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# Exploring the knowledge filter: How entrepreneurship and university-industry relationships drive economic growth

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Contents

## Abstract

Knowledge is recognized as a crucial element of economic growth in addition to physical capital and labor. Knowledge can be transformed into products and processes and is, in this way, exploited commercially. The ability to produce, identify, and exploit knowledge depends on the existing knowledge stock and the absorptive capacity of actors such as employees at firms and researchers at universities and research institutions. The existing knowledge stock might not be commercialized to its full extent; therefore, knowledge flows must occur and transmission channels are needed. The paper tests the hypotheses that entrepreneurship and university-industry relations are vehicles for knowledge flows and, thus, spur economic growth.

JEL classification: M13, O18, O31

Keywords: Regional growth; regional development, Knowledge; Entrepreneurship, university-industry relations.

## Zusammenfassung

*“Der Knowledge-Filter: Wie Entrepreneurship und Forschungskooperationen zwischen Universitäten und Unternehmen wirtschaftliches Wachstum beeinflussen“*

Neben physischem Kapital und Humankapital beeinflusst Wissen das wirtschaftliche Wachstum. Wissen fließt in neue Produkte, Dienstleistung und Produktionsprozesse ein. Das verfügbare und bereits generierte Wissen gemeinsam mit der absorptiven Kapazität von Forschern in der Privatwirtschaft und Forschungseinrichtungen sind wichtig für die Generierung neuen Wissens und dessen Anwendung. Weil bestehende Unternehmen oftmals nicht den gesamten Bestand an Wissen nutzen, entstehen Kommerzialisierungsmöglichkeiten für neue Unternehmen. Zusätzlich wird das Wissen aus Hochschulen und Forschungsinstituten nicht automatisch kommerzialisiert, hierfür sind Wissenstransferkanäle notwendig. Dieser Aufsatz untersucht, inwiefern Unternehmensgründungen und Forschungskooperationen zwischen Unternehmen und Hochschulen einen Beitrag für den Wissenstransfer leisten können und das wirtschaftliche Wachstum positiv beeinflussen.

JEL Klassifikation: M13, O18, O31

Schlagworte: regionales Wirtschaftswachstum, regionale Entwicklung, Wissen, Unternehmensgründungen, Forschungskooperationen.

## 1. Introduction

It is important to understand why regions post different growth rates. Labor and physical capital certainly are important sources of economic growth, but knowledge creation, flows, and capitalization are also important elements in stimulating economic development. Recent empirical studies (Plummer and Acs, 2005; Acs and Varga, 2005; Audretsch and Keilbach, 2004a, 2004b; Varga and Schalk, 2004) have shown that knowledge spillovers positively affect technological change and economic growth. An earlier study by Glaeser et al. (1992) found evidence that growth in cities is promoted by local competition and by a great level of diversity. Entrepreneurship is a possible vehicle to increase the level of industrial diversity and to affect local competition by challenging incumbent firms. Historic industrial diversity promotes a diversified skill base which allows new high-tech industries to utilize these skills and profit from them (Henderson et al., 1995).

This study focuses on the commercialization of knowledge, which is understood as the transformation of knowledge into products, processes, and organizations and their contribution to regional economic growth. Different factors may explain why the degree of knowledge commercialization varies across regions. One explanation could be differences in the amount of research and development activities across regions. Research and development is crucial for the ability to identify, absorb, and exploit internally- and externally-generated knowledge created by other firms or research institutions (see Cohen and Levinthal, 1989). Therefore, a low level of research and development in a region may not just result in a lower level of absorptive capacity but also in a lower degree of knowledge exploitation in these regions.

Another reason may be underexploited knowledge: incumbent firms do not exploit new knowledge to the full extent, or knowledge generated in research institutions and universities is hardly commercialized at all. Consequently, knowledge flows are necessary for other actors to exploit the new knowledge. Entrepreneurship and university-industry relations may function as mechanisms for knowledge flows as well as the commercialization of knowledge.

