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## The role of regional knowledge production in university technology transfer: Isolating coevolutionary effects

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## The Role of Regional Knowledge Production in University Technology Transfer: Isolating Coevolutionary Effects

The rate and magnitude of university-to-industry-technology-transfer (UITT) is a function not only of university characteristics but also of regional factors. A university's embeddedness in an innovative regional milieu moderates UITT. This necessary balance of the supply side ("technology push") and demand side ("market pull") of technology transfer has so far neither been systematically addressed in the technology transfer literature nor has it been acknowledged by policy makers. We investigate UITT as a function of the interrelation of the industrial innovative milieu of a region and the characteristics of regional universities to identify the impact of the industry on UITT. Thereby we do not only aim to reduce the existing empirical gap in the academic entrepreneurship literature but also to inform policy in its attempt to foster UITT in European regions.

*- work in progress -*

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### **Non technical summary**

The rate and magnitude of university-to-industry-technology-transfer (UITT) is a function not only of university characteristics but also of regional factors. A university's embeddedness in an innovative regional milieu moderates UITT. This necessary balance of the supply side ("technology push") and demand side ("market pull") of technology transfer has so far neither been systematically addressed in the technology transfer literature nor has it been acknowledged by policy makers.

We investigate UITT as a function of the interrelation of the industrial innovative milieu of a region and the characteristics of regional universities to identify the impact of the industry on UITT. Thereby we do not only aim to reduce the existing empirical gap in the academic entrepreneurship literature but also to inform policy in its attempt to foster UITT in European regions.

This paper builds largely on two strands of economic literature which have barely been linked so far. On the one hand there is substantial work investigating the regional production of

innovation within the “knowledge production function”-framework proposed by Griliches. These papers explain regional growth successfully as a function of industry R&D, university R&D and business services, as well as the importance of academic research for regional growth. Moreover Varga was able to demonstrate first evidence for the impact of the industrial structure on UITT within this framework. However, due to the nature of this strand of research the results are based on relatively coarse and input oriented economic indicators rather than the innovative output. Furthermore this kind of research defines regions as administrative units instead of actual industrial areas.

On the other hand there is a plethora of detailed research on determinants of UITT which concentrates on characteristics, resources, structures and processes of universities without regard to regional influences. The few papers which do employ controls for industrial context find mixed results. This can be ascribed to the unsystematic manner the indicators are chosen and operationalized.

We tackle the shortcomings of the existing research by carefully constructing a unique dataset of German regions and universities which contains detailed information on regional (e.g. industrial innovations, GDP, industry concentration, services concentration, industry diversity, entrepreneurship, population density) as well as university (e.g. size, transfer intense departments, research output, technology transfer output, human capital, industry relations, third party funding) characteristics. In addition we define regions as Functional Urban Areas (or travel-to-work areas) which enables us to observe actual industrial contexts while controlling for spillovers through human capital mobility.

Our model estimates the magnitude of university technology transfer as a function of regional knowledge production. To control for imminent reverse causality and multicollinearity of the hypothesized *interrelation* of industry and university we use a multistage negative binomial regression strategy. In the first stage we explain industrial innovative output as a function of

regional and industrial characteristics. The estimated values of the industry innovation are then instrumented as exogenous variable in the second stage which estimates UITT as function of regional industrial innovation.

Our results clearly show a highly significant and negative influence of regional characteristics on UITT. For the first time we are able to isolate the negative effects of a successful regional innovative milieu on UITT. These findings do not only help to further reduce the gap between regional economics and academic entrepreneurship literature, but can inform regional policy. The outcomes of this study call for differentiated science- and economic-policy measures, which should be tailored to specific regional needs and characteristics.

### **Coevolution of universities and regional industries**

In recent years universities as suppliers of economically relevant knowledge have attracted wide attention among researchers and policy makers alike (Etzkowitz, Webster, Gebhardt, & Terra, 2000). Resting on new research patterns, for example in bio-, nano- and information-technology, universities are able to transform their fundamental research into products and prototypes and commercialize those (Zucker & Darby, 1996). This has created a new class of Academic Entrepreneurs and has set up university-to-industry-technology-transfer (UITT) as a “third mission” (Etzkowitz & Leydesdorff, 2000; Feller, 1990; Rip, 2002) of universities. At the same time new high-tech industries have emerged around research intensive universities benefiting from knowledge spillovers (Romer, 1986) by universities – and from industry agglomeration (Arrow, 1962b; Romer, 1990) – as well as intended UITT. One of the first and most famous accounts on universities as triggers<sup>1</sup> of regional industrial growth comes from Saxenian (1994) in her case study on Silicon Valley. Since then a plethora of single university impact studies (for a critical review see Drucker & Goldstein, 2007) have confirmed these

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<sup>1</sup> Biologically „coevolution“ can be defined as “the change of a(n) [...] object triggered by the change of a related object” (Yip et al., 2008, p. 290).

early findings. The ‘university-trigger’-view of regional growth is especially popular with policy makers as it identifies a single institution as focal point of intervention.<sup>2</sup>

