnorr-Bäcker 2009). Due to fragmented R&D and production processes, most of the firms only provide parts of complex value creation chains while being embedded in various networks. As a consequence of their high innovation intensity, the anchorage of the actors within regional specialisations is central. One general expectation concerning the overall role of nanotechnology firms is their contribution to job generation thereby strengthening regional competitiveness. It is reasonable to assume that the characteristics of the economic surrounding feed back to nanotechnology firms' performance and vice versa. Along this line of reasoning this paper addresses the impact of two economic key characteristics of nanotechnologies and their potential for job creation and growth: As *high technology*, the usual arguments in the context of the proximity-productivity relationship, i.e. the linkages between innovation, spillovers and economic performance also apply to nanotechnologies. Especially important are hence not only firm specificities but also a sufficiently specialised surrounding to translate spillovers to actual productivity gains. Key determinants are thus a sufficiently high overlap of firms' activities (absorptive capacity) as well as the availability of qualified labour. Consequently, the actors' regional anchorage and especially the composition of regional labour markets are central determinants of success. In contrast to this is the *general purpose character* of nanotechnologies, which basically allows introducing the technology in any context. This implies that a certain degree of regional specialisation is not mandatory per se, but, depending upon the state of development of the technology, even the contrary may the case: Too narrow regional specialisation patterns may inhibit the technology's use in a multitude of application fields, thereby possibly suppressing potential opportunities for cross-fertilisation and innovation-enhancing feed-back mechanisms across diverse and so far unrelated value creation chains. This is the starting point of the paper at hand. It addresses two major questions: (i) (How) do firm-specific and location-specific characteristics interact and influence the process of job creation of nanotechnology firms?, and (ii) What is the impact of regional specialisation in this context? Put differently, which characteristic of nanotechnologies predominates: its character as a high technology (i.e. being located in a sufficiently specialised region thereby benefitting from regional (knowledge) spillovers is of major importance) or the character as a general purpose technology (according to which opportunities aside from already existing specialisations may be more important for firm success)? The empirical analysis is based on an online survey carried out 2011 among German nanotechnology firms. The regional levels are German Raumordnungsregionen, i.e. official statistical units used in Germany lying between NUTS2 and NUTS3. We apply a two-step regression approach starting with OLS and subsequently followed by a fixed-effect panel regression in order to analyse how nanotechnology firms' employment growth is affected by both firm-specific and location-specific determinants. In doing so, we especially link the analysis to existing specialisation patterns. Our main results may be summarised as follows: Location of nanotechnology firms matters for employment growth. However, the relative importance of the degree of specialisation of the economic surrounding decreases in favour of diversification. This might be interpreted as an indication of the relevance of the general purpose character of nanotechnologies.

The remainder of the paper is as follows: In Section 7.2 we supply the theoretical background and derive our main hypotheses (section 7.3). Section 7.4 introduces our methodology and data. In section 7.5 we present our results and interpretations and section 7.6 briefly concludes.

7.2 Related literature

There is a vast literature on firm growth referring to sales, revenues, or employment. Most prominent determinants underlying the analyses are the characteristics of the firm (e. g. size, age, industry affiliation, financing strategy), of the entrepreneur (e. g. education, skill distribution), or firm location (e. g., Storey (1994) for an overview). Related theories range from neoclassical considerations on optimal size (Coase 1937), over internal learning-by-doing processes (Penrose 1995) and evolutionary concepts in which the 'fitness' of firms plays a central role (e.g. Coad 2007) to the socio-economic view which highlights the importance of resource availability and the competition for these resources (e.g. Uhlaner et al. 2007). Empirical findings suggest that there is not one single key determinant driving firm growth but the result is highly context specific and depends upon the interaction of several influencing factors (e. g. Harhoff et al. 1998, Delmar et al. 2003, Coad 2007). Independent of the studied determinants, country or sector, the literature unambiguously highlights the positive relationship between innovative activity and firm growth (e.g. Acs and Audretsch 1988, Del Monte and Papagni 2003, Adamou and Sasidharan 2007, Harrison et al. 2008 or Coad and Rao 2008). The studies also stress the overall importance of employment and the availability of qualified labour for innovation (e.g. Acs and Audretsch 1990, Pianta 2005, López-García and Puente 2009). Feldman (1994) or more recently Feldman and Kogler (2010) provide evidence that especially innovative activity tends to cluster thereby pointing to the importance of specialisation; at the same time several studies show that firms in clusters reach higher levels of innovation (e. g. Moreno et al. 2004, Fromhold-Eisebith and Eisebith 2005). Of special interest are the characteristics of local knowledge thereby suggesting that specialised local knowledge has a particularly positive effect on innovation and firm growth (Feldman and Audretsch 1999). Fritsch and Slavtchev (2008, 2010) also confirm that innovating firms are not isolated, self-sustained entities but rather highly linked to their environment. Location matters since it may provide access to specialised networks of firms, suppliers, institutions, or labour (see also Porter 2000; more critically Martin and Sunley 2003). Other arguments discussed in the context of clustering include stronger pressure to innovation or lower costs for innovation commercialisation (Ketels 2009). Spillover opportunities and thus the proximity-productivity linkage decrease with distance, as knowledge that is highly contextual most frequently requires interaction and face-to-face contact (von Hippel 1994). However, until recently there are only few studies that analyse the role of location and the proximity-productivity relationship for post-entry performance, i.e. the growth of firms (e.g. Gabe and Kraybill 2002, Boschma and Weterings 2005, Audretsch and Dohse 2007, Weterings and Boschma 2009). The concept of regional clusters systematically picks up this proximity-productivity relationship systematically thereby relying on specific economic activities and has become a popular policy measure. While a cluster always refers to a specialised network of firms and institutions there is no finally accepted definition of industrial clusters. Porter's considerations however, might be seen as representing the standard concept (Martin and Sunley 2003). Porter (2000 p: 254) defines cluster as "geographically proximate group of inter-connected companies and associated institutions in a particular field that is linked by commonalities and complementarities". As a positive external knowledge spillover they increase their productivity and economic performance. There is, indeed, evidence that firms in clusters reach higher levels of innovation (Moreno et al. 2004; Fromhold-Eisebith and Eisebith 2005). The basic reasoning behind specialisation or industry-specific advantages being relevant for the efficiency of local innovation activity implies that local agents can share the same assets and can benefit from goods and services provided by specialised suppliers as well as from a local labor market pool (Marshall 1890). The cluster environment provides not only a stronger pressure to innovate, but also a richer source of relevant knowledge and ideas as well as lower costs for innovation commercialization (Ketels 2009). Cluster strength is hence considered a determinant of prosperity differences across space. As a clustered industry indicates that there are significant benefits from co-location, the industry's productivity is assumed to increase with the level of specialisation within the cluster. In the light of this, knowledge diffusion will occur when firms are embedded in more specialised environment (Marshallian externalities) or in regions that are more diversified (Jacobian externalities). More precise, the assumed relevance of clusters hence refers to the characteristics of local knowledge and suggests that specialised local knowledge has a particularly positive effect on innovation and firm growth. We contribute to this literature by extending the basic question of the impact of specialised local knowledge endowment (both *amount* and *composition*). In doing so our research focuses on nanotechnology firms' growth. This is particularly challenging since this young technology is not only innovation and therefore knowledge intensive but is also coined by a general purpose character. Thus, the relationship between regional specialisation and firm growth is not per se clear in the discussed context.

Our paper is most closely related to Audretsch and Dohse (2007) who find that regions abundant in knowledge resources provide a particularly fertile soil for the growth of young, technology-oriented firms. They consider new market firms and point to the need of investigating the relationship between local knowledge endowment and firm performance in other high and emerging technologies. Our unique data-set on German nano-firms allows us to test their main hypotheses in the promising field of nanotechnology. While Audretsch and Dohse (2007) only elaborate on the influence of the accessible stock- and hence the quantity - of local knowledge, we extend the analysis to the *composition* and hence the quality of the local knowledge base. Besides, we test the robustness of our hypotheses by two different econometric approaches and introduce novel measures that expand their explanatory power.

7.3 Derivation of hypotheses

Following the argumentation above, we propose the natural expectation that location characteristics do affect the growth of firms in nanotechnologies. We moreover assume that employment growth in nanotechnology firms is strongly related to successful innovative activity. Following Feldman (1994), knowledge spillovers (from closely related external factors and knowledge sources) are especially relevant for small firms since the resources necessary in order to maintain the knowledge base are typically beyond their means. The new growth literature hence finds a propensity for knowledge inputs and spillovers to agglomerate and therefore it can be reasonably assumed that firms that are in fact using knowledge inputs, such as firms in high-tech or innovation-intensive industries, will perform better once they are located in a high-density region, as these firms will have better access to knowledge resources and knowledge spillovers. Hence, characteristics of location seem to preserve and even reinforce an innovating firm growth. However, until recently little effort has been done to analyse the role of location and its economic characteristics for post-entry performance, i.e. the growth of firms (Audretsch and Dohse 2007). The importance of agglomeration and the impact of spatial proximity on firm performance have only been studied recently (e.g. Gabe and Kraybill 2002, Audretsch and Dohse 2007, Weterings and Boschma 2009). Following Audretsch and Dohse (2007 p: 100), who find that regions abundant in knowledge resources provide a particularly fertile soil for the growth of young, technology oriented firms, we carry out such an analysis, also focusing on the special role of locational characteristics for the growth of firms in high-tech, particularly nanotechnology-applying industries. However, we will go one step further by considering the composition of local knowledge agglomeration. We therefore suggest that the extent to which external knowledge is crucial and can be absorbed differs widely across different firm size classes and knowledge intensive sectors. Paying attention to the characteristics of the structure of the region a firm is located in (so-called location characteristics) and the knowledge processing characteristics of the firm itself. We suggest that the impact of location characteristics on employment growth in nanotechnology differs across firm size classes, knowledge intensive sectors and age groups (see description in section 4.3). We therefore hypothesise that:

H1: Location characteristics do influence the employment growth of firms in nanotechnology. In particular, the impact of location characteristics on specific knowledge intensive sectors, firm size and firm age classes matters here.

Put differently, we hence suppose that regions rich in knowledge provide a particularly good environment for the growth of technology-oriented, i.e. knowledge intensive firms. Taking into account the peculiarities of nanotechnologies as GPT and the interaction with the characteristics of location, the arguments suggest that specialisation might not be conducive for the employment growth of firms that are active in the exploration of general purpose nanotechnologies since this hampers the inflow of knowledge from other fields and even suppresses positive effects stemming from diversity and nanotechnologies' application in a wide variety of fields. Catalysing knowledge recombination and fertilising ideas from other application fields most presumably cannot be processed in an environment with a single focus. However, firms experience a tension when they aim to advance and exploit existing knowledge and at the same time explore new fields simultaneously (Leten et al. 2007). Therefore, local specialisation seems to be necessary to develop sufficiently strong capabilities in particular domains in order to be able to realise economies of scale in technology development while incrementally advancing the technology. Hence, local specialisation effects might have a positive effect on growth in nano-firms: Firms that are not particularly intensive in knowledge are assumed to rather exploit existing knowledge. We therefore separate the analyses again. The smaller and the younger a firm is, the more we assume it to be prone to specialisation externalities due to the fact that small firms are often highly specialised and enter the market via specialised niches (van der Panne 2004). Since the exploration of the field is intensive in knowledge we moreover assume that knowledge intensive, exploring firms are particularly benefiting from diversity and hence specialisation might have a negative impact. Given the GPT nature of nanotechnology and the chances that are inherent in diversity and exploration of the field and on the other hand the minimum degree of knowledge in the respective field needed to be able to keep up with leading edge development, we assume that too less and too much regional specialisation negatively influence firm performance in either of the firm classes we distinguished. We suggest that local specialisation effects (see description in section 4.3) have a negative impact on nanotechnology firm growth. Put another way, the effects of the co-location of the distinct industry the nanotechnology firm belongs to negatively impact the development of the firm since it restrains the growth opportunities across diverse fields that nanotechnology, being a general purpose technology, offers. Having stated this conjecture, we hence hypothesise that the feature of nanotechnology being a GPT outweighs the benefits local specialisation is found to inhere for the growth of high-tech firms in general means.