This paper analyzes regional economic performance by using a production function approach similar to Audretsch and Keilbach (2004a). One contribution of this study is the examination of a cross-sectional time series, which allows controlling for unobserved heterogeneity between the regions. A second contribution is that university research and its utilization by private businesses are also considered. The results of the econometric analysis suggest that regions with a high level of entrepreneurship and university-industry relationships experience greater productivity, and consequently, economic growth. In particular, both start-ups in innovative industries and university research in engineering science foster economic growth. The remainder of this paper is organized as follows. Section 2 presents the theoretical framework and links the channels of knowledge flows to economic performance. Section 3 describes the methodology and database. The relationship between economic performance and entrepreneurship and university-industry relations is empirically tested in section 4. Section 5 provides a summary and a conclusion.

## 2. The Capitalization of Knowledge and the Importance of Knowledge Flows

Although knowledge is understood as an essential driver of economic growth, it is hardly linked to growth in empirical analyses. The new growth theory proposed that knowledge stimulates technological progress, thereby increasing productivity. Romer (1986, 1990) and Lucas (1988) explained economic growth through the accumulation and spillover of technological knowledge. New knowledge is a crucial input factor for innovation and is commercialized by transforming it into new products, processes, and organizations. Research and development activities are a vehicle for private businesses, universities, and other research institutions to generate new knowledge. Firms face the decision to carry out research and development by themselves; engage in research alliances with other firms, universities, or government laboratories; contract out specific research and development projects; and recruit researchers and scientists from other firms or research institutions (Bercovitz and Feldman, 2005; Arundel and Geuna, 2004). Therefore, not only the knowledge-producer but also other organizations such as private and public businesses, research institutions, or universities can also apply and commercialize the newly generated knowledge. Whereas the other organizations are usually in the same industry or discipline, they may also be in related or different industries or disciplines. However, the possibility to exploit knowledge from the environment particularly requires it to flow. Knowledge spillovers allow other economic actors to exploit the newly created knowledge as well as resulting in an acceleration of economic growth. Cohen and Levinthal (1989) conclude that research and development activities not only generate innovations but also increase the firm's ability to identify, assimilate, and exploit externally created knowledge (see also Cohen and Levinthal, 1990; Zucker et al., 1998). This indicates that the higher the level of research and development activities, the greater the level of absorptive capacity as well as the pool of knowledge that can be exploited.

The created knowledge may be underexploited. One explanation may be that incumbent firms do not want to take the risk combined with new products or processes. They might focus on exploiting the profit possibilities of their given product program, and they are not interested in searching for new opportunities and realizing them (Audretsch, 1995; Geroski, 1995). Furthermore, the deployed technology, the factual production capacity, or the availability of qualified human capital may also affect the exploitation of knowledge. Even if firms do not commercialize knowledge to the full extent, patenting or secrecy may be an effective tool in order to protect intellectual property and to hinder knowledge spillovers (Cohen et al., 2002a). Cohen (2005) suggests that patents are not as important as secrecy, lead time, and complementary capabilities, which are the key mechanisms for appropriating returns to innovations in most industries. Patents only play a critical role in a small number of industries, in particular drugs and medical equipment; other industries use the other mechanisms to protect innovations (see also Arora et al., 2004).

Underexploited knowledge also results if research carried out at universities and research institutions is hardly translated into new products or services (Pavitt, 2001). The two primary missions of universities are research and teaching and not specifically the capitalization of their generated knowledge. A direct contribution to the industry via research alliances with firms as well as an active strategy in extending the research process into the development process are, possibly, a third mission of universities (Etzkowitz and Leydesdorff, 2000; Etzkowitz, 1998). Therefore, possible vehicles for the commercialization of academic research are university-industry partnerships or the creation of university spin-off companies (Rosenberg and Nelson, 1994; Hall et al., 2003; Arundel and Geuna, 2004; Meyer, 2003; Di Gregorio and Shane, 2003; Meyer-Krahmer and Schmoch, 1998). The importance of academic research was also underlined by Mansfield (1998) as well as by Beise and Stahl (1999). They concluded that a part of new products and processes could only be developed because of academic research and would have been substantially delayed otherwise.