On the other hand universities are not a Greenfield development. The features of a university, its departments and size and endowment are the results of an interactive process. Innovation develops new industries demanding more and different human capital. Universities, guided by policy makers, adjust their teaching and research to the new demand. Researchers then may commercialize their new knowledge, thereby fostering new industries. This virtuous cycle creates jobs, infrastructures and supporting industries (Nelson, 1994). The developing regional innovative milieu is a combination of resource endowment (commodities, money and labor) and human capital. Regional growth is a path-dependent learning process shaped by former rounds of mutual structural and institutional adaption (Maskell & Malmberg, 1999). Apart from conceptual works (e.g. Etzkowitz & Klofsten, 2005; Etzkowitz et al., 2000; Gunasekara, 2006) Hülsbeck & Lehmann (2007) explain this process using the unlikely example of Bavaria. They describe how several rounds of adaption transformed the agricultural state into the sixth biggest economy in the EU and its capital Munich into the world’s leading biotechnology cluster.<sup>3</sup>

This reciprocal path-dependence (coevolution) poses a chicken-and-egg problem for economic theory and research. In microeconomic theory the work of Solow (1956) proves the existence of a latent variable other than technology (K) and labor (L) in (regional) economic growth. The endogenous growth model (Romer, 1986, 1990) models this variable as new

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<sup>2</sup> A striking example is the EU’s innovation policy (Lisbon-Agenda), which concentrates on university related measures to foster regional growth (EC, 1995, 2001a, 2001b).

<sup>3</sup> Historical accounts of early rounds of co-evolutionary stages can for example be found for the British and German chemical industry (Murmman & Landau, 1998) and for the optical industry in Germany (Audretsch & Lehmann, 2004).

knowledge embedded in human capital (H). New knowledge itself consists of innovation (Arrow, 1962b) and education (Uzawa, 1965) and therefore a result of the interactive learning processes. New knowledge is created by combining existing knowledge (A)<sup>4</sup> with human capital (H\*A). Innovation is formed by employing labor (L) to existing knowledge (L\*A). Output (Y) is produced by applying existing technology (K) to the aforementioned factors:

$$Y = (H * A)^\alpha * (L * A)^\beta * K^\eta \quad (1.1)$$

Romer (1990) distinguishes three societal domains with unique roles in this production process. Universities produce new knowledge through research and education (H\*A), Industrial R&D creates innovation (L\*A) and industrial production uses technology (K) to create goods. However, these clear distinctions are becoming more and more blurred and have been heavily criticized (Dasgupta & David, 1994). “Entrepreneurial universities” (Etzkowitz, 2003) adopt more and more roles of industrial R&D (L\*A) by engaging in UITT (Link & Siegel, 2005; Siegel, Waldman, Atwater, & Link, 2003; Thursby, Fuller, & Thursby, 2009). Besides they also begin to take part in the production process (K) by holding shares of spin-off firms (Bray & Lee, 2000; Lockett, Wright, & Franklin, 2003; O’Shea, Allen, Chevalier, & Roche, 2005) or creating venture capital (O’Shea, Allen, & Morse, 2005). As this process continues it is becoming more and more difficult to disentangle industry and university characteristics leading to innovation.

Microeconomic empirical research has eluded these problems by estimating innovation (P)<sup>5</sup> as a combination of R&D spending of industry (RD<sub>i</sub>) and university (RD<sub>u</sub>):

$$P = RD_i^\alpha * RD_u^\beta \quad (1.2)$$

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<sup>4</sup> A at time t can be thought of as H at time t-1, or: “yesterday’s human capital is today’s technology”.

<sup>5</sup> As measured by counts of patents, innovations or citations.

This regional knowledge production function (KPF) – or Griliches-Jaffe-model (Griliches, 1979; Jaffe, 1989) – and its variations have been widely used to explain the varying knowledge production of regions (for a survey see Drucker & Goldstein, 2007). Although this approach has yielded fundamental insights into how knowledge is transformed into innovation it has a couple of drawbacks. First the existing research uses coarse proxies for estimating R&D. For example industry R&D spendings are measured as number of employees with a second or third degree in hard sciences while a good part of these people may work in management and technical sales. Therefore this indicator not necessarily reflects the R&D intensity but rather the complexity of products (related to R&D intensity). University R&D on the other hand is measured accurately as these figures are publicly available. Nevertheless the allocation of this money in fundamental and applied research, doctoral education or UITT is not accounted for although this plays a central role in transforming knowledge in economically relevant knowledge (L\*A) by universities. This “knowledge filter” (Acs, Audretsch, Braunerhjelm, & Carlsson, 2004) remains unobserved in that line of research. The second flaw of the KPF research tactics is that it is only measuring combined effects of regional and university features. It is not able to single out specific effects of industry and university or their interactions. Therefore it is neither possible to reproduce the postulates of endogenous growth models<sup>6</sup>, nor can a causal link be shown between regional and university determinants.

In this paper we overcome the discussed shortfalls in separately identifying the regional effects on industrial innovation and then using this as a proxy for regional effects on university innovation. By it we can identify regional influences on the entrepreneurial

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<sup>6</sup> There is in fact an additional body of research modeling endogenous growth under simplified assumptions. These studies aim to test a system of equations in a restrained model of environmental conditions to gain theoretical insights but have no direct implication for the empirical question of UITT (Drucker & Goldstein, 2007). Good examples and literature reviews can be found in the work of Max Keilbach (2000).

university while controlling for university characteristics. This research tactic enables us to cut out the historical coevolutionary effects of regional and university development and to isolate the present real effects of regions on UITT. The remainder of the paper is organized as follows. In section two and three we give a short outline of key research in regional economics and UITT to decide relevant indicators for both levels of our model. In section four estimation issues and model selection are discussed. Section five presents the results of our analysis. The paper closes by critically reviewing theoretical explanations for our findings.