H2: Local specialisation effects impacts the employment growth of firms in nanotechnology negatively. (a) While specialisation has a direct negative impact on employment growth in particularly knowledge intensive firms and older firms, (b) too much local specialisation hampers employment growth in general.

Finally, we analyse the robustness of the impact of specialisation effects and location characteristics on employment growth. Thus, we investigate whether the yearly changes of the level of specialisation might interfere with the yearly changes in the growth rates. In this context, we hence more technically assume that:

H3: Specialisation effects that are related to average employment growth are the same as those that are related to a year-to-year consideration of employment growth.

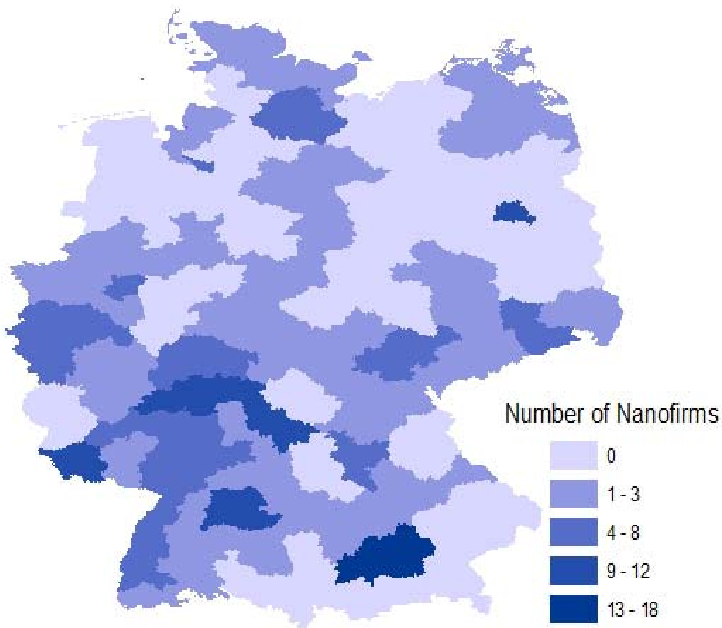
The expected results will sharpen our understanding of the association between concentrated activity of firms and the corresponding performance in the field of nanotechnologies as an emerging GPT. They may serve as a starting point for regional policy aiming at the improvement of the regional factors influencing the growth of firms in growth-promising nanotechnologies.

7.4 Methodology and data

7.4.1 Data source

In our unique data set, we focus on firms operating in fields that develop or apply nanotechnology. That means that we investigate firms that are concerned with nanotechnology in any possible way, be it basic R&D or the employment of nanotechnology in later stage of the value creation chain, irrespective of whether this is their main field of activity. These firms are not only knowledge intensive by operating in a high-tech sectors, but particularly because nanotechnologies are still in a nascent stage of development and hence these firms are intensive in innovation - which is by definition knowledge intensive. However, nanotechnology firms operate across a wide range of industries and are therefore particularly heterogeneous in nature, e.g. referring to SIZE, KIS and AGE. This is why we investigate one the one hand all firms together and on the other hand have to construct different subsample across these characteristics. Our data set of firms consists of records from the 'competence atlas nanotechnology in Germany' (www.nano-map.de), an online database providing information on firms that are concerned with nanotechnologies. We then conducted an online survey in 2011, asking the firms for information on employment numbers for different years, profits, year of foundation, zip code and their industry affiliation (i.e. NACE classification of the 2-digit and 3-digit industry affiliation) on the basis of their main products. This is particularly necessary since nanotechnology as GPT do not constitute a single industry, but are present in a wide range of different industries. 216 of 1950 contacted firms answered, which gives a response rate of 11.1 percent. The non-response bias (respectively t-test) is a commonly used method (e.g. Wooldridge 2010, Armstrong and Overton 1977) to ensure whether our firm sample is not prone to sample selection. We run a t-test for the two groups of interest, i.e. early and later answering firms, the latter ones representing the firms that will never provide a response. The corresponding p-values are non-significant for both, the number of employees and the profits, indicating that our firm sample is representative of the entire population. In doing so, the independent samples t-test compares the difference in the means from the two groups to a given value (usually 0). In this vein, we split our firm sample into two groups: (i) response at an early stage (first wave of survey) and (ii) response at a later time (second wave of survey). The t-test statistics obviously show that there are neither in the case of number of employees nor in the case of profits significant differences between the two groups. The results indicate that there is no statistically significant difference between the mean values for the first wave and the second wave of survey ($t = 1.1866$, $p = 0.2371 > 0.05$). In other words, the firm sample is not prone to sample selection. The level of analysis within our survey is the geographical level of planning regions ('Raumordnungsregionen'). Germany consists of 97 planning regions. This level is chosen as it is particularly suited to approximate spatial and functional interrelations between core cities and the corresponding hinterland (BBR 2001). Therefore, they are homogeneous and comparable entities, which are large enough to assume that spillovers are intraregional and hence no connection between the different regions has to be included in our estimations (Audretsch and Dohse 2007). It has to be mentioned that the nano-firms in our sample are not equally distributed: Out of the 97 planning regions, the nanotechnology firms in our sample are located in 62 different regions[1], some of them hosting a multitude of firms. Figure 1 displays this distribution. The data for the regional part of the analyses, i.e. mainly the employment data for the corresponding planning regions comes from the Federal Employment Agency (Bundesagentur für Arbeit), statistics of employees subject to social insurance contributions and from the Federal Office for Building and Regional Planning (BBR, INKAR).

Figure 7.1 Distribution of answering firms across Germany



[1] 62 different regions: avg.: 3.8 max: 18 and min: 1

7.4.2 Dependent variable

Before starting with the regressions, an operationalisation of the term firm growth is necessary. There is a wide range of definitions that deal with firm growth. Garnsey et al. (2006, p. 11) suggest that "firms' growth can be measured in terms of input (e.g. employees), in term of value of the firm and in terms of output (e.g. turnover, profit)". In our analyses, we use the growth measure of the growth of employees. We hence define our dependent variables by measuring the log-form of employment growth as the ratio of the year t (respectively 2010) to year t-1 (respectively 2006). The variable values for the year of the financial crisis, 2008, were replaced by the average (i.e. mean value) of the other available years' values. More precisely, it might be that the stochastic properties of the growth rates exhibit entirely different growth features as in the other years of the studied time period. In other words, growth events (i.e. growth rates) during the financial crises (respectively 2008) seem to occur with a significantly higher probability to follow extreme growth events. Nevertheless, in some cases number of employees is completely missing for all years. Hence, we are not able to replace these missing values.

7.4.3 Explanatory variables

Regarding our hypotheses, we employ several independent variables. These variables display firm-specific and location-specific characteristics. The firm-specific variables reflect rather usual factors found to influence employment growth, such as firm size, age and industry affiliation. Location-specific variables by contrast shall reflect the knowledge characteristics that are specific to the environment the firm is located in. An overview of the description of explanatory variables is given in Table 1 and the independent variables are discussed as follows:

(1) Firm-specific characteristics

The *SIZE*-dummy controls for the size of the firm, as smaller firms more intensively and more frequently rely on knowledge spilling over for generating new knowledge and innovative activity than larger firms (Audretsch 1998). We hence assume small and medium-sized firms (*SIZE* = 1) to benefit differently from location-specific characteristics than larger ones (SIZE = 0). *KIS* is an industry-dummy, indicating whether a firm belongs to a particularly knowledge intensive sector within the sample (*KIS*=1, *high-KIS*) or not (*KIS*=0, *low-KIS*).[2] *KIS* is constructed by the share of 'knowledge workers' in an industry's labour force, which is measured by the share of employees with a university degree. Sectors with an above-average share of knowledge workers are hence seen as knowledge intensive (see Audretsch and Dohse 2007). We use this dummy in order to be able to distinguish between firms that are operating in above average knowledge-intensive industries among our sample of firms and hence especially prone to knowledge spillovers as positive externality raising their productivity. Moreover, *high-KIS* firms should be able to better incorporate, i.e. to use the knowledge that is spilling over as it is widely accepted that firms that are themselves active in knowledge processing and production exhibit a high absorptive capacity (Cohen and Levinthal 1990). We expect location hence to have a more relevant, positive influence on *high-KIS* firms. We investigate whether firm age (*AGE*) is an initial trigger for firm growth in nanotechnology.

[2] Although it is natural to assume most of the firms in nanotechnologies to be intensive in knowledge as nanotechnologies definitely are considered as high-tech, this is not what we expect from our data. We surveyed firms that are processing nanotechnologies in which way whatsoever. Subsequently it might well be that the main activity of the firm is not in a high-tech sector.

Age is consistently found to be a relevant impact factor on firm performance (Coad 2010). Since we assume that the impact of local knowledge characteristics on firm growth depends on firm characteristics, we use the modal age of the firms in our sample as cut-off point for creating a subsample of young and older firms each. Hence, we employ *KIS*, *AGE* and *SIZE* of nanotechnology in form of a dummy in order to be able to introduce different subsamples and investigate the particular role of location specific characteristics given differing firm-specific characteristics.

(2) Location-specific characteristics and the nature of the regional knowledge base

The location-specific variables refer to the role of locations, particularly to possible knowledge spillovers generated in the region. With *HQ,* we introduce a region-dummy referring to whether a region exhibits a share of highly qualified (*HQ*) employees in the top quartile, measured by employees with university degrees. The IND variable, by contrast, displays the absolute number of employment employees in the firms' industry in its region. In both, the *HQ* and *IND* we hence implicitly assume that the regional human capital displays the regional knowledge resources, which is commonly done, as knowledge can be considered as incorporated in individuals who are able to process it (Rigby and Essletzbichler 2002).[3] The distinction between these two variables is useful, as the *HQ* dummy is a relatively general measure of knowledge intensity in the region, whereas *IND* is more specialised, pointing to the actual strength of the firm's industry in the considered region. We expect both to have a positive influence on firm growth. *INDDENS* by contrast is a catch-all region-specific variable catching agglomeration effects in general by displaying the industry density of a region to improve the model fit. It measures the number of industry employees subject to social insurance contributions per square metre in the respective region. A further standard measure capturing regional knowledge resources is the presence of a university in a region, as universities are at the same time supportive and necessary for regional innovation and economic development (Feldman and Kogler 2010). Research results are open to the public and ready to be exploited as knowledge spillovers. We therefore employ the absolute number of students in a region STUD. Since we expect knowledge spillovers to increase with available knowledge resources, STUD should have a positive impact on firm growth. A similar argumentation holds for R&D, a variable displaying the share absolute number of employees mainly concerned with R&D in a region. The knowledge inherent in and produced by human capital (mainly) concerned with *R&D* is likely to be another source of knowledge spillovers. The specialisation *(*Location Quotient*, LQ)* variable measures region-specific knowledge-resources and refers to the characteristics of the knowledge within a region. It is constructed using employment data, corresponding to the industry in which the firm operates. *LQ* is calculated by the ratio of the share of employees of a region in the industry into which the nanotechnology firms classified itself, divided by the total share of employees in this very field in the whole country:

$$LQ_{i,j} = \frac{\frac{Employees\ in\ region\ i\ in\ industry\ j}{Employees\ in\ Germany\ in\ industry\ j}}{\frac{Employees\ in\ region\ i}{Employees\ in\ Germany}} = LQ$$

[3] We hence subsequently treat human capital as proxy for knowledge resources, bearing in mind the remark by Audretsch and Dohse (2007), that, although the interpretation of the average level of human capital in a region proxying local knowledge resources as part of the local firm's productions function is straightforward it remains still abstract, as it lacks a mechanism by which human capital actually contributes to higher growth (see also Rauch 1993).