Furthermore, different studies suggest that knowledge spillovers depend on a strong regional component, thereby taking advantage of spatial proximity to research facilities, universities, and industry specific agglomerations (Jaffe et al., 1993; Anselin et al., 1997, 2000; Audretsch and Feldman, 1996; Glaeser et al., 1992; Henderson et al., 1995). Analyzing patent citations, Jaffe et al. (1993) found that knowledge spillovers from academic research to private industries have a strong regional component. Arundel and Geuna (2004) found that proximity is important for the use of public science. Spillovers from university may also affect firm growth (Audretsch and Lehmann, 2005). The closer that firms are located to a university and the higher the number of academic papers published at this university, the higher the growth rates for these firms are. The argued explanation for the regional localization of knowledge is usually the tacit nature of knowledge, which is obtained via direct, interpersonal contacts (Anselin et al., 1997, 2000; Maskell and Malmberg, 1999; Hippel, 1987; Senker, 1995). As long as there is a delay between the discovery of knowledge and its codification, the premier mechanisms for knowledge flows are interpersonal interactions (Arundel and Geuna, 2004). Firms are then able to access knowledge faster and more successfully and are more likely to know where to access new knowledge via local, direct, and interpersonal contacts. A study by Meyer-Krahmer and Schmoch (1998) showed that informal contacts also have a high value for academic researchers. University researchers ranked collaborative research and informal contacts as the two most important interaction types between universities and industry. According to in-depth interviews, both interaction types are characterized by a high degree of bi-directional exchange of knowledge.

Acs et al. (2005) develop the concept of a knowledge filter, which functions as a barrier limiting the total conversion of knowledge into new products, processes, and organizations. Thereby, knowledge is transformed into economically useful knowledge by either incumbent firms or start-ups. Incumbent firms learn, increase their absorptive capacity, and incorporate new knowledge into their firm-specific knowledge; thus, they absorb knowledge spillovers. New ventures are assumed to be the mechanism to transmit knowledge and transform it via knowledge spillovers into economically relevant knowledge. Nevertheless, their concept does not account for universities as knowledge-producers and university-industry relations as a mechanism for knowledge spillovers. Entrepreneurship as well as university-industry relations are proposed as possible transmission channels for knowledge. It is assume that they penetrate the knowledge filter, thereby stimulating the commercialization of knowledge. Furthermore, these two determinants in addition to research and development activities may, particularly, explain why regions post different growth rates.

Entrepreneurial activity, taking the opportunity and setting up a business, is one possible mechanism in which knowledge spills over and the capitalization of knowledge occurs. Founders of the new ventures might have worked for incumbent firms or universities before they commercialize the new knowledge, thereby inheriting knowledge from their former employer. Innovative start-ups may introduce new products or even create new markets. According to Audretsch (1995), many radical innovations have been introduced by new firms rather than by incumbents. Studies on spin-offs found that frustration with the (former) employer as well as the expectation of greater financial rewards are reasons that cause individuals to leave their employer and lead them to create their own firm (Garvin, 1983; Klepper and Sleeper, 2005). Starting a firm might be the most promising or even the only possibility to commercialize knowledge (Audretsch, 1995). Particularly, frustration may arise among the scientists and engineers if their ideas about a new product or process are rejected by their employer (see Garvin, 1983 for examples). According to Agarwal et al. (2004), existing organizations with abundant underexploited knowledge represent seed-beds for spin-offs. Employee mobility and spin-offs are important vehicles for the diffusion of knowledge in technology- or knowledge-intensive industries. This pattern can be observed in the laser industry, disk drive industry, tire industry, and the wireless telecommunication industry (Klepper and Sleeper, 2005; Buenstorf and Klepper, 2005; Agarwal et al., 2004; Dahl et al., 2003; Sull, 2001; Franco and Filson, 2000; Christensen, 1993).

University-industry linkages are proposed as the second mechanism facilitating the exploitation of knowledge and the flow of ideas (Mansfield and Lee, 1996; Fritsch and Lukas, 2001; Arundel and Geuna, 2004; Meyer-Krahmer and Schmoch, 1998). Interactions between universities and industry are recognized to increase the rate of innovation in the economy and many governments have taken up the cause of enhancing these research alliances (Cohen et al., 2002a; Spencer, 2001; Laursen and Salter, 2004). According to the European Commission, firms in Europe especially fail to commercialize new knowledge generated in universities and other public research institutions in comparison to their U.S. counterparts (EC, 2001; Arundel and Geuna, 2004). Unsurprisingly, public research hardly results in ready-to-produce innovations; however, if the generated knowledge is transferred via research alliances it may accelerate technology transfer and enable firms to develop new products and processes (Cohen et al., 2002a; Spencer, 2001; Mansfield, 1991, 1998; Rosenberg and Nelson, 1994).