### **Regional economics and the role of universities**

The aim of regional economic research is to explain regional variations in growth and related factors (competitiveness, entrepreneurship) as a function of growth models (recent surveys include Breschi & Lissoni, 2001; Döring & Schnellbach, 2006). A key issue in this strand of literature is ‘knowledge spillover’ because of the non-appropriability of knowledge. New knowledge cannot only be used by a cost-bearing innovator, but also by other firms not bearing these costs. As new knowledge is embedded in human capital, which itself is considered rather stationary, the utility of spillovers sharply decays with increasing distance (Dasgupta & Stiglitz, 1980; Fujita & Thisse, 2002, p. 173; Griliches, 1979). Different explanations and contributing factors have been theoretically considered and empirically tested. Key issues with relevance to the university’s role are discussed in this section.

Marshall-Spillovers arise among firms within the same industry. The regional concentration of a specific industry increases spillovers by monitoring, imitation and exchange of human capital. Economies of scale are realized because of more effective specialization of firms and a bigger supply of industry-specific human capital. Eventually universities react by offering

education tailored to the dominant industry (Arrow, 1962b; Marshall, 1890; Romer, 1990). An alternative view is offered by Jacobs-Spillovers. This theory claims that spillovers do not chiefly emerge by industrial concentration but diversity. Industries using similar technologies but not competing in the same markets cluster together to actively exchange new knowledge and leverage each other's innovation and productivity (Bairoch, 1991; Jacobs, 1969; Rosenberg, 1963). These industries use universities as boundary-spanners and "innovation-hubs" (Youtie & Shapira, 2008). Empirical findings on this rival views remain mixed.

Henderson (1986) examines Brazilian and US metropolitan areas to find out whether regions profit from industry-specific spillovers. In his analysis areas with high industry concentration (Marshall-Spillovers) also show high productivity. However this positive correlation disappears in regions with high population density. Opposite to the expected outcome the biggest cities and most dense areas show negative effects of overpopulation and no positive spillover effects on productivity. Glaeser, Kallal, Scheinkmann & Schleifer (1992) consider the importance of industry concentration and diversity for employment growth in 170 US metropolitan areas between 1956 and 1987. They infer that diversity has a stronger effect on employment in mature industries while concentration is more important to young and fast growing entrepreneurial industries. Both studies (Glaeser et al., 1992; J. V. Henderson, 1986) examine growth effects of different types of industry agglomeration but not directly the underlying question of knowledge spillovers. Jaffe, Trajtenberg & Henderson (1993) explore knowledge spillovers by tracking patent citations. They compare region and industry of citing and cited industrial and university patents. By it they are able to show: a) a strong regionalization effect of patent citations confirming the local confinement of spillovers, b) a diversity of spillovers across industries and technologies, and c) no differences in these patterns between firm- and university patents.

Nelson (1986) reports early empirical evidence on the university's influence on industrial innovation. Basing on a questionnaire survey of R&D managers in 130 different industries a high relevance of university research for technological change is supported. This relevance is highly correlated with the rate of innovation within an industry. The regionality of this influence is shown by Jaffe (1989). By employing a regional knowledge production function on the level of US-states he shows significantly positive influence of university R&D spending on firm R&D and firm patents. Similar effects have been shown for product innovations (Acs, Audretsch, & Feldman, 1992, 1994; Audretsch & Feldman, 1996). These effects are later reproduced in several studies on the more detailed level of metropolitan areas, where an even stronger regionalization effect of university spillovers is established (Acs, Anselin, & Varga, 2002; Anselin, Varga, & Acs, 1997, 2000). These effects are not confined to the United States. Audretsch & Lehmann in several studies based on German entrepreneurship data show positive correlations of university spillovers on new firm formation confirming the international validity of prior research (Audretsch & Lehmann, 2005a, 2005b, 2006; Audretsch, Lehmann, & Warning, 2005).

The inverse effect of regional industry on universities has been scarcely looked into. To our knowledge the paper by Varga (2000) is one of a kind so far. He combines the observations of the regional constraints on university spillovers with the mixed results of the 'concentration vs. diversity' debate of industry agglomeration. The study argues the presence of three parties is necessary to enable university spillovers. 1. high-tech-industries increase demand for skilled human capital, contract research and academic consulting. 2. Industrial services like consultants and venture capitalists increase the likelihood of university spin-offs. 3. The share of regional entrepreneurship increases demand for university cooperation because of resource

constraints of small firms (see also Acs et al., 1994; Audretsch, Keilbach, & Lehmann, 2006). These postulates are tested by estimating the Griliches-Jaffe-Model of the knowledge production function as hierarchical regression. The parameter  $\beta$  from equation (II) above is approximated by the number of employees in high-tech industries, industrial services and the number of self-employed. The findings show a highly significant and positive influence of high-tech industries on university spillovers. Further investigations show moderating effects of population density which had not been considered in the original model.