LQ[4] indices are usual measures for specialisation externalities (Paci and Usai 1999). For the empirical analysis we employ a standardisation, making the index symmetric and easier to interpret by using the formula $LQ=100^*(LQ^2-1)/(LQ^2+1)$, which constrains possible values within the interval (−100,100) (see Vollrath, 1991 and Grupp, 1994). Values above 0 hence indicate an above average, values below 0 below average specialisation. Following our hypotheses, we expect *LQ* to influence the growth of firms. Table 7.1 pictures the different explanatory variables and a short description of variables. In general, we distinguish between firm-specific characteristics (SIZE, AGE and KIS) and locations-specific characteristics (HQ, INDDENS, IND, STUD, R&D and LQ).

Table 7.1 Description of explanatory variables

Category	Variable	Description	Nature
Firms-specific characteristics	SIZE	Small and medium enterprises, defined as those with less than 251 employees (SME=1).	subsamples and control variable
	KIS	Firms in sectors with an above-average share of employees with university degree are knowledge intensive (KIS=1).	subsamples and control variable
	AGE	Age of the firm in terms of years since foundation. Cut-off point used to distinguish between young and old firms is modal age.	subsamples and control variable
Location- specific characteristics	HQ	Region exhibits a share of highly qualified employees with university degree in the top quartile.	independent variable
	INDDENS	Measures industry density (employees in industry per km²) in a region, catchall variable for agglomeration effects.	independent variable
	IND	Absolute employment in the firms' industry in its region, pointing to the actual strength of the firm's industry in the considered region.	independent variable
	STUD	Absolute number of students in the considered region.	independent variable
	R&D	Absolute number of employees in R&D in the considered region.	independent variable
	LQ	LQ is calculated by the ratio of the share of employees of a region i in industry j, divided by the total share of employees in this very field in the whole country.	independent variable

7.4.4 Descriptive statistics and stochastic properties

The final database consists of 216 firms. The descriptive statistics for the employed variables are given in Table 7.6 (in the appendix). In respect to the different stochastic properties of the entire sample, the variables *KIS, SIZE, AGE*[5] are hence used to distinguish between the different subsamples. Table 7.2 shows the number of firms differentiated by different firm size classes. Firms classified as SME are defined as those with less than 251 employees

[4] Note that, for reasons of readability LQ will be used instead LQ_ij.

[5] A majority of previous research tends to emphasise that younger firms exhibit higher growth rates than their larger counterparts (Jovanovic, 1982) and firm growth decreases with firm age (Acs and Mueller 2008, Coad 2010). In this context, the discussion on different age groups becomes apparent. A challenging task is still the cut-off point in terms of younger and older firms.

(European Commission 2003). Obviously, SME firms are overrepresented in our sample. However, this is in line with the overall distribution of firms across size regardless of their technological background: Actually, there are more SME than larger firms in nanotechnology and hence SME are always overrepresented. More particularly, nano-firms are mostly SMEs and more seldom larger firms (Schnorr-Bäcker 2009), which is why our sample represents the population well. Table 7.2 moreover shows the share of firms differentiated *KIS*[6] (i.e. the most knowledge intensive sectors) and *AGE* (i.e. younger and older firms). Additionally, Table 7.2 pictures that our sample consists of an above average number of firms active in knowledge intensive sectors (*KIS*). Finally, we distinguish our sample between younger and older firms. The cut-off point in terms of younger and older firms is represented by the modal age of eight years (Fagiolo and Luzzi 2006, Huergo and Jaumandreu 2004a,b). In this vein, the distinction between different age groups provides additional information on the growth process. To sum up, the firm sample operates across a wide range of industries and is therefore particularly heterogeneous in nature, e.g. referring to SIZE, KIS and AGE. Therefore, we run independent group t-tests to test the different specifications (i.e. *SIZE, KIS* and *AGE*) against each other. In the case of the different firm SIZE classes, the t-statistic is -2.4202 with 214 degrees of freedom. The corresponding two-tailed p-value is 0.0163, which is less than 0.05. The same is true for the different AGE classes, i.e. t-statistics is -2.6107 with 214 degree of freedom and a corresponding two-tailed p-value of 0.0097. Finally, we conclude that the difference of means in growth rates between SME/larger firms and younger/older firms is different from 0. Surprisingly, in the case of knowledge intensive sectors (KIS=1/KIS=0) the mean difference of KIS=1and KIS=0 is not different from 0 (i.e. t=0.0187; df=214 and p-value=0.9851). We are nevertheless convinced that these subsamples operate on different frequencies and are differently influenced by location specific characteristics (see Audretsch and Dohse 2007).

Table 7.2 Firm-specific characteristics

Category	Subsample	Description	Frequency	Percentage
SIZE	SME	$1 \leq x \leq 250$	144	66.6
	Large-sized	>250	72	33.4
KIS	High-KIS (KIS=1)	Above average share of R&D employees	178	82.4
	Low-KIS (KIS=0)	Below average share of R&D employees	38	17.6
AGE	Younger	≤ 8 years (modal age)	42	19.5
	Older	> 8 years (modal age)	174	80.5

*Measure based on Audretsch and Dohse (2007).
** Cut-off point in terms of younger/older firms: Modal age of 8 years since foundation.

7.4.5 Regression approach and model fit

First, we set up a regression approach using OLS estimation (see equation (1) and (2)) to analyse the average growth of firm. As independent variables all the described variables are used. We use the standard regression approaches since it can be expected that our residuals are approximately normally distributed. There is no evidence for a deviation from a normal distribution in our data. We also do not find other problems, such as heteroscedasticity for our regressions with the logarithm of relative growth as dependent variable. Reynolds et al. (1994) and more recently Audretsch and Dohse (2007) developed an estimation approach that includes location-specific determinants of growth, which we will build on for investigating

[6] The firms in our sample operate on 10 different nanotechnology fields: avg.: 2.1 max: 7 and min: 1.

whether firm growth in nanotechnology is affected by different location-specific characteristics. Again, we analyse the average growth effect of these independent variables. For our investigation we run the log-level model. In the log-level model, $100*\alpha_1$ is sometimes called the 'semi-elasticity' of y with respect to x. (Wooldridge 2010 p: 45). First, we primarily investigate the impact of indicators on the average growth (from 2007 to 2010) of employment. In our equations, *LOCATION* stands for the various measures of location-specific characteristics. In our case, we use *HQ, INDDENS, IND, STUD* and *R&D*. We set up regressions for subsamples of different firm size classes (*SIZE*), knowledge intensive sectors (*KIS*) and different age groups (*AGE*) all using the following model:

(1) $(\log(empl_{2010}) - \log(empl_{2007}))_j = a_o + \sum_{k=1}^{5} a_k LOCATION_{kj} + a_6(SIZE)_j + a7(AGE)j + a8KIS + \varepsilon$

Equation (1) shall preliminarily investigate whether former findings in the literature on the relationship between location characteristics (as discussed above) and employment growth hold for the studied case. The employment of the specialisation effect might catch some of these effects, which is why we analyse this basic model first. However, in equation (1) the degree of specialisation of the local knowledge base is still neglected. Since we assume that regional specialisation has an influence on nano-firm, we add the *LQ* measure as well as its squared term LQ^2. Thus, we investigate the impact of indicators on the average growth (from 2007 to 2010) of employment:

(2) $(\log(empl_{2010}) - \log(empl_{2007}))_j = a_o + a_1 LQ_j + a_2 LQ_j^2 + \sum_{k=3}^{7} a_k LOCATION_{kj} + a8(SIZE)j + a9(AGE)j + a10KIS + \varepsilon$

Third, we analyse the robustness of the impact of specialisation and location characteristics on employment growth. Thus, we change the perspective from *average growth* to a year-to-year consideration of growth. We investigate whether the yearly changes of the level of specialisation might interfere with the yearly changes in the employment growth rates. This means, if growth in one year depends on an increasing level of specialisation or not, the relationship between current employment growth and previous specialisation might be a direct effect or an indirect effect. As things stand, specialisation effects are yet proved for average employment growth. Hence, it is not known whether specialisation effects also occur for yearly changes (very short-run consideration). It has also not been proven that year-to-year specialisation effects do exhibit employment growth. To prove this, it would be necessary to disentangle this dynamic effect we conduct a cross-sectional time series model. Hence, we estimate firm growth using cross-sectional time series estimation the fixed effects model. In particular, we run the model to gain a more detailed insight on individual characteristics that may contribute to the predictor variable and to control for unknown heterogeneity. More information on the panel dimension of the panel data and, specifically on, the time variation of each variable is given in Table 7.8 (in the appendix). To decide whether the fixed effects model is suitable (probably using random effects model), we perform the Hausman test. We do not fail to reject the null hypothesis and conclude that fixed effect model is appropriate (Prob>chi2 is significant). To see if time fixed effects are needed when running a fixed effects model, we run the joint test to see if the dummies for all year are equal to 0 (i.e. if they are not then time fixed effects are needed). We reject the null hypothesis that all year coefficients are jointly equal to zero therefore time fixed effects are needed in the panel specification (i.e. Prob>F is significant). Furthermore, we conduct one regression set for all firms together and then two other regressions for each of *SIZE*, *KIS* and *AGE* subgroups separately. Hence, our equation (3) follows as:

(3) $\log(empl)_{it} = a_o + a_1 LQ_j + a_2 LQ_j^2 + \sum_{k=3}^{7} a_k LOCATION_{kj} + \varepsilon$

Finally, we test for multicollinearity (see appendix correlation matrix in Table 7.6) and endogeneity. Moreover, we use the first year value in 2006 (or the first available value) of observation as independent variables in the case of H1 and H2. Some of our independent variables are correlated such as *HQ* and STUD (r=0.6294***) and *HQ* and *R&D* with r=0.5931***. *HQ* represents the share of highly qualified employees with university degree in the region that might be captured by *STUD* or *R&D*. Hence, we set up different regression models.

7.5 Results and interpretation

In the following section we will discuss the main findings of the regression analyses and present the interpretation. The regression results are reported in Tables 7.3 – 7.5.