The types of university-industry relations amongst others may include informal information sharing among research partners, one-on-one research ventures, contract research on solving a specific problem of firms, or seminars for industry (Hertzfeld et al., 2005; Meyer-Krahmer and Schmoch, 1998). Arundel and Geuna (2004) found that Europe’s largest firms mainly assess public research output by hiring trained scientists and engineers, through informal personal contacts, by contracting research out to public research organizations, and through joint research projects. Analyzing the influence of public research on industrial R&D in the U.S., Cohen et al. (2002b) found that the dominant channel of knowledge transfer was publications and reports followed by informal exchange, public meetings or conferences, and consulting. Businesses rated contract research, cooperative ventures, patens, and hiring graduates as moderately important. However, they only included those firms with R&D laboratories in their study. Scott (2003) points out that firms use research alliances with universities as a vehicle to expand and complement their absorptive capacity. Especially firms that have downsized their research and development facilities may benefit from linkages with universities (Adams et al., 2001). Additionally, small ventures use collaborative research with universities or research institutions to obtain access to R&D inputs (Audretsch and Feldman, 1996). On the contrary, Czarnitzki and Rammer’s (2000) study on Germany suggests that firms with fewer than 500 employees use less knowledge from universities and research institutions than large firms. In manufacturing, only 11 percent of the small firms draw knowledge from publicly funded research institutes compared to 24 percent of large firms. Moreover, universities are used more often as a source of knowledge than other research institutions such as Fraunhofer Gesellschaft or Max Planck Society. Laursen and Salter (2004) found that firms which frequently draw from externally generated knowledge are also more likely to use universities as a source of knowledge (see also Bercovitz and Feldman, 2005). Therefore, university-industry research partnerships are transmission channels for both small and large firms to generate, receive, apply, and commercialize knowledge.

## 3. Data and Methodology

In order to test the hypothesis that entrepreneurship and university-industry relations stimulate economic growth, a Cobb-Douglas production function is employed in order to estimate regional economic performance for the West German regions between 1992 and 2002 (in the style of Audretsch and Keilbach, 2004a). The analysis is restricted to West Germany because East Germany can be regarded as a special case with very specific conditions not comparable to the West in the 1990s (Fritsch, 2004; Kronthaler, 2005). One important contribution of this paper is the analysis of panel data, hence, the consideration of the cross-section and time-series dimension. The spatial analysis is on the level of planning regions, which usually consist of a core city and the surrounding counties. There are at least two reasons to use the spatial concept of planning regions. First, they account for the economic interaction between the counties and cities. Secondly, most universities in Germany are located in cities. The spatial concept of planning regions takes into account that adjacent districts without a university benefit from research carried out at universities in the same planning region.[1]

The following model is employed to analyze the impact of capital, research and development, entrepreneurship, and university-industry relations on economic performance:

$$\ln\left(Y_{it}/L_{it}\right) = \alpha_1 \ln\left(K_{it}/L_{it}\right) + \alpha_2 \ln L_{it} + \alpha_3 \ln RDI_{it} + \alpha_4 \ln RDP_{it} + \alpha_5 \ln E_{it} + \alpha_6 \ln UI_{it} + \alpha_7 AGG_{it} + \varphi_{it} + \mu_i + \nu_{it}$$

The parameter $\alpha_1$ represents the elasticity of capital intensity. An additional term on labor is included in the model to test for deviation from the case of constant returns to scale (parameter $\alpha_2$), which proves to be significant. The output elasticities of R&D in private businesses (*RDI*) and in universities (*RDP*) are measured by the parameters $\alpha_3$ and $\alpha_4$. The impact of entrepreneurship (*E*) and university-industry relationships (*UI*) is measured by the parameters $\alpha_5$ and $\alpha_6$. The model includes population density (*AGG*) as