A significant relationship between university and industry within a region cannot be contested. Alas the nature of the relationship remains unclear. In a knowledge economy the theoretical boundary between knowledge production and innovation becomes more and more blurred. Empirical research building on the endogenous growth model has so far not been able to isolate the interaction of UITT and industrial innovation. The knowledge production function by its design estimates combined effects of knowledge production and innovation while other studies fail to control for important agglomeration effects identified by prior research. Even Varga's (2000) seminal work suffers from a few flaws as agglomeration effects cannot be incorporated in the KPF and the number of high-tech employees (instrument for university spillovers) are not independent from employees in industrial R&D (variable for industry RD expenditure). The regional factors determining the regional embeddedness of university spillovers might be summarized as follows:

1. The existence of *urbanization* economies ( $U$ ) which can neither be credited to industry concentration nor diversity but rather to lowered transaction costs (J. V. Henderson, 1983, 1986, 1994).
2. Regional industrial *concentration* ( $C$ ) leading to economies of scale and specialization in industry, services and universities alike (Arrow, 1962b; Glaeser et al., 1992; Marshall, 1890; Romer, 1986, 1990).

3. Industrial *diversity* ( $D$ ) as a prerequisite for knowledge exchange and inter-industrial leverage of innovation and productivity (Glaeser, 1999; Glaeser, Scheinkman, & Shleifer, 1995; Jacobs, 1969; Jaffe et al., 1993; Rosenberg, 1963; Scherer, 1965, 1982).
4. *Productivity* ( $Y$ ) of the regional industry as indicator for its absorptive capacity of spillovers (Chapple, Lockett, Siegel, & Wright, 2005; Link & Siegel, 2005; Varga, 2000).

Keeping the sectoral blurring of new knowledge creation one could rewrite the regional knowledge production function (1.2) as:

$$P = I_i^\alpha * I_u^\beta \quad (1.3)$$

With  $I_i$  as regional industrial innovation and  $I_u$  as university innovation. With  $I_i$  as:

$$I_i = U^{\delta_1} * C^{\delta_2} * D^{\delta_3} * Y^{\delta_4} \quad (1.4)$$

### **University characteristics and technology transfer**

Within the last decade the new field of academic entrepreneurship research has literally exploded. In their recent review Rothaermel, Agung & Jiang (2007) identify more than 120 studies while Phan & Siegel (2006) summarize more than 50 empirical papers concerning UITT in the USA and UK alone. Like other young areas of interest much of the research is eclectic and atheoretical. Therefore we will not try to give a full account of the insights into UITT but again focus on relevant university characteristics within our coevolutionary framework. A university's embeddedness in a regional innovative milieu might lead to more and earlier technology transfer and the accumulation of human and financial capital within the university

Because of the nature of spillovers (see above) the demand for UITT is geographically limited and varies among industries (Jaffe, 1989). The supply of UITT is therefore a function of former rounds of exchange and learning between industry and university. Over time a university accumulates relevant knowledge about the patentability of certain types of technologies and innovations, about patenting processes, marketing, and licences. Phan and Siegel (2006) note the importance of this kind of path dependence: As university bureaucracy and policies tend to evolve slowly, early technology transfer experience creates more technology transfer in subsequent periods. It is very likely that a “history and tradition” (O’Shea et al., 2005) of UITT leads not only to more spillovers in the future but is at the same time a sign of regional demand for university spillovers.

Mowery, Sampat & Ziedonis investigate the effects of the Bayh-Dole-act (BDA)<sup>7</sup> on patenting activities of US-universities in several studies (Mowery, Sampat, & Ziedonis, 2002; Mowery & Ziedonis, 2002; Sampat, Mowery, & Ziedonis, 2003). Contrary to prior research (see R. Henderson, Jaffe, & Trajtenberg, 1998; Sampat et al., 2003) they cannot confirm positive effects of the Bayh-Dole Act on UITT. By using the BDA as an exogenous shock forcing universities into UITT they are able to study the role of learning and experience in UITT. First Mowery & Ziedonis (2002) note a significantly lesser quality and larger quantity of university patents after BDA. This change is caused by the entry of former non-patenting universities while the quality and quantity of experienced universities remains stable. Second Mowery, Sampat & Ziedonis (2002) inspect the UITT related learning of new entrants and find that these are closing the gap to incumbent universities. However they cannot explain this

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<sup>7</sup> The Bayh-Dole-act (US Public Law 96-517) assigns the property rights of publicly funded inventions by academic researchers to their respective university or institution.

learning by using ‘supply-side’ indicators. Neither patenting nor marketing efforts nor strong ties to experienced institutions are able to explain the learning curves of new entrants.

Mowery, Sampat & Ziedonis (2002) ascribe their results to unobserved learning among universities, for example through human capital exchange. We contest this view. In the light of regional economics and endogenous growth we find it much more likely that different levels of UITT supply are shaped by regional demand. This perception is backed up by a number of findings. Friedman & Silberman (2003) find that UITT depends on the concentration of regional high-tech industries. Owen-Smith & Powell (2003) show the relevance of local network embeddedness for university patenting in life sciences. The relevance of university life sciences departments for UITT (see Carlsson & Fridh, 2002; Coupe, 2003; Siegel et al., 2003) confirms their results. The same holds true for other hard science departments and engineering (Thursby, Jensen, & Thursby, 2001).