7.5.1 Location characteristics

As we want to especially gain information on the location characteristics that contribute to the growth of nano-firms, we differentiate between the characteristics of the structure of the region a firm is located in. We preliminary assume that *location characteristics do influence employment growth of nano-firms*. Furthermore we suggest that *the impact of location characteristics on specific knowledge intensive sectors, firm size and firm age classes matters here.* The results for the regression analysis are presented in Table 7.3. In our analysis we use the following location-specific characteristics (as described in section 7.4.3): *HQ, INDDENS, IND, STUD, R&D* and the control variables *SIZE, KIS* and *AGE*. For some of the region-specific characteristics we find significant results.

Table 7.3 OLS estimates: Robust standard errors

VARIABLES	(I) All firms EMP	(II) SME EMP	(III) Larger firms EMP	(IV) KIS=1 EMP	(V) KIS=0 EMP	(VI) Younger EMP	(VII) Older EMP
HQ	0.219**	0.198*	0.233	0.250**	-0.0415	0.540*	0.143
	(0.0918)	(0.119)	(0.169)	(0.106)	(0.123)	(0.298)	(0.0906)
INDDENS	0.000164	0.00121	-0.00162	-1.65e-05	0.00104	-0.000605	6.25e-05
	(0.000733)	(0.00116)	(0.00104)	(0.000872)	(0.00109)	(0.00279)	(0.000594)
IND	-1.85e-07	5.69e-08	-3.69e-07	-1.08e-07	-2.27e-05***	-8.28e-06	-1.55e-07
	(3.20e-07)	(3.48e-07)	(3.56e-07)	(3.13e-07)	(6.99e-06)	(1.63e-05)	(3.37e-07)
STUD	-9.10e-07	-1.21e-06	-1.29e-06	-8.60e-07	-2.38e-06*	-1.84e-06	-9.13e-07
	(8.87e-07)	(1.23e-06)	(1.35e-06)	(9.30e-07)	(2.40e-06)	(3.66e-06)	(8.08e-07)
R&D	-4.48e-06**	-5.30e-06*	-4.84e-06	-4.74e-06**	-3.66e-06	-1.13e-05*	-2.90e-06
	(2.05e-06)	(3.00e-06)	(3.43e-06)	(2.38e-06)	(3.18e-06)	(6.44e-06)	(1.97e-06)
SIZE	0.153***			0.108	0.143	0.345*	0.105*
	(0.0556)			(0.0807)	(0.104)	(0.188)	(0.0610)
KIS	0.00526	-0.0260	0.0154			0.0199	0.0111
	(0.0577)	(0.0841)	(0.0572)			(0.186)	(0.0637)
AGE	-0.0010***	-0.00359*	-0.000127	-0.000328	-0.000635		
	(0.0004)	(0.00193)	(0.000458)	(0.000533)	(0.000623)		
Constant	-0.0114	0.213**	0.110	0.0289	0.220	-0.128	0.0156
	(0.0668)	(0.0833)	(0.0960)	(0.106)	(0.137)	(0.235)	(0.0668)
Observations	216	134	72	171	35	42	174
R-squared	0.063	0.056	0.101	0.060	0.464	0.171	0.033

Standard errors in parentheses*** p<0.01, ** p<0.05, * p<0.1

In the first step, we find significantly negative coefficients for the *AGE* of firms. This especially holds for the subsamples of all firms and smaller firms. Older firms are hence less likely to show higher growth than younger firms, which is in line with the findings of many other scholars before. It can be seen as ‘stylized fact’ that growth tends to decline with firm age (Audretsch and Dohse 2007). Older firms are characteristically more routinized, more inert and less able to adapt (Coad 2010). In contrast, we find a positive effect of *SIZE* for both age classes. Against the expectation that firm growth decreases as the firm becomes larger (stylized effect), we find a positive coefficient. The positive coefficients suggest that employment growth tends to increase as the firm becomes larger.

More important in the context of our concern is the impact of *HQ* representing the knowledge intensity in the region. The positive and significant coefficients of highly qualified employees (*HQ*) in the region on the employment growth of all firms points out that firms exhibit higher growth in regions characterised by a share of highly qualified employees in the top quartile. However, this finding does not hold for all subgroups and varies across different firm size classes, *KIS* and *AGE* groups. Actually, the coefficient of *HQ* is significantly positive in smaller firms but not in larger. Thus, the impact of *HQ* in the region is especially relevant for smaller firms. This might be due to the fact that larger firms are not as much depending on external knowledge and on possible knowledge spillovers stemming from high local endowments in knowledge since they benefit from internal economies of scale in knowledge production as their own knowledge stock is larger. Looking at the results of firms that belong to a knowledge intensive industry (i.e. *KIS*=1), we also find a strongly positive significant coefficient. This means firms with high knowledge intensity experience higher employment growth in regions with access to highly qualified employees which is very intuitive. Otherwise and in the case of low-knowledge industry (*KIS=0*) the coefficient shows no longer a significance. This seems similarly plausible since these firms do not rely as much on knowledge activities and hence regional knowledge endowment is not particularly important. Furthermore, we find another interesting issue concerning the impact of *HQ* (model VI and VII). We find a positively significant coefficient for firms that are younger than 8 years, but the coefficient is insignificant in case of older firms. This suggests that younger firms experience higher employment growth if they have access to qualified knowledge workers in their region. This finding also goes in line with the general findings by Dosi et al. (1995) and it even more emphasises the relevance of possible knowledge spillovers for new firms that are entering or just entered the nanotechnology-market and its relevance for success in the beginning phase where fundamental knowledge is gained.

Interestingly in the case of low-*KIS* growth is moreover even negatively influenced by the size of the group of employees that work in the same industry they are engaged in (*IND*). As the numbers of employees in the same industry also proxies the strength of regional competition, it might indeed especially affect those firms negatively that do not profit as much as others from the positive effects of this concentration, such as (intra-industry) knowledge spillovers.

Let us now look at the results for the independent variable of *R&D* representing the absolute number of R&D employees in the region. As things stand, we negative and statistically significant coefficient of *R&D* for SME*,* knowledge intensive sectors (*KIS=1*)and younger firms indicating that average employment growth tends to decline with a higher share of R&D employees in the region. While this result might be counterintuitive in the first place, it could be a hint to what we will investigate in our second hypothesis: It is not knowledge *per se* that positively influences firm growth, *but* the influence of knowledge and the potentially resulting spillovers depends on the characteristics of the available knowledge. The kind of R&D processed might e.g. be too basic or to incoherent to be beneficial for firms that are interested in commercialisation. For instance, Frenken et al. (2007) as well as Boschma and Iammarino (2009) refer to such an issue, when they argue that for knowledge to spill over effectively, and hence contribute positively to a firm’s performance, related variety in form of complementarities among industries and their knowledge is necessary.

To sum up, our expectations (hypothesis 1) are strongly confirmed by our results. We confirm that location characteristics can stimulate the growth of firms in nanotechnology. Besides typical impact factors such as *AGE* and *SIZE,* the share of highly qualified employees (*HQ*) does play a major role. We moreover obtain the result that the impact of *HQ* on firm growth varies across firm size, knowledge intensive industries and age groups. This means, in turn, that the share of highly qualified employees is more important in smaller firms than in larger firms, and seems to be more relevant in firms that are active in particularly knowledge intensive industries. Simultaneously, the impact of *HQ* is more decisive in younger firms. We therefore set up a more precise hypothesis 1 suggesting that "While the share of highly qualified employees is more important in smaller and younger firms as well as in firms belonging to a particularly knowledge intensive industry, a high share of R&D employees in the region has no positive impact on non-knowledge-intensive and older firms". We hence mostly confirm the findings in the literature that young, small and knowledge intensive firms with access to a high density of knowledge workers do experience an above average growth (Audretsch and Dohse 2007). Thus, nanotechnology firms innovate and grow as other highly knowledge intensive firms do, regardless of the peculiarities a GPT implies. Moreover, nanotechnology firms rely as much on knowledge spillovers as other high-tech (but not GPT) firms from other industries. Finally and most simply, the location-specific measures indicate that the growth of firms in nanotechnology is affected by their location-specific characteristics.

7.5.2 Specialisation of the regional knowledge base

Remember we suppose that regions that provide knowledge enrich the growth of technology-oriented, i.e. knowledge intensive firms. Since the extent to which external knowledge is crucial and can be absorbed differs widely across different firm size classes and knowledge intensive industries, hypothesis 2 states that *(a) specialisation has a direct negative impact on employment growth in particularly knowledge intensive firms and older firms, while (b) too much local specialisation hampers employment growth in general*. We moreover assume a non-linear impact and character of *LQ*. As you can see in Table 7.4, the independent variable of interest is *LQ,* representing the extent of regional specialisation. Moreover, we also included LQ^2 in order to be able to control for non-linear effects of specialisation. Additionally, we differentiate our sample into different firm size classes (*SIZE*), knowledge intensity (*KIS*) as well as age groups (*AGE*).

As model I in Table 7.4 shows, the coefficient of *LQ* does appear significant with a negative sign. This clearly indicates that specialisation in any application field of general purpose nanotechnology can has an overall negative impact on the growth of nano-firms in terms of employment. This is a hint to the fact that specialisation is counterproductive for explorative, knowledge intensive purpose in the GPT field under investigation here. Specialisation suppresses multiple opportunities for nanotechnology as GPT to develop and inhibits possibilities of catalysing effects and cross fertilisation. The differentiation into different subgroups emphasises that, however, this effect differs across different firm characteristics: The results for the independent variable of *LQ* are still significantly negative for high-KIS and older firms (see Table 4: model IV and VII). These are the firms that are especially prone to exploitation activities since they are knowledge-intensive. It might hence be the case that knowledge intensive firms explore the nano-field as their flexibility of thinking might make it more easy for these firms to perceive possibilities of application of old nano-knowledge in new fields. Another interesting issue is that *HQ* still shows statistically significant coefficients. In the case of all firms, SME and firms operating in knowledge intensive sectors we find significant coefficient with a positive sign. We interpret this as a statistical support for the fact that firms where knowledge is a crucial driver of employment growth strongly depend on highly qualified employees (as knowledge sources) in the region. The same is true for the independent variable of *R&D*.