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1 Although polytechnics (also called universities of applied science or *Fachhochschule* in German) are located in smaller cities and rural areas, they receive very little in the way of grants from private businesses. Only one planning region does not have a university or a polytechnic. Grants from industrial sources do not exist in about ten percent of the planning regions. This is often due to the fact that music conservatories and art schools rarely receive research grants from private businesses. There are a few examples of universities that did not receive any grants.

a control variable. Population density is meant to control for agglomeration externalities, e.g., the proximity to universities and research institutions, availability of human capital and highly skilled employees. The subscript $i$ denotes the planning regions in West Germany and $t$ denotes time, namely 1992 to 2002. The fixed-effect estimator allows controlling for the unobservable regional specific effect ($\mu_i$). The regressions estimate the heteroscedasticity-robust standard error. Additionally, the regressions control for spatial autocorrelation by including the average residuals of adjacent regions ($\varphi_{it}$). However, the coefficients of the other variables hardly change if this control variable is not included in the models. This might indicate that the concept of planning regions already account for spatial interaction and spillovers.

Regional aggregate output $Y$ is measured by regional gross value added of all industries (at constant 1995 prices). The physical capital stock $K$ is estimated with gross fixed capital formation (investments, at constant 1995 prices) following the perpetual inventory method (see also Audretsch and Keilbach, 2004a or Audretsch et al., 2006).[2] Due to confidentiality, the gross fixed capital formation of some districts is not reported; therefore, two planning regions had to be excluded from the analysis. Labor $L$ is measured by the number of employees. The establishment file of the German Social Insurance Statistics provided the number of employees in each region. The number of employees does not comprise civil servants, army personnel, or self-employed because they are not obliged to contribute to the social insurance system. Only employees in public and private businesses must be reported to the Federal Employment Office for enrollment in the social insurance system (for details see Fritsch and Brixy, 2004).

The share of employees devoted to research and development in the private sector measures R&D in private industries (*RDI*). Public research (*RDP*) is measured by the share of researchers and scientists at universities per overall employees in the respective region. Employees in the private sector who have a university degree in engineering or natural science are used as a proxy for employees engaged in research and development

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2 Various publications of the Federal Statistical Office and statistical offices of each state provided data on regional gross value added and gross fixed capital formation (investments). Data on gross fixed capital formation (investment) are annually published by each statistical office of the German Federal States (series E I 6). Data on regional gross value added are published by the working group of the Statistical Offices of the German Federal States, Volkswirtschaftliche Gesamtrechnung der Laender every other year between 1976 and 1990 and annually since 1992.

in private businesses. Information exists for the years from 1987 to 2002. It is most likely that the number of employees engaged in research and development is overestimated. First, not every employee in these occupations must be automatically engaged in research and development. Secondly, researchers may move from research and development into other functions later in their career, for example, the co-ordination of other researchers or staff (Zellner, 2003; Biddle and Roberts, 1993). The share of employees characterized as R&D personnel ranges from 0.8 percent to 5.7 percent. The Federal Statistical Office provided data on the number of researchers and scientists at each university for the years 1992-2002. Researchers and scientists are comprised of professors, research assistants, or technical personal in laboratories (all full-time personal). On average, 0.3 percent of the employees in each region are scientists or researchers at universities.

Regional entrepreneurial activity is measured by the number of new ventures formed per 1,000 employees in the respective district. The German Social Insurance Statistics (IAB) as well as the ZEW foundation panel provided information on regional entrepreneurship. Both data sources are not fully comparable but complement one another. First, the German Social Insurance Statistics only lists new businesses with at least one employee who is subject to obligatory social insurance (for details see Fritsch and Brixy, 2004). The ZEW Foundation Panel also registers start-ups consisting of only owners and only new independent firms not branches or plants of existing firms (for more detail see Almus et al., 2002; for details on a comparison see Fritsch and Niese, 2002). Between 1996 and 1998 the German Social Insurance Statistics reported on average 189,000 start-ups and the ZEW Foundation Panel reported 260,000 start-ups (Fritsch and Niese, 2002). The number of start-ups is correlated by 0.95 on the regional level between 1992 and 2002.