In university-research the most critical resource is human capital. The ability to attract researchers to a certain university depends on the university’s resource endowment, reputation and the quality of living (Florida, 2002) which all are functions of regional embeddedness. The accumulation of scientists and engineers in a university implies a higher quantity of available human capital, which is linked to the ability of new knowledge creation (Feldman & Lichtenberg, 1997; Friedman & Silberman, 2003; Powers & McDougall, 2005; Thursby et al., 2001). Zucker, Darby & Armstrong (2002) have argued that “star” scientists are more able to capture rents from their intellectual capital, and Gregorio & Shane (Gregorio & Shane, 2003) have shown that an increase in university-wide quality rankings leads to disproportional

higher technology transfer. Therefore the faculty quality should have a positive impact on UITT.

Another critical resource is third party funding of research activities. It is a well known fact that average budgets for research of public universities are small. Hence research funding by third parties like regional industry or national research funds is a prerequisite for knowledge creation and transfer. Blumenthal, Campbell, Anderson, Causino & Louis (1996) have shown for Life Sciences, that industry funding generates more transferable knowledge and technology transfer. These findings are generalized for other sciences by several studies (Carlsson & Fridh, 2002; Chapple et al., 2005; Coupe, 2003). Payne & Siow (2003) find positive effects of third party funding (Florida, 2004; Smith & Florida, 1994) on the quantity of research and knowledge transfer but negative effects on research quality. Despite the growing industry interest in supporting basic research, national research agencies, scientific foundations, and EU-research framework programs are the largest sponsors of research. These providers of research funding are more and more concerned about the spending and the expected value of their money in terms of transferable knowledge (EC, 2008; O'Shea et al., 2005). Summarizing we expect university innovation ( $I_u$ ) to depend on the following aspects:

1. The *experience* ( $X$ ) of former UITT as a measure of regional coevolutionary supply and demand.
2. The faculty quality and quantity as indicator of UITT-relevant *human capital* ( $H$ ).
3. The research *funding* ( $F$ ) as prerequisite of new knowledge creation and transfer.

This can be formulated as:

$$I_u = X^{\mu_1} * H^{\mu_2} * F^{\mu_3} \quad (1.5)$$

## Isolating regional influences on university to industry technology transfer

Because of coevolutionary effects we cannot simply insert equations (1.4) and (1.5) in (1.3) and estimate a simple regression model. At the same time we are restricted in the choice of regression models because  $I_i$  and  $I_u$  are measured using patent counts (see below) therefore we cannot employ linear simultaneous equation modeling like three-stage least squares estimation (3SLS). On the other hand multilevel analysis for count data (e.g. mixed-effect poisson regression) is not available as we cannot guarantee a full specification of the model (Long, 1997). Instead we manually mimic the logic of 3SLS by:

1. Estimating  $I_i$  (Model 1) and  $I_u$  (Model 2) independently based on equations (1.4) and (1.5) and predicting  $\hat{I}_i$  and  $\hat{I}_u$  by using their respective regressions.
2. Estimating the regional knowledge production function (Model 3) and predicting  $\hat{P}$  from  $P = U^{\delta_1} * C^{\delta_2} * D^{\delta_3} * Y^{\delta_4} * \hat{I}_u^{\delta_6}$ , thereby capturing the covariate influence of university innovation on regional knowledge production.
3. Estimating university innovation as  $I_u = X^{\mu_1} * H^{\mu_2} * F^{\mu_3} * \hat{P}^{\mu_3}$ , thereby isolating the interaction effect of regional knowledge production on university technology transfer (Model 4).
4. And finally - to document the independence of the instrument  $\hat{I}_u$  - we estimate

$$\hat{I}_i = U^{\delta_1} * C^{\delta_2} * D^{\delta_3} * Y^{\delta_4} * \hat{I}_u^{\delta_6} \quad (\text{Model 5})$$

To do this we use a unique and hand collected data set on German universities and their surrounding regions which contains detailed information on regional (e.g. industrial innovations, GDP, industry concentration, services concentration, industry diversity, entrepreneurship, population density) as well as university (e.g. size, transfer intense

departments, research output, technology transfer output, human capital, industry relations, third party funding) characteristics. The endogenous variables  $I_i$  and  $I_u$  are patent counts for regions in the year 2005 and, because of the small amount of university patents the sum of these patents for the five year period from 2002 to 2005.<sup>8</sup> In addition we define regions as Functional Urban Areas (or travel-to-work areas) (Antikainen, 2005; for Germany: Eckey, Kosfeld, & Türck, 2006) which enables us to observe actual industrial contexts while controlling for spillovers through human capital mobility.