Table 7.4 OLS (robust standard errors) with LQ-variables

VARIABLES	(I) All firms EMP	(II) SME EMP	(III) Larger firms EMP	(IV) KIS=1 EMP	(V) KIS=0 EMP	(VI) Younger EMP	(7) Older EMP
LQ	-0.000928*	-0.000572	-0.000819	-0.00104*	0.000428	-0.000812	-0.00113**
	(0.000524)	(0.000863)	(0.000652)	(0.000626)	(0.000742)	(0.00190)	(0.000564)
LQ²	-4.61e-06	-3.87e-06	2.41e-06	-7.83e-07	-1.56e-05	-7.17e-06	-4.54e-06
	(8.39e-06)	(1.27e-05)	(9.29e-06)	(1.02e-05)	(1.08e-05)	(2.91e-05)	(8.70e-06)
HQ	0.219**	0.196*	0.246	0.265**	0.00931	0.544	0.138
	(0.0910)	(0.118)	(0.173)	(0.105)	(0.148)	(0.353)	(0.0895)
INDDENS	6.70e-05	0.00113	-0.00167	-0.000152	0.000884	-0.000793	-5.39e-05
	(0.000755)	(0.00119)	(0.00108)	(0.000894)	(0.00103)	(0.00290)	(0.000618)
IND	-1.38e-07	3.81e-08	-2.17e-07	-9.55e-08	-2.38e-05**	-5.63e-06	-1.24e-07
	(2.57e-07)	(4.15e-07)	(3.77e-07)	(2.52e-07)	(9.06e-06)	(1.73e-05)	(2.74e-07)
STUD	-4.40e-07	-8.38e-07	-1.02e-06	-3.43e-07	-2.99e-06	-9.66e-07	-4.63e-07
	(8.98e-07)	(1.37e-06)	(1.31e-06)	(9.75e-07)	(2.46e-06)	(4.18e-06)	(8.20e-07)
R&D	-4.34e-06**	-5.40e-06*	-4.46e-06	-4.54e-06*	-4.78e-06	-1.12e-05	-2.51e-06
	(2.12e-06)	(3.01e-06)	(3.53e-06)	(2.47e-06)	(3.53e-06)	(6.85e-06)	(2.05e-06)
SIZE	0.141**			0.101	0.103	0.346*	0.0903
	(0.0549)			(0.0800)	(0.104)	(0.203)	(0.0596)
KIS	0.00194	-0.0325	0.0251			0.00574	0.0102
	(0.0580)	(0.0835)	(0.0608)			(0.241)	(0.0639)
AGE		-0.00327	-7.73e-05	-0.000226	-0.000662		
		(0.00204)	(0.000467)	(0.000530)	(0.000723)		
Constant	-0.00283	0.214**	0.0693	0.00380	0.298**	-0.133	0.0239
	(0.0715)	(0.0880)	(0.113)	(0.112)	(0.140)	(0.243)	(0.0735)
Observations	215	134	71	170	35	42	173
R-squared	0.075	0.059	0.130	0.075	0.502	0.176	0.054

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Since specialisation suppresses exploration (e.g. Greve 2007) this explains the negative influence of specialisation on employment growth. Older firms already survived the critical start-up phase and moreover are more prone to possessing the necessary endowment with resources to further explore the field. For the other subsamples such as differentiation across *size* and *low-KIS* or younger firms, no significant effect of specialisation can be found. This is contrary to our expectation that especially young and small firm benefit from specialisation since they occupy mostly specialised niches when entering the market. This is why *H2a* cannot be confirmed by our results. In order to test *H2b,* we also included the squared form of *LQ* in the model. Our results suggest that too much specialisation does not have any influence on the employment growth in firms active in nanotechnologies except for the case of low-KIS firms where too much specialisation and too much anti-specialisation, in contrast to moderate specialisation is harmful. Although generally specialisation of the regional knowledge base has no impact on a *low-KIS* firm's performance, employment growth declines when the region becomes too specialised. Since this does only hold for one particular case, *H2b* cannot be confirmed here. This might be due to the fact that specialisation in general already is counterproductive to the firms' employment growth. This effect does not seem to become more serious with increasing specialisation.

Summarising, we hence state that regional specialisation does have a mostly negative impact on nano-firm employment growth, even though not for all firms similarly but depending on their knowledge processing characteristics. As things stand, Hypotheses 2 can therefore be confirmed in general means. The results hence suggest that the average impact of specialisation on employment growth (as discussed above) appears to be related to average employment growth as well as to the year-to-year consideration of employment growth.

7.5.3 Robustness of the impact of specialisation

In a last step, we analyse the robustness of the impact of specialisation and the location characteristics on growth. We try to highlight the fact whether yearly changes of the level of specialisation might interfere with yearly changes in the employment growth rates. This means, if growth in one year depends on an increasing level of specialisation, the relationship between current employment growth and previous specialisation might be a direct effect. To disentangle this dynamic effect we conduct regressions where we include the different measures of specialisation *LQ, LQ²* and the different *LOCATION* measures. Hence, we hypothesise that *specialisation effects that are related to average employment growth are the same as those that are related to a year-to-year consideration of employment growth*. Again, Table 7.6 (in the appendix) clearly shows that *LQ* and *LQ²* (r=-0.4078) are correlated. We already stated in hypothesis 1 that firms in nanotechnology are affected by location-specific characteristics (e.g. *HQ*, *INDDENS, IND, STUD, R&D*). Thus, we neglect most of these indicators because in this analysis it is beyond the scope to analyse the pure impact of location again. Now we only consider the more particular impact of the level of specialisation. The findings vary (see Table 7.5).

Table 7.5 Panel estimates (incl. time-fixed effects)

VARIABLES	(I) All firms EMP	(II) SME EMP	(III) Larger firms EMP	(IV) KIS=1 EMP	(V) KIS=0 EMP	(VI) Younger EMP	(VII) Older EMP
LQ	-0.00231	-0.00284	0.00425	-0.00296	0.00376	0.00133	0.000602
	(0.00178)	(0.00214)	(0.00278)	(0.00195)	(0.00565)	(0.00811)	(0.00163)
LQ²	-2.83e-05*	-3.79e-05*	3.24e-05	-3.16e-05*	2.30e-05	-0.000143*	3.36e-06
	(1.64e-05)	(1.98e-05)	(2.37e-05)	(1.75e-05)	(5.99e-05)	(8.53e-05)	(1.46e-05)
INDDENS	-0.00192	-0.00801	-0.00228	-0.00385	-0.00371	-0.000430	-0.00210
	(0.00894)	(0.0134)	(0.00725)	(0.00985)	(0.0233)	(0.0430)	(0.00700)
IND	-2.70e-05	-6.34e-05	-3.29e-05	-1.20e-05	-0.000143**	-2.53e-06	-4.24e-05**
	(2.72e-05)	(3.99e-05)	(2.41e-05)	(3.01e-05)	(6.87e-05)	(0.000164)	(2.12e-05)
_Iyear_2008	0.106***	0.138***	0.0482***	0.104***	0.132***	0.153**	0.0939***
	(0.0181)	(0.0260)	(0.0160)	(0.0205)	(0.0394)	(0.0749)	(0.0146)
_Iyear_2009	0.109***	0.151***	0.0188	0.111***	0.101***	0.191**	0.0841***
	(0.0177)	(0.0245)	(0.0162)	(0.0201)	(0.0368)	(0.0744)	(0.0143)
Constant	5.130***	3.576***	9.076***	5.120***	5.824***	3.033	5.753***
	(0.470)	(0.640)	(0.463)	(0.504)	(1.433)	(2.496)	(0.361)
Observations	652	429	223	538	114	131	521
R-squared	0.116	0.158	0.070	0.114	0.192	0.163	0.135
Number of id	222	150	76	184	38	47	175

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We start our discussion with a comparison between the firm characteristics that relate to average growth (H2) and the firm characteristics that relate to a year-to-year consideration (H3). As a result, if we change the perspective from average growth to a year-to-year consideration, we receive different results in the case of all subsamples. Obviously, the coefficients for *LQ* never become significant. First, if we look at the results for all firms together, we find no longer a negative coefficient for *LQ*. What we find is a significant negative coefficient for *LQ²* in the overall model I and the three subsamples of small firms (model II), high-KIS (model IV) and younger firms (model VI). We interpret this as a statistical support for the fact that employment growth tends to decline with very low and very high levels of specialisation. Put differently, specialisation hampers year-to-year employment growth of local firms if a certain threshold of specialisation is undercut or exceeded. Also in these cases the effect of the average growth path is not confirmed for the year-to-year perspective. For the year-to-year consideration, our results suggest that specialisation indeed influences firm employment growth in a non-linear way (see Table 5). While the marginal effect of specialisation is initially insignificant, it becomes significant and negative for regions that exhibit extreme values of specialisation. This means although generally specialisation of the regional knowledge base has no impact on a firm's performance, employment growth declines when the region becomes too much or too less specialised. Even though there is no general positive effect for lower levels of specialisation this reminds us of an inverted u-shaped relationship between specialisation and performance often found in empirical work on production (Betrán 2011) stating that too much (or to less) specialisation has a negative influence on performance.

Generally spoken, this model does not confirm the results of the OLS regressions (average growth) around hypotheses 2. Hence, the results contradict what we expected in hypothesis 3, which is why we have to reject it. The characteristics accompanying average growth are not usually related to occurrence of year-to-year employment growth. However, an analysis of the year-to-year growth process of nano-firms provides additional information, as discussed above. If we change the perspective from average growth to year-to-year consideration the findings vary. Hence, the temporal structure of the growth process itself should be considered. And what is most important in terms of our initial questions: We never find a positive impact of specialisation on the employment growth of nano-firms. Referring to the prevailing of high-tech of GPT features referring to the relevance of the surrounding, GPT features seem to outweigh high-tech ones – although further empirical investigation needs to be done to disentangle the concrete effects of specialisation on firm growth in high – and nanotechnologies.

7.6 Conclusions

Nanotechnology firms' growth is influenced by the locations that host the firms. More particularly, we examined whether the local endowment with knowledge influences the growth of these firms. As we expected in view of nanotechnology firms operating on an innovation and hence knowledge intensive high technology field, the performance of these firms is – in general – stimulated by the local access to (high) knowledge. However, the actual impact of knowledge varies across firms with different characteristics. While the share of highly qualified employees never hampers growth (although it seems not to advance it either in e.g. larger firms), the local stock of employees concerned with R&D indeed has a hampering effect. We interpret this as a hint to the necessity of the knowledge to be marketable. However, this might also be interpreted as the inefficiency of knowledge transfer from universities to technology. Finally, knowledge is as relevant for nanotechnology firms as for other highly knowledge intensive firms, regardless of the peculiarities a GPT implies: Nanotechnology firms rely as much on knowledge spillovers as other high-tech (but not GPT) firms from other industries. The impact, however, depends on knowledge processing characteristics like it is the case in other industries.

Moreover, the impact of knowledge for nano-firm growth also depends on the characteristics of knowledge itself. We set out to investigate the special influence of specialisation of the regional knowledge base. When analysing average employment growth rates, the impact of specialisation is counterproductive to some firms, it has no effect on growth in others. In the year-to-year consideration, however, regional specialisation only has a negative effect in extreme situations. Although these results differ, it becomes clear that specialisation does not have a positive effect on firm growth in nanotechnology. The relevance of these effects has, however, to be seen in context with the special characteristics of GPTs, which develop their positive and accelerating effect on growth in a setting that is open to exploration and cross-application (which is not supported by specialisation). These findings point to the importance of our study: Although it is popular among policymakers to support the establishment of specialised nano-clusters, our results suggest that this regional specialisation is not conducive for the firms. Moreover, it might even become a burden for the performance of some firms, depending on the local degree of specialisation and the firm's knowledge processing characteristics. However, our findings are relying on a small number of firms in nanotechnology only. Moreover, the indicators on the impact of local knowledge resources, such as *STUD* and *R&D* could be refined (e.g. disentangling relevant STUD and R&D, such as students in technological fields) in order to be able to further investigate *which* local knowledge is relevant. Further research should also be done on the effect of specialisation in a larger sample or other (GPT) settings to confirm these results, especially in view of findings that state a positive effect of specialisation for many other, but different circumstances and industries. It moreover lies beyond the scope of this paper to investigate the mechanisms behind our findings. It would be interesting to learn how exactly local knowledge is processed, where spillovers indeed are effective and how specialisation exactly affects innovation in high-technologies.