The advantage of the ZEW Foundation Panel is that it allows identifying innovative start-ups on the basis of the NACE industry classification (Nomenclature générale des Activités économique dans les Communautés Européennes) since 1990. The German Social Insurance Statistics first introduced the NACE as an industry classification in 1998, using another industry classification since 1983. The industry classification NACE allows identifying innovative start-ups: namely, start-ups in R&D-intensive manufacturing industries, knowledge-intensive services, and technology-intensive services. It is assumed that start-ups in innovative industries reflect knowledge-related entrepreneurship. Founders of businesses in innovative industries are rather unlikely to start a venture out of necessity and are more likely to enhance knowledge spillovers by being a spin-off of a research intensive firm or research institution. The share of innovative start-ups is used as an indicator of knowledge related entrepreneurship. According to the ZEW Foundation Panel, the share of innovative start-ups, start-ups in knowledge- and technology-intensive service industries, is on average 12 percent.

*Table 1: Descriptive statistics*

| | Mean | Std. dev. | Minimum | Maximum |
|---|---|---|---|---|
| Share of employees in R&D in private industries to all employees (%) | 2.26% | 0.94 | 0.84% | 5.69% |
| Share of researcher and scientists in universities to all employees (%) | 0.26% | 0.24 | 0% | 1.15% |
| Start-up rate (German Insurance Statistics) | 7.27 | 1.49 | 4.53 | 13.66 |
| Grants from firms in private industries (thousand Euro, constant 1995 prices) | 80,557 | 139,727 | 0 | 1,129,768 |
| Total amount of grant (thousand Euro, constant 1995 prices) | 26,421 | 36,199 | 0 | 260,486 |
| Share grants from industry to total amount of grants | 27.46% | 21.70 | 0 | 100% |
| Share of total amount of grants by selected general disciplines: | | | | |
| • Mathematics and information technologies | 4.90% | 8.22 | 0% | 61.17% |
| • Natural sciences (biology, chemistry, physics) | 16.38% | 16.10 | 0% | 78.81% |
| • Medicine | 13.17% | 19.70 | 0% | 89.76% |
| • Engineering sciences | 20.49% | 26.22 | 0% | 100.00% |
| • Social sciences (linguistics, cultural studies, economics and business, law etc.) | 17.68% | 21.12 | 0% | 100.00% |
| Population density (inhabitants per square kilometer) | 337.43 | 377.09 | 71.54 | 2288.01 |

*Notes*: All data on the regional level and within the time period of 1992-2002.

The regional level of university-industry relations is measured by the amount of grants given from firms in the private sector to universities per academic researchers and scientists (constant 1995 prices). This information is available for each university and has been aggregated to the spatial level of planning regions from 1992 to 2002. The available data on industry grants do not differentiate between disciplines such as mathematics, information technologies, biology, physics, chemistry, engineering, medicine, or social science. Only the total amount of grants (comprising of grants from the German Science Foundation, industry, governmental organizations, and foundations) is separately reported for different disciplines. Although the total value of grants from industrial sources is highly correlated with the total value of all grants with a correlation coefficient of 0.95, the distribution between the disciplines cannot be assumed to be the same. Some disciplines might be dominated by industrial funds, others by the foundations, or governmental institutions.

A closer examination of the total amount of grants regarding different disciplines shows that engineering receives most of the grants. The field of engineering acquired on average 20 percent of all grants. Researchers and scientists in natural science (i.e., biology, chemistry, or physics) acquired on average 16 percent of all grants. The disciplines of mathematics and information technologies received on average 5 percent of all grants and are, herewith, even behind general social sciences. Furthermore, the universities, unfortunately, are not asked to report the location of financial granter. Therefore, there is no information on the location of the firms that gave grants. Of course, it is rather unlikely that research alliances are only formed between firms and universities that are located in the same planning region. However, Mansfield and Lee (1996) concluded that the proximity of a university in addition to its size and quality enhance research collaboration between large U.S. corporations and universities. Fritsch and Schwirten (1999) analyzed three German regions and found that research partners of universities and polytechnics are mostly located in Germany and about 40 percent are located in the close surroundings of the universities or polytechnics. Nevertheless, location may be less relevant if the university's research is unique and indispensable for a firm and such research can be purchased easily