Operationalized indicators and descriptive statistics for the discussed factors are shown in table 1. Some factors are modeled by a number of variables to catch different aspects. Urbanization is measured by population density and the percentage of employed population to control for variation in population composition (e.g. pupils and retirees). To control for overpopulation regional dummies (e.g. Ruhr-Valley) and a squared term of population density is used. Industrial concentration is controlled by composition of the industry as this influences technology transfer and innovation (Jaffe, 1989; Jaffe et al., 1993). Industrial diversity is controlled for trade-off effects with industrial concentration ( $C*D$ ). University experience is modeled as the sum of patents prior to 2002 divided by the age of the first patent of the respective university to account for quantity and frequency (Arrow, 1962a), to control for economies of scale a squared term is added to the regression. The quantity of human capital in universities is captured by the number of researchers, the production of new knowledge is captured by the number of PhD students and publications per year, while the quality of the new knowledge is controlled for by the number of citations. Given the applied character of

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<sup>8</sup> Patent counts have been heavily criticized as economic indicators, due to unobservable heterogeneity in patent quality. This criticism holds true only on the individual firm level, where patent data are used to determine the innovative capability of a single firm. A sufficient number of observations, guaranteed by long observation periods or counts on regional level, can compensate for that weakness (Acs & Audretsch, 1989; Griliches, 1990).

much of engineering research the existence of an engineering department is additionally controlled for. A correlation matrix of the discussed indicators is shown in table 2.

<b>Factor</b>	<b>Variable</b>	<b>Abbrev.</b>	<b>Mean</b>	<b>St.-Dev.</b>	<b>Min</b>	<b>Max</b>
<b>Industrial Innovation (<math>I_i</math>)</b>	Industrial Patents	IndPat	712.023	1011.759	19	4631
<b>University Innovation (<math>I_u</math>)</b>	University Patents	UniPat	45.439	59.226	1	387
<b>Urbanization (<math>U</math>)</b>	Population Density	PopDens	359.513	330.438	80.926	1667.684
	% of employed Population	EmpPop	0.462	0.050	0.350	0.587
	Binary:Ruhr-Valley=1	Ruhr	0.076	0.267	0	1
<b>Concentration (<math>C</math>)</b>	Normalized Gini coefficient of industries (# employees)	IndConc	0.576	0.106	0.320	0.835
	% employees Life Sciences	LifeScience	0.140	0.094	0	0.460
	% employees Electronics/IT	Electronics	0.113	0.094	0	0.444
	% employees Engineering	Engin	0.630	0.158	0.211	1
<b>Diversity (<math>D</math>)</b>	# Industries	Div	13.439	3.926	3	20
	(C)*(D)	IndInter	7.663	2.453	2.088	13.053
<b>Productivity (<math>Y</math>)</b>	GDP per capita	GDPCap	25.836	5.786	16.288	43.902
	Binary: East=1	East	0.196	0.400	0	1
<b>Experience (<math>X</math>)</b>	University patents per year since first patent	PatYear	2.510	4.110	0	25.667
<b>Human Capital (<math>H</math>)</b>	# Post-Doc Researchers	PostDoc	1709.720	1165.091	200	5203
	# PhD-Researchers per Professor	PhD	1.502	0.779	0	3.307
	Publications per PostDoc per year	PubYear	10.370	4.173	0	17.313
	Citations per PostDoc per year	CitYear	64.243	33.483	0	147.699
	Binary-Control: Engineering Department=1	EngDep	0.561	0.500	0	1
<b>Funding (<math>F</math>)</b>	Third Party Funding per year	FundYear	108.968	50.799	0	253.004

**table 1: Indicators and descriptive statistics**

	<b>IndPat</b>	<b>UniPat</b>	<b>PopDens</b>	<b>EmpPop</b>	<b>IndConc</b>	<b>LifeScience</b>	<b>Electronics</b>	<b>Engin</b>	<b>Div</b>	<b>IndInter</b>	<b>GDPCap</b>	<b>PatYear</b>	<b>PostDoc</b>	<b>PhD</b>	<b>PubYear</b>	<b>CitYear</b>
<i>UniPat</i>	0.17															
<i>PpDns</i>	0.23	-0.08														
<i>EmPop</i>	0.48	0.02	0.22													
<i>IndCo</i>	0.34	-0.04	0.32	0.37												
<i>LifeSci</i>	0.08	0.06	0.23	0.03	0.20											
<i>Electro</i>	0.12	0.27	-0.14	0.23	-0.44	-0.12										
<i>Engin</i>	0.16	-0.10	0.26	0.28	0.11	-0.39	-0.22									
<i>Div</i>	0.05	-0.09	0.20	0.12	-0.20	0.12	0.41	0.03								
<i>IndInr</i>	0.14	-0.14	0.38	0.32	0.29	0.26	0.18	0.08	<b>0.87</b>							
<i>GDP</i>	0.64	-0.06	0.34	<b>0.87</b>	0.41	0.15	0.16	0.31	0.18	0.40						
<i>PtYear</i>	0.05	<b>0.85</b>	0.02	0.11	0.00	0.05	0.21	-0.03	-0.05	-0.07	-0.01					
<i>PstDoc</i>	0.41	0.51	0.04	0.20	0.01	0.28	0.29	-0.16	0.24	0.21	0.31	0.29				
<i>PhD</i>	0.32	0.38	0.15	0.24	0.07	0.19	0.10	0.09	0.01	0.04	0.30	0.21	0.74			
<i>PbYea</i>	0.18	0.37	0.17	0.16	-0.04	0.11	0.14	0.12	0.15	0.12	0.20	0.28	0.63	0.77		
<i>CitYea</i>	0.30	0.27	0.18	0.29	-0.03	0.13	0.24	0.08	0.20	0.18	0.40	0.20	0.73	0.77	<b>0.88</b>	
<i>FndYr</i>	0.50	0.52	0.08	0.23	0.06	0.21	0.23	-0.03	0.17	0.16	0.36	0.28	<b>0.92</b>	<b>0.80</b>	0.63	0.72

table 2: Correlations of indicators; corr >0.5 in italics, >0.8 in bold font

The exogenous variables are not correlated. As expected a university's transfer experience (PatYear) is highly correlated with its transfer activities (UniPat), productivity (GDPCap) is highly correlated with employment (EmpPop) and there is a trade-off between industrial concentration and diversity (Div, D\*C). Additionally we observe moderate to strong expected correlations among the human capital and funding variables of universities.