The conclusion of this paper remains that local knowledge endowment indeed positively influences firm growth in nanotechnology, while local knowledge specialisation surely is not always positively affecting the growth of individual firms, pointing to the relevance of the GPT feature of nanotechnology for processing knowledge in firms.

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7.7 References

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7.8 Appendix

Table 7.6 Correlation matrix

	EMP	HQ	INDDENS	IND	STUD	R&D	LQ	LQ^2	SIZE	KIS	AGE
EMP	1.0000										
HQ	0.0573 (0.4020)	1.0000									
INDDENS	0.0482 (0.4809)	0.3720 (0.0000)	1.0000								
IND	-0.0343 (0.6160)	-0.0793 (0.2260)	-0.0584 (0.3726)	1.0000							
STUD	0.0165 (0.8092)	0.6294 (0.0000)	0.4509 (0.0000)	-0.0936 (0.1527)	1.0000						
R&D	-0.0509 (0.4567)	0.5931 (0.0000)	0.0989 (0.1299)	0.0069 (0.9162)	0.2374 (0.0002)	1.0000					
LQ	-0.1074 (0.1164)	0.2296 (0.0004)	0.0195 (0.7670)	-0.0005 (0.9945)	0.1924 (0.0031)	0.2309 (0.0004)	1.0000				
LQ^2	-0.0214 (0.7552)	-0.1158 (0.0770)	-0.0186 (0.7777)	-0.0794 (0.2261)	0.0389 (0.5542)	-0.0541 (0.4098)	-0.4078 (0.0000)	1.0000			
SIZE	0.1632 (0.0163)	-0.1130 (0.0832)	-0.1324 (0.0422)	-0.0183 (0.7802)	-0.1192 (0.0676)	-0.1142 (0.0800)	-0.0656 (0.3174)	-0.0599 (0.3620)	1.0000		
KIS	0.1624 (..0172)	0.1646 (0.0117)	0.0169 (0.7973)	-0.0054 (0.9347)	-0.0054 (0.9347)	0.2196 (0.0007)	0.0638 (0.3308)	0.1095 (0.0946)	0.1457 (0.0258)	1.0000	
AGE	-0.1922 (0.0056)	-0.0240 (0.7224)	-0.0560 (0.4065)	0.0666 (0.3245)	0.0142 (0.8339)	0.0481 (0.4760)	0.0497 (0.4633)	0.0289 (0.6700)	-0.1420 (0.0353)	0.0055 (0.9333)	1.0000

Table 7.7 Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
EMP	216	0.1398783	0.4411129	-3.610918	1.633717
KIS	236	0.8177966	0.3868325	0	1
SME	236	0.6313559	0.4834625	0	1
AGE	222	3.000362	1.200884	0	5.83773
HQ	236	0.1150768	0.0354213	0.0472828	0.1844673
INDDENS	236	45.43375	39.07808	2.165327	165.8995
IND	235	10295.4	12475.71	13	70531
STUD	236	38148.5	33889.06	0	134260
R&D	236	9112.375	11739.87	140	39879
LQ	234	-5.342925	58.55617	-100	99.46871

Table 7.8 Time variation of each variable (panel dimension)

Variable		Mean	Std. Dev.	Min	Max	Observations
EMP	overall	4.7548	3.2879	0	12.9645	N=880
	between		3.3131	0	12.9205	n=224
	within		0.1998	2.1004	8.8239	T=3.93
LQ	overall	-5.3078	58.4519	-100	99.5346	N=702
	between		58.3518	-100	99.4997	n=234
	within		4.6276	-30.2863	37.3654	T=3
LQ^2	overall	3439.94	3057.249	0.7897	10000	N=702
	between		3025.52	13.3764	10000	n=234
	within		468.0969	-21.2303	5992.402	T=3
INDDENS	overall	45.3757	39.1297	2.1295	167.8201	N=707
	between		39.308	2.1729	165.6239	n=236
	within		0.8798	41.6692	52.7028	T=2.99
IND	overall	9760.35	12534.96	0	68722	N=708
	between		12579.75	0	68096	n=236
	within		273.0092	8373.681	11276.35	T=3

8 Conclusion and future work

8.1 Conclusion

In general, firm growth has many growth stimulation factors and sources. Some of them are analysed in this book. A multidimensional approach of the firms' growth process is introduced. It is shown that a multidimensional consideration of the firms' growth process is of high importance because a multiplicity of interrelated factors and sources influence firm growth. This thesis captures aspects of time, space and organisations, and deals with the mixing of these dimensions. The detailed insight into 'unknown' factors, interrelationships and linkages is a great benefit in the explanation of the structure and procedure of firm growth processes. Generally speaking, this work allows for a detailed insight into the distinction between firm-internal and firm-external factors and knowledge sources to growth and controls for 'stylized facts' such as firm size, firm age and industry affiliation grounded in the previous empirical literature. Additionally, the thesis creates the opportunity of implementing further research directions (e.g. entrepreneurial dimension). In order to derive the main conclusions, the key achievement of each working package is stressed. The investigations of the presented thesis feature the following general findings:

RQ1 deals with the investigation of the interrelationships between firm-internal growth factors and time. The analysis is captured in chapter 2 and 3 to trigger WP1. *Chapter 2* investigates whether firm characteristics, which – in literature - are related to firm growth, are also related to the development path of firms. It is tested which firm characteristics are related to growth dynamics during a longer period of time, referring to the sequence of growth and decline steps. The analysis employs panel-data on 178 German manufacturing firms in the period of 1992 to 2007. A major conclusion is that the determinants of growth paths are not the same as the determinants of firm growth at one point of time. Obviously, the temporal structure of the impact of growth related factors on firm growth matters. Furthermore strong interrelationships and linkages between them exist. It is analysed whether the factors, which are found to be related to firm growth in literature, are also related to the continuous growth of firms in the medium term. In literature, it is usually examined whether certain characteristics are related to a higher average growth rate. In this work it is studied whether these characteristics are also related to the probability of various development paths, such as permanent growth. Hence, in this paper, the perspective is moved from average growth to the structure of development paths. Changing the perspective does not change the results fundamentally but provides many additional insights. As such, smaller firms are more likely to exhibit growth paths, especially growth paths in which they experience growth and, sometimes, stagnation. By contrast, larger firms are more likely to show stagnation or decline paths. Paths of permanent decline are especially rare among smaller firms. Furthermore, the study shows that export shares and innovation efforts do not significantly relate to growth paths but rather stagnation paths. Hence, in general, high export shares and innovation efforts come along with a high stability of firm size. The author concludes that high export shares and innovation efforts make firms more resistant with respect to crises and other external events. This study draws the conclusion that the temporal dimension indeed influences firm growth. With reference to this approach it can be stated that studying the development paths of firms instead of average growth provides many additional insights. As a result, certain characteristics of firms are related to specific development paths. So far, studies on firms' development paths are quite rare so that there is a great potential for further studies to explore development paths of firms.

Chapter 3 examines the time structure of the effects of R&D activities on firm growth. In this section, the short-term structure of the impact of R&D investments (i.e. R&D, capital expenditure) on turnover growth is examined. Also, the discussion about whether R&D investments are connected to firm growth in the subsequent periods and how this relationship depends on other firm characteristics (for example size and industry) is stressed. Additionally, the relationship between R&D investments and the autocorrelation dynamics of firm growth is highlighted. To do so, firm level data of 1000 European companies is used including details on their R&D investments from 2003 to 2006. A regression approach is applied using a linear model which takes R&D activities and the autocorrelation dynamics of firm growth into account. One main result is that, on average, the autocorrelation of growth rates varies with firm size. Considering all firms in the sample, the firms show strong autocorrelation in their year-to-year growth rates. For small- and medium sized enterprises we do not find significant autocorrelation of growth rates. For the relationship between expenditures and firm growth we find a strong dependency on firm size and industry. While it can be obtained nearly no significant results for small and medium sized enterprises (neither tangibles nor intangibles), a strong positive relationship between intangible innovation activity (R&D expenditures) and growth for large firms is examined. For intangible investments (capital expenditures) it is considered that permanently high capital expenditures are related to low growth rates, while one-time capital expenditures are often followed by higher firm growth. Besides these general finding, most relevant for the results is the kind of industry that is analysed. No relationships are found, e.g., for the metal industry and real estate. Within the manufacturing industry strong differences are detected between high-tech and low-tech industries. Furthermore, the industries also differ in the time structure of the relationship between R&D and growth. Hence, the analysis, first of all, suggests that the characteristics that are connected to high growth should be examined for each industry separately. Studies that aggregate over all industries provide information about the average behavior of firms, but ignore a lot of details and the result depends crucially on the mixture of firms in the data set. The study also shows that still more research about the time structure of growth processes is needed. Both, the time structure of the effects of R&D as well as capital expenditures on growth, needs to be further examined on an industry-specific level, using longer time series than available for our study. Furthermore, the study finds clear differences in the impact of tangible and intangible investments on firm growth. Both kinds of investments are supported by government programs. The results suggest that one-time investments in capital as well as in R&D help firms to grow, at least, in a number of industries. However, the various industries differ in whether they benefit from these two kinds of investments. The separation of various industries is a first step. More detailed analyses might help to specify the relevant characteristics of firms and to give advice to policy makers about how respective programs could be focused adequately.

RQ2 deals with the existence and the emergence of complementarities and the spatial embeddedness into cooperation networks over time (WP2). *Chapter 4* contains the corresponding analysis. This investigation contributes to the effect of cooperative and non-cooperative R&D subsidies on firm growth. For the empirical analysis, an unbalanced panel of 2.199 German manufacturing firms covering the time period from 1999 to 2009 is used. A dynamic panel estimation technique is employed to control for growth autocorrelation as well as for endogeneity. The study's outcome suggests that non-cooperative R&D subsidies have a stimulating impact on large firms' employment growth. In contrast, being engaged in many subsidized cooperations leads to significant growth reduction. In case of large firms, one exception is the subsidized cooperation with geographically distant firms, which can positively influence employment growth. For small firms, interactions with research organizations are found to rather facilitate their development. This work particularly contributes to the existing literature by differentiating between cooperative and non-cooperative R&D subsidies, which are shown to have distinct effects. Moreover, the firms' spatial embeddedness into subsidized cooperation networks is evaluated with respect to its importance for employment growth. Concerning the empirical results the author does not find any indication that the granted amounts of R&D subsidies matter. All observed significant effects relate to the number of subsidized projects a firm is engaged in. Neither the total amount of received subsidies, nor the size of subsidized project is found to impact firm growth. For a policy evaluation, the findings imply that the effectiveness of programs is less related to the invested resources, but to the actual specification of the program in terms of the number of supported projects, their cooperative character, as well as the particular types of cooperations which are supported. Evidence shows that the number of subsidized non-cooperative projects a firm is involved in can stimulate its growth, at least in case of large firms. This implies that policy should rather initiate a great number of small projects instead of focusing the monetary support on a few large-scale projects. Interestingly, it is found that the number of subsidized cooperative projects a firm is engaged in is related to significant negative effects on the firms' employment growth. This finding contrasts the growing occurrence of this type of subsidies in recent years. However, the results provide some evidence for complementarities, i.e. if subsidies for cooperation aim at supporting interactions between firms and research organizations they can yield positive effects. The same is true when subsidized joint projects connect large firms to other firms located at larger geographical distances. Accordingly, this study highlights the importance of the respective design of R&D support policies. Clearly a "one size fits all" approach to R&D subsidies programs will yield suboptimal results. It can very well be argued that R&D subsidies primarily aim at enhancing the firms' innovative capacities, but these do not necessarily influence the firms' employment growth.