## 4. Entrepreneurship and University-Industry Relations and Economic Growth

If entrepreneurship and university-industry relations are successful in penetrating the knowledge filter, knowledge flows are facilitated and a positive impact on economic performance can be expected. The empirical results indicate that not only physical capital and labor are sources of growth but also the regional knowledge stock, entrepreneurship, and university-industry relations are relevant. A statistically positive relationship between regional labor productivity and capital intensity is always found (table 2). The results confirm that both research in private firms and at universities are necessary conditions for economic growth. The impact of research and development activities in the private sector on regional economic performance is stronger than the impact of research carried out at universities. A possible explanation for the lower impact of university research is that knowledge generated in universities is rarely commercialized by the university, it still needs to be applied, and does not automatically result in new products and processes (see also Pavitt, 2001). Its commercialization depends on additional knowledge transfer channels.

The two proposed transmission channels for knowledge spillovers enter the regression in the predicted positive way (model II). Regions with a higher level of new firm formation activity also experience greater economic productivity. Setting up a firm reflects the commercialization of knowledge. Entrepreneurship penetrates the knowledge filter and stimulates economic growth. University-industry relations also confirm their ability to penetrate the knowledge filter.

*Table 2: Impact of general entrepreneurship and university-industry relations on regional economic performance*

| | Economic performance | |
|---|---|---|
| | ( I ) | ( II ) |
| Capital intensity | 0.113** (2.96) | 0.157** (4.35) |
| Labor | –0.546** (11.87) | –0.402** (9.30) |
| R&D in private industries (RDI) | 0.228** (9.57) | 0.178** (8.39) |
| R&D in universities (RDP) | 0.034** (5.58) | 0.029* (4.91) |
| Entrepreneurship (start-up rate) | – | 0.133** (15.45) |
| University-industry relations (industrial grants per researcher) | – | 0.006** (3.86) |
| Agglomeration (population density) | 0.001** (3.08) | 0.001** (3.27) |
| Spatial autocorrelation (error) | 0.865** (14.52) | 0.809** (12.65) |
| Constant | 4.962** (7.15) | 2.566** (3.89) |
| $R^2$-adjusted | 0.7258 | 0.7602 |
| F-Value | 352.86 | 321.13 |
| Observations | 767 | 767 |

*Notes*: ** significant at 1%-level, * significant at 5%-level, t-values in parentheses, fixed-effect estimator with heteroscedasticity robust standard errors.

The results suggest that research relations are a significant vehicle to commercialize the knowledge generated at universities, which is usually abundant but underexploited. Research collaboration between the industrial sector and universities allow knowledge transfers in both directions and significantly affect regional economic productivity. The region’s population density controls for agglomeration externalities, which proves to be positive and significant. Agglomerated areas are usually characterized by a greater amount of skilled labor, human capital, and research institutions which are conducive to superior economic performance (Glaeser et al., 1992).

The general measure of entrepreneurship may be misleading because it does not differentiate between necessity and opportunity entrepreneurship. New ventures in knowledge- or technology-intensive industries are most likely founded because of opportunities and are a better reflection of knowledge spillovers. Therefore, the proportion of innovative start-ups (based on the ZEW Foundation Panel) is included in the model to measure knowledge-related entrepreneurship (table 3). Knowledge-related entrepreneurship can be interpreted as a premium additional to the rate of return of general entrepreneurship. New firms in innovative industries are an important mechanism for knowledge spillovers and the commercialization of knowledge. Furthermore, results suggest that regional divergence is amplified if regions with a low level of innovative start-ups are not able to close the gap with other regions. Audretsch and Keilbach (2004b) found that high-tech and knowledge-intensive entrepreneurship had a positive impact on the region’s growth rate of labor productivity.

The effect of university-industry relations most likely differs by discipline, i.e., engineering, natural science, and information technologies. Some disciplines like social science receive few grants from industrial sources but do receive grants from the German Science Foundation or other governmental institutions. As mentioned earlier, statistics regarding industrial grants do not allow a differentiation between disciplines. However, since the total value of grants from industry, German Science Foundation, or other governmental agencies is reported separately and the total value is highly correlated with industrial grants, the total value of grants per researcher in each discipline is used as a proxy (compare model I and II, table 3). Grants in engineering sciences significantly affect regional economic performance. Grants in mathematics and information technologies are also significant. Research in natural science is less applied, and the results show that grants in this area do not have a direct effect on regional economic performance. The results are not surprising; research in engineering sciences is expected to be more applied in nature.