<i>Endogenous:</i>	1: $I_i$	2: $I_u$	3: $P(I_i)$	4: $I_u$	5: $\hat{I}_i$
$\hat{I}_u$			0.0042 *** (0.001)		0.00001 (0.0001)
$\hat{P}$				-0.0001 * (0.000)	
PopDens	0.0032 *** (0.001)		0.0027 *** (0.001)		0.0032 *** (3.520E-11)
PopDens <sup>2</sup>	0.0000 *** (0.000)		0.0000 *** (0.000)		-1.83E-06 *** (2.080E-14)
EmpPop	-12.7693 *** (3.410)		-11.9298 *** (3.151)		-12.7693 *** (1.760E-07)
IndConc	18.5906 *** (2.257)		17.0151 *** (2.137)		18.5906 *** (5.790E-08)
Life Science	4.2256 *** (1.045)		3.5404 *** (0.984)		4.2256 *** (4.780E-08)
Electronics	3.6523 *** (0.961)		2.3014 *** (0.793)		3.6523 *** (4.660E-08)
Engin	1.2878 * (0.698)		0.7657 (0.604)		1.2878 *** (3.160E-08)
Div	0.9785 *** (0.105)		0.9293 *** (0.101)		0.9785 *** (4.83E-09)
IndInter	-1.5725 *** (0.158)		-1.4478 *** (0.163)		-1.5725 *** (7.920E-09)
GDPcap	0.1479 *** (0.031)		0.1460 *** (0.028)		0.1479 *** (1.250E-09)
PatYear		0.1720 *** (0.041)		0.1748 *** (0.041)	
PatYear <sup>2</sup>		-0.0041 ** (0.002)		-0.0042 *** (0.002)	
PostDoc		0.0003 *** (0.000)		0.0003 ** (0.000)	
PhD		0.2450 * (0.132)		0.2376 * (0.131)	
PubYear		0.1029 *** (0.036)		0.0977 *** (0.036)	
CitYear		-0.0157 *** (0.006)		-0.0150 *** (0.006)	
EngDep		0.4319 *** (0.148)		0.4436 *** (0.148)	
FundYear		0.00001 (0.0001)		0.0000 * (0.000)	
Constant	-6.1512 *** (1.758)	1.6939 *** (0.288)	-5.3709 *** (1.684)	1.7237 *** (0.284)	-6.1512 *** (6.440E-08)

N=66, negative binomial regressions with robust standard errors; \*=0.1, \*\*=0.05, \*\*\*=0.01 significance; binary variables estimated but not reported. Goodness-of-Fit-tests (Pregibon, 1980) for all models show excellent fit (\*\*\*).

**table 3: Regression models**

The results of our regressions show the expected results. Model 1 and 2 reproduce the results of prior research in regional economics and university to industry technology transfer as illustrated in sections two and three of this paper. Model 3 confirms prior research investigating regional knowledge production as a function of university innovation. The parameter  $\hat{I}_u$  is significant and positive as predicted by the endogenous growth theory and the Griliches-Jaffe-Model of regional knowledge production as well as the results of the study by Varga (2000). Model 4 concerns our main interest in this study. Our question was to what

extent regional knowledge production affects UITT after controlling for combined effects due to coevolution of region and university. We find a significant and negative relationship between both parameters that cannot be explained by model overidentification or estimation problems. Signs, coefficients and standard errors for regional (model 1 and 3) and university (model 2 and 4) controls remain robust and unchanged. The negative sign of the parameter  $\hat{P}$  can be reproduced if  $I_i$  and  $I_u$  are linearized and estimated a log-linear three-stage least square estimation with two equations (not reported). Furthermore our "control"-model 5 documents the independence of our instrument. At this point we can conclude a trade-off between *existing* regional knowledge production and *additional* university innovation.

### **Regional innovative milieus as knowledge filter**

In their paper "The Missing Link" Acs, Audretsch, Braunerhjelm & Carlsson (2004) address the problem of knowledge spillovers by extending existing endogenous growth models. Regional variations in growth occur because the spillover of new knowledge and creation of innovation is not an automatism but is moderated by a knowledge filter. This mechanism defines the efficiency of turning new knowledge into economically relevant knowledge. Acs & Plummer (2005) identify two independent transmission channels: a) entrepreneurship and b) incumbent firms. Their results are similar to our findings presented above. While entrepreneurship widens the knowledge filter, incumbent firms tend to narrow the filter. Although using data for US metropolitan areas and spatial regression models (LISA) Acs & Plummer likewise identify significantly negative interactions of incumbent regional knowledge and additional knowledge transmission as our model 4. Müller (2006) in her investigation of the knowledge filter in Germany finds results analogous to our model 3: UITT has a positive effect on the total amount of regional knowledge production. Our paper is

the first to mainly address the role of incumbent firms as parts of regional innovative milieus. While prior investigations into the knowledge filter seek to identify the role of entrepreneurship. Because of their age and involvement in buyer-supplier-networks incumbent firms are more suitable for product and process innovations along their industries value chain. They might not be willing or able to incorporate revolutionary new knowledge (as supplied by universities). By focusing on path dependent channels of knowledge transmission they narrow the knowledge filter. Therefore the more successful the regional industry and the denser the industrial web of knowledge, the harder it is for universities to transfer additional knowledge into the industry. On the other hand a less successful regional innovative milieu might be looking for new ways to innovate and therefore might be more open to additional university innovation.