RQ3 highlights the importance of firm-external factors and their spatial relatedness as well as their internalisation. This question embodies the main part of this thesis and is captured in chapter 5, 6 and 7 of WP3. *Chapter 5* places growth relevant knowledge spillover processes in a concrete space. Instead of imposing artificial and arbitrary regional delimitations and constructing imprecise measures of the available regional knowledge, the author looks at the exact geographical point locations of firms and their economic distance to different external sources of potential knowledge dissemination. This allows estimating the distance-weighted contribution of geolocated external factors to the growth of firms. As a main conclusion of the analysis it can be stated that both, other related firms and universities, are associated with firm growth. Moreover, it is revealed that the impact of external knowledge sources fundamentally depends on firm size, varying between median (or only slightly) growing, strongly shrinking and strongly expanding firms. More precisely, the author finds that a highly specialized agglomeration 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. Furthermore, the empirical results suggest that firms require a certain size and thus absorptive capacity to be able to benefit from academic research activities. For large firms, research activities in the direct firm surrounding tend to have a strong risk reducing character. As an overall conclusion it can be stated that usually the empirical studies use entities such as regions or labour market regions that might be too large for detailed information on the firms' internalisation process of external knowledge. Hence, using the exact geographical locations of firms and their economic distance provides detailed information on the behavior of firms regarding their internalisation procedure of external knowledge.

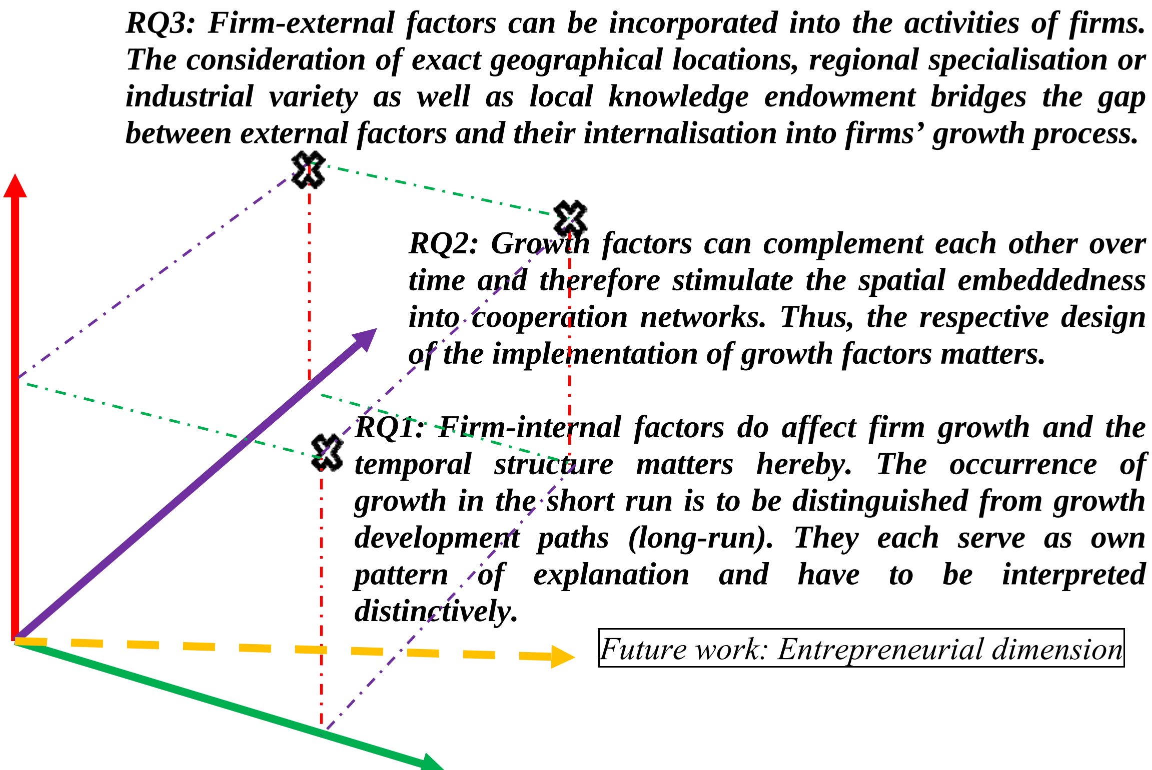
Chapter 6 This chapter examines the contribution of specialisation and industrial variety to employment growth and therefore highlights the controversial discussion about Marshallian (technical) externalities (i.e. specialisation) and Jacobian externalities (i.e. diversification). Usually, the impacts of regional factors on regional aggregates are studied without explicitly considering the firm-level. By contrast, this study focuses on the direct effects of regional characteristics on employment growth, especially the impact of localisation economies and Jacob's externalities. The empirical analysis employs a panel of German firms which is derived from the Creditreform Markus database covering the time from 2003 to 2011. A regression with a cross-sectional time series estimation technique is applied. Our findings show that Jacob's externalities in terms of unrelated variety are likely to dampen average employment growth in SME but this effect disappears and even becomes a positive outcome as we control for year-to-year employment growth. Contradicting, related variety strongly stimulates employment growth in SME. Furthermore, we find that the probability to detect a positive effect of localization economies (Marshall's externalities) increases as the level of industrial classification becomes narrower (3-digit and 4-digit). Otherwise, the probability to perceive a negative impact of Marshall's externalities increases as the industry aggregation gets more broadly defined. Finally, employment growth of larger firms is positively influenced by being well connected to KIBS, while the positive effect of being well embedded into high population density does only hold for SME.

Chapter 7 analyses the contribution of local knowledge endowment to employment growth in nanotechnology firms. The author applies a unique data set focusing on firms operating in fields applying nanotechnology. Nanotechnology firm growth is influenced by the locations hosting the firms. More particularly, it is examined whether the local endowment with knowledge influences the growth of these firms. As expected in terms of nanotechnology firms operating on an innovation and hence, knowledge intensive high technology fields, the performance of these firms is – in general – stimulated by the local access to (higher) knowledge. However, the actual impact of knowledge varies across firms with different characteristics. While the share of highly qualified employees never hampers growth (although it seems not to advance it either in e.g. larger firms), the local stock of employees concerned with R&D indeed has a hampering effect. This is interpreted as a hint for the need of the knowledge to be marketable. However, this might also be interpreted as the inefficiency of knowledge transfer from universities to technology. Finally, knowledge is as relevant for nanotechnology firms as for other highly knowledge intensive firms, regardless of the peculiarities a general purpose technology (GPT) implies: Nanotechnology firms rely as much on knowledge spillovers as other high-tech (but not GPT) firms from other industries. The impact, however, depends on knowledge processing characteristics like it is the case in other industries. Moreover, the impact of knowledge for nano-firm growth also depends on the characteristics of knowledge itself. The author therefore sets out to investigate the special influence of specialisation of the regional knowledge base. When analysing average employment growth rates, the impact of specialisation is counterproductive to some firms, while it has no effect on growth for other firms. In the year-to-year consideration, however, regional specialisation only has a negative effect in extreme situations.

Although these results differ, it becomes clear that specialisation does not have a positive effect on firm growth in nanotechnology. The relevance of these effects has, however, to be seen in context with the special characteristics of nanotechnology as a general purpose technology and as a high technology. The main conclusion of this study is that local knowledge endowment indeed influences firm growth in nanotechnology positively, while local knowledge specialisation is surely not always positively affecting the growth of individual firms. This point leads to the relevance of nanotechnology as a GPT in terms of processing knowledge in firms.

Figure 8.1 illustrates the comprehensive multidimensional approach of firm growth and stresses the concluding remarks drawn in section 8.1. The investigation shows that the expected underlying growth processes can be seen as a heterogeneous procedure with a high complexity as well as with individual characteristics. It is therefore confirmed that three different dimensions play a substantial role in the context of firm growth. The empirical studies demonstrate the dynamics, interrelationships and linkages between the diverse components. For this reason, three major conclusions can be drawn from this work; so that the thesis is concluded with three general remarks (see Figure 8.1) and highlights the importance of the respective design of R&D support policies.

Figure 8.1 Main conclusions and future work



Source: Own illustration (2012)

8.2 Future work

In this work, a multidimensional approach for modelling and understanding firm growth processes is presented. However, the research findings and results should therefore be conducted. Obviously, it is possible to include additional components and dimensions which might contribute to firm growth. Therefore, future tasks and further research could focus on the following ideas: The identification of further components and dimensions (see Figure 8.1) of firm growth processes could be useful to consider (e.g. entrepreneurial dimension). Usually, the impact of firm characteristics on firm growth is studied without explicitly considering the entrepreneurial dimension such as entrepreneurial aging. Therefore, further studies should especially focus on entrepreneurial characteristics which influence firm growth. The implications of demographic aging for economic growth and regional disparities are repeatedly studied (e.g., Ludwig 2005). However, the age distribution of the population (i.e. aging of the employees and entrepreneurs) might be important for firm activities as well (e.g. Lévesque and Minniti 2005). Actually, too much emphasis is put on the macro-economic effects of demographic aging and too little emphasis is put on micro-economic effects such as firms' growth activities. Furthermore, entrepreneurial issues should be studied. First, entrepreneurial activities and competencies can influence firm growth in different ways. For example, it can be expected that younger and older entrepreneurs and employees work differently and, as a consequence, engender different strategies and competencies which effect firm growth. However, the type of the entrepreneurial strategies and competencies is quite unclear. Second, it can be expected that some firms do not show any impact of entrepreneurial aging on firm growth, meaning that firms usually remain completely independent of the age distribution of the entrepreneurs and employees. As such, studying these relationships across different firm sizes, one can observe different relationships implying that, on average, smaller and larger firms operate on different frequencies. The aim should be to obtain a clearer picture of the impact of entrepreneurial aging on firm growth. Further studies should try to understand why individuals offer and enable different strategies and competencies to the firm. Also, the important implications of the phenomenon of entrepreneurial aging should be highlighted. In addition, one might also examine the overall impact of the demographic aging itself, because it is impossible to explicitly study the entrepreneurial structure without this knowledge.