*Table 3: Impact of knowledge-related entrepreneurship and university-industry relations on regional economic performance*

| | Economic performance ( I ) | ( II ) | ( III ) |
|---|---|---|---|
| Capital intensity | 0.149** (4.19) | 0.148** (4.29) | 0.156** (4.88) |
| Labor | -0.412** (9.48) | -0.419** (9.94) | -0.412** (10.17) |
| R&D in private industries (RDI) | 0.177** (8.47) | 0.176** (8.40) | 0.172** (8.51) |
| R&D in universities (RDP) | 0.028** (4.75) | 0.029** (4.61) | 0.026** (4.80) |
| Entrepreneurship (start-up rate) | 0.123** (13.76) | 0.125** (14.04) | 0.121** (13.83) |
| Share innovative start-ups | 0.211** (2.85) | 0.208** (2.79) | 0.177** (2.41) |
| University-industry relations (industrial grants per researcher) | 0.006** (3.80) | | |
| Grants total amount per researcher | – | 0.008** (2.95) | |
| Grants engineering sciences per researcher | – | | 0.015** (3.83) |
| Grants mathematics and information technologies per researcher | – | | 0.026** (2.67) |
| Grants natural science per researcher | – | | -0.006 (1.31) |
| Agglomeration (population density) | 0.001** (2.94) | 0.001** (2.89) | 0.001** (3.10) |
| Spatial autocorrelation (residuals) | 0.795** (12.44) | 0.787** (12.97) | 0.776** (12.83) |
| Constant | 2.734** (4.13) | 2.816** (4.41) | 2.665** (4.42) |
| $R^2$-adjusted | 0.7620 | 0.7613 | 0.7684 |
| F-Value | 281.42 | 287.30 | 249.54 |
| Observations | 767 | 767 | 767 |

*Notes*: ** significant at 1%-level, * significant at 5%-level, t-values in parentheses, fixed-effect estimator with heteroscedasticity robust standard errors.

## 5 Concluding Remarks

This paper addresses an important research question – the transfer and commercialization of knowledge through entrepreneurship as well as university-industry relationships and the impact of this on regional economic growth. The results are threefold. First, a well developed regional knowledge stock is a crucial determinant of regional economic performance. New knowledge needs to be generated at existing firms and research institutions before it can be exploited. Researchers at firms and universities must be able to apply and assimilate knowledge. The evidence suggests that both basic and applied research promotes growth. Secondly, regions with a higher level of entrepreneurship experience greater economic performance. In particular, new firm formation in innovative industries is an important mechanism to commercialize knowledge. Thirdly, universities are a source of innovations: the more firms draw from knowledge generated at universities, the more those regions experience economic growth. Consequently, it may be concluded that the proposed knowledge transmission channels – entrepreneurship and university-industry relations – increase the permeability of the knowledge filter, thus improving regional economic performance.

Empirical studies found that firms are most likely to draw from university research if they follow specific innovation strategies. Firms with internal R&D strategies that focus on exploratory activities will allocate a greater share of their R&D resources to grants supporting university research. Furthermore, firms specifically prefer universities as research partners when they are concerned about the appropriation of the results (see also Schmidt, 2005). Laursen and Salter (2004) found that firms using university knowledge are in a small number of industrial sectors and that these firms already have a more open-search strategy drawing from external knowledge sources. Additionally, universities are of modest importance compared to other knowledge resources such as suppliers and customers. Therefore, research visibility of universities is important and should be increased if possible. The German government and the European Commission have already introduced various instruments to foster research partnerships and cooperation between universities, research institutes, and private businesses. Public support programs are usually conditional on being joint research projects between different actors, for example, private businesses, universities, or other research institutions.

Policy implications regarding entrepreneurship would be to stimulate entrepreneurial awareness and to develop entrepreneurial skills. It is not sufficient to have policies based solely on the generation of knowledge but rather policies need to be based on the exploration and commercialization of new knowledge. Furthermore, especially innovative start-ups may encounter financial constraints. Thus, public policy may focus on creating a healthy business environment for venture capitalists.

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