The thesis also shows that still, more research on the time structure of growth processes is needed. Especially the long-run structure of the effects of R&D investments on growth needs to be examined further on an industry-specific level. In this respect, using longer time series than the ones available for this thesis is recommendable. Further research is needed on the questions of how to measure the productivity of intangibles and how external intangibles can be internalised by firms. Our future work is to explore the reasons why firms that are engaged in R&D activities perform better than other firms and why particularly the high growth firms appear to be more engaged in R&D activities. In addition, future work could investigate different innovation indicators such as product and process R&D separately. Product and process innovations can be assumed to have very different impacts on firm growth. Furthermore, there is a need for qualitative research in this research area. It is important to learn more about the motives for innovation activities and how the impact on firm growth depends on these motives. Case studies could be a very helpful tool for this. Simultaneously, it appears necessary to take a look at the methodology and econometric techniques. Furthermore, it seems likely that significant inter-industrial differences and complementarities exist in terms of the effectiveness and relevance of R&D subsidies. For instance, R&D subsidies are likely to be of larger importance in research-intensive industries. In this thesis, the employed data only covers support programs by the German Federal Government. Support from inter-national organizations (e.g. the EU) might have very distinct effects which are not considered in this study. The same might be true for programs initiated at the sub-national level (regions, districts, cities, local authorities). These issues clearly outline the path for future research. Furthermore, the age of firms seems to be strongly related to firm growth, empirical literature mostly neglects or incorrectly substitutes it by size. The author expects that the impact of external knowledge sources also depends on firm age, however, more work has to be done with respect to identifying reasonable age groups. Firms of different industries could be analysed separately, because there are strong arguments implying that the spatial range and functional form of knowledge spillovers differ substantially across industries. More sophisticated matrices should be used to assess true technological relatedness. Additionally, further research should also be done on the effect of specialisation in a larger sample or other (GPT) settings to confirm these results, especially in view of the findings stating a positive effect of specialisation for many other, but different circumstances and industries. Moreover, it lies beyond the scope of this study to investigate the mechanisms behind the findings. It would be interesting to learn how exactly local knowledge is processed, where spillovers are indeed effective and how specialisation exactly affects innovation in high-technologies.

More information about the complementarities and their effects are necessary in order to enhance detailed results and to obtain more insights into the indirect effects of growth related factors and knowledge sources. In particular, the question arises whether the impact of a firms' position within a network implies any knowledge complementarities and whether it matters with which types of organisations they cooperate with. The gained knowledge would be an additional, valuable achievement for understanding the complexity, heterogeneity and idiosyncrasy of firm growth.

Finally, firms' growth properties are important features of the dynamics of regional growth because firms can be seen as economic entities at different levels of aggregation. Instead of looking at the micro-level of firms (e.g., Stanley et al. 1996) and at the macro-level of countries (e.g., Castaldi and Dosi 2009) it would be very interesting to highlight the meso-level of spatial aggregation or merely the distribution of economic activities across regions (e.g., Duschl and Brenner 2012). The dynamics of regional growth might be fundamentally driven by the aggregation of firm growth rates. If we know more about the stochastic properties of firms' growth rates (e.g., extreme growth events) one would be able to reconstruct regional backward linkages and the possible multiplier effect in the local and regional economy (e.g., Erickson 1974). This book is a first step in this direction.

8.3 Policy implications and recommendations

This thesis investigates how firm-internal factors impact firm growth and how firm-external factors (respectively spatial knowledge sources) can be incorporated and internalised into firm activities. Being interested in how particular company features influence firm growth processes, empirical examinations are accomplished in the context of firm growth as showcase examples. Relevant and appropriate policy implications can only be derived for particular firm cohorts (e.g. SME, large-sized firms), while in general, policy implications for firm support might fail to have a growth-sustaining impact. Hence, the implementation of policy instruments comes along with the desire to regulate specific activities across different firm cohorts. With respect to the comprehensive presented in this book, different firm groups can be determined requiring specific policy instruments. It is distinguished between policy instruments fostering SMEs and larger firms, whereas policy implications would be necessary to support growth-enhancing factors which are internal or external to the firm. Based on the findings in this book, Figure 8.2 summarises particular firm features and their specific needs and requirements.

Figure 8.2 Policy implications and recommendations

	Firm-internal factors (i.e. innovation-economic aspects)		Firm-external factors (i.e. spatial aspects)		
	Innovation/ R&D activity	Export orientation	Public Funding/ R&D subsidies	Interaction with other actors	Local knowledge endowment
small-sized	o	o	o	+	+
medium-sized	o	o	o	+	+
large-sized	+	+	+	+	-

o: no significant impact; +: significantly positive impact; -: significantly negative impact

The current policy on small and medium-sized enterprises (SMEs) creates a coherent, pragmatic and horizontal framework for these enterprises. It aims to unlock the vast untapped potential of SMEs to create growth and employment within the European Union. Due to the promotion of entrepreneurship, improved access to internal and external markets, the improvement of their growth potential (employment growth) as well as their effective partnerships with SME stakeholders (e.g. cooperation networks) SMEs are going to become more competitive and innovative. More precisely, SMEs are very heterogeneous and consequently, they differ in their needs (for example manufacturing or service firms). Some of them experience stagnation or even decline paths, while others experience high growth rates. Some are active in different technology fields and markets, others in local or regional markets. In order to unlock the growth potential of SMEs as a whole, policies and action to support them need to reflect this diversity.

According to the European Commission (2006), the success of effective policy instruments depends on the effective involvement of important SME needs and requirements. Therefore, specific actions are proposed for different key areas. First, special attention should be paid to the promotion of the regional knowledge base and the reduction of access gaps to new knowledge (from different industry fields). Knowing that related variety strongly stimulates employment growth in SME, policy should aim at stimulating thematic networks and linkages bringing together a variety of partners (i.e. firms) around a given objective so as to facilitate coordination activities and the transfer of new knowledge. Furthermore, it is revealed that the impact of external knowledge sources fundamentally depends on firm size. More precisely, it can be stated that a highly specialised agglomeration rather hampers the growth of large firms, but boosts the growth of small firms. Being closely located to more diverse, but yet related firms is conducive for both small and large firms. Moreover, regional cluster policies (i.e. related and unrelated industrial classes) should promote and stimulate strategic partnerships of firms, universities and higher education institutes in order to foster and strengthen an efficient and sustainable market strategy of SMEs. Just to name an example, the high-performance cluster *NanoChance* intends to foster strategic partnerships between business and science. The aim is boost high potential nanotechnology firms (for more information see BMBF 2011a). Second, improving and providing support to particular project funding (e.g. R&D subsidies) and enabling easy access to public authorities (e.g. public ministries) might contribute to the growth in the number of SMEs. European Commission

(2006) states that "financial support initially provided at Community level by the Multiannual Programme for Enterprises and Entrepreneurship (2001-2006), has now been increased by the Competitiveness and Innovation Framework Programme (CIP) (2007-2013). It is also vital to strengthen SMEs' capacities for research and innovation, as continued innovation is essential for the sustainable development of SMEs. SME involvement in the 7th Research Framework Programme will thus be facilitated". In many instances, subsidy programs are precisely designed to stimulating cooperation between particular types of organisations. To name an example, the German *BioRegio* program provides subsidies for cooperation in R&D projects that are formed between organisations located within the same geographical region (e.g. Dohse 2000). This particularly concerns the importance of cooperation between different types of organisations (universities, research organisations, firms), which we find to vary strongly between small and large firms. Likewise, the discussion on Cluster policy comes into focus. The concept of regional clusters systematically picks up this proximity-productivity relationship systematically thereby relying on specific economic activities and has become a popular policy measure. While a cluster always refers to a specialised network of firms and institutions there is no finally accepted definition of industrial clusters. Porter's considerations however, might be seen as representing the standard concept (Martin and Sunley 2003). Porter (2000 p: 254) defines cluster as "geographically proximate group of inter-connected companies and associated institutions in a particular field that is linked by commonalities and complementarities". As a positive external knowledge spillover they increase their productivity and economic performance. There is, indeed, evidence that firms in clusters reach higher levels of innovation (Moreno et al. 2004; Fromhold-Eisebith and Eisebith 2005). The basic reasoning behind specialisation or industry-specific advantages being relevant for the efficiency of local innovation activity implies that local agents can share the same assets and can benefit from goods and services provided by specialised suppliers as well as from a local labor market pool (Marshall 1890). The cluster environment provides not only a stronger pressure to innovate, but also a richer source of relevant knowledge and ideas as well as lower costs for innovation commercialisation (Ketels 2009). Cluster strength is hence considered a determinant of prosperity differences across space. As a clustered industry indicates that there are significant benefits from co-location, the industry's productivity is assumed to increase with the level of specialisation within the cluster. In the light of this, knowledge diffusion will occur when firms are embedded in more specialised environment (Marshallian externalities) or in regions that are more diversified (Jacobian externalities). More precise, the assumed relevance of clusters hence refers to the characteristics of local knowledge and suggests that specialised local knowledge has a particularly positive effect on innovation and firm growth. Third, more systematic cooperation and consultation with stakeholders is an essential guideline of the new SME policy. When policies are being developed, SMEs will be consulted by the Commission's SME Envoy or the "SME Panel", a new quick-and-easy mechanism for the consultation via the Enterprise Europe Network (European Commission 2006). Fourth, the recent situation in Germany and most of the European Member States can be characterised by the general absence of specific policies that exclusively address internal R&D activities in small- and medium-sized firms. Supporting the acquisition of tangible (R&D capital expenditure) and intangible assets (R&D expenditure), including firm internal innovation activities, should be eligible to enhance growth. As a main result of this book, it can be stated that firm-external factors and knowledge sources result in knowledge spillover and growth in SMEs (e.g. Boschma and Iammarino 2009). To put it differently, firm-external factors and knowledge sources are responsible for employment growth in SMEs (see Table 8.2). It appears in this thesis that regional framework conditions need to be taken into account when stimulating and supporting growth in SMEs. By positioning the regional knowledge base and spatial characteristics similarly, a sustainable, idiosyncratic and multidimensional approach to firm growth in SMEs could be established.

On the contrary, the results suggest that larger firms invest more in R&D (i.e. firm internal factors), and therefore are more innovative (positive outcome in terms of turnover growth), than smaller firms (see Figure 8.2). One explanation is that large companies often benefit from economies of scale, which lowers the costs per unit produced. In addition, larger companies often exert market power, which means that they can sell their products above marginal costs. This results in positive profits and positive linkages between export orientation and growth. As a result, large firms have the possibility to reinvest their profits into growth-enhancing and firm-internal factor (such as R&D expenditures) and sources contributing to firm growth. Therefore, compared to smaller firms, large firms are often highly focused on firm-internal strategies, which indicates that their profits are lower or that they just break-even. SMEs have fewer opportunities to invest in R&D, simply because they have fewer resources to invest. For smaller firms it is not taken for granted that their profits are reinvested into R&D activities which might lead to growth in the following years (Coad 2009). Additionally, large firms might have incentives to innovate because they are better able to capture the benefits of the R&D programs (as discussed above) and because they are more likely to experience market power (Gilbert 2006). Policy towards larger firms should therefore analyse the 'winners' and learn from them. There should be a focus on innovation agencies supporting innovation activities of potential firms. This leads to an optimal use of strategic and innovative use of resources. Additionally, the main task should be to target and to receive sustainable growth. Another important issue is that collaboration, cooperation and networks are of much importance for larger firms as well as public funds and financial support for R&D projects. Put differently, firm-internal factors as well as firm-external knowledge sources are simultaneously responsible for growth in larger firms and should therefore be considered likewise. However, the results of this thesis indicate that intra-regional collaborations (i.e. local knowledge endowment) are less conducive for larger firms than for SMEs (see Table 8.2), but there are two sides of the coin. Thus, supporting industrial giants, i.e. larger firms, could lead to promising regional developments because they are in turn beneficial for the local knowledge endowment of the respective region.

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Erklärung

(gemäß §10, Abs. 1 der Promotionsordnung vom 15. August 2006)

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München, den 09.10.2012

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