## Literature

- Acs, Z. J., Anselin, L., & Varga, A. (2002). Patents and innovation counts as measures of regional production of new knowledge. *Research Policy*, 31(7), 1069-1085.
- Acs, Z. J., & Audretsch, D. B. (1989). Patents as a Measure of Innovative Activity. *Kyklos*, 42(2), 171-180.
- Acs, Z. J., Audretsch, D. B., Braunerhjelm, P., & Carlsson, B. (2004). *The Missing Link: The Knowledge Filter and Entrepreneurship in Endogenous Growth*: SSRN.
- Acs, Z. J., Audretsch, D. B., & Feldman, M. (1992). Real effects of academic research: comment. *The American Economic Review*, 363-367.
- Acs, Z. J., Audretsch, D. B., & Feldman, M. (1994). R & D Spillovers and Recipient Firm Size. *Review of Economics & Statistics*, 76(2), 336-340.
- Acs, Z. J., & Plummer, L. A. (2005). Penetrating the "knowledge filter" in regional economies. *The Annals of Regional Science*, 39(3), 439-456.
- Anselin, L., Varga, A., & Acs, Z. (1997). Local geographic spillovers between university research and high technology innovations. *Journal of Urban Economics*, 42(3), 422-448.
- Anselin, L., Varga, A., & Acs, Z. (2000). Geographical Spillovers and University Research: A Spatial Econometric Perspective. *Growth & Change*, 31(4), 501-515.
- Antikainen, J. (2005). The concept of Functional Urban Area. *Informationen zur Raumentwicklung*, 447-456.
- Arrow, K. J. (1962a). The economic implications of learning by doing. *The Review of Economic Studies*, 155-173.
- Arrow, K. J. (1962b). Economic welfare and the allocation of resources for inventions. In R. R. Nelson (Ed.), *The Rate and Direction of Inventive Activity* (pp. 609-626). Princeton, NJ: Princeton University Press.
- Audretsch, D. B., & Feldman, M. P. (1996). R&D Spillovers and the Geography of Innovation and Production. *American Economic Review*, 86(3), 630-640.
- Audretsch, D. B., Keilbach, M. C., & Lehmann, E. E. (2006). *Entrepreneurship and economic growth*: Oxford University Press, USA.
- Audretsch, D. B., & Lehmann, E. E. (2004). Universitäten als regionale Förderer der Wirtschaft? *ifo Dresden berichtet*(3), 18-23.
- Audretsch, D. B., & Lehmann, E. E. (2005a). Does the Knowledge Spillover Theory of Entrepreneurship hold for regions? *Research Policy*, 34(8), 1191-1202.
- Audretsch, D. B., & Lehmann, E. E. (2005b). Mansfield's Missing Link: The Impact of Knowledge Spillovers on Firm Growth. *Journal of Technology Transfer*, 30(1/2), 207-210.
- Audretsch, D. B., & Lehmann, E. E. (2006). Do Locational Spillovers Pay? Empirical Evidence from German IPO Data. *Economics of Innovation and New Technology*, 15(1), 71-81.
- Audretsch, D. B., Lehmann, E. E., & Warning, S. (2005). University Spillovers and new firm location. *Research Policy*, 34(7), 1113-1122.
- Bairoch, P. (1991). *Cities and Economic Development: from the Dawn of History to the Present*: University of Chicago Press.
- Blumenthal, D., Campbell, E. G., Anderson, M., Causino, N., & Louis, K. S. (1996). Participation of Life Science Faculty in Research Relationships with Industry. *New England Journal of Medicine*, 335(23), 1734-1739.

- Bray, M. J., & Lee, J. N. (2000). University Revenues from Technology Transfer: Licensing Fees vs. Equity Positions. *Journal of Business Venturing*, 15(5/6), 385-392.
- Breschi, S., & Lissoni, F. (2001). Knowledge spillovers and local innovation systems: a critical survey. *Industrial and Corporate Change*, 10(4), 975-1005.
- Carlsson, B., & Fridh, A.-C. (2002). Technology transfer in United States universities. *Journal of Evolutionary Economics*, 12(1-2), 199-232.
- Chapple, W., Lockett, A., Siegel, D., & Wright, M. (2005). Assessing the relative performance of U.K. university technology transfer offices: parametric and non-parametric evidence. *Research Policy*, 34(3), 369-384.
- Coupe, T. (2003). Science Is Golden: Academic R&D and University Patents. *Journal of Technology Transfer*, 28(1), 31-46.
- Dasgupta, P., & David, P. A. (1994). Toward a new economics of science. *Research Policy*, 23(5), 487-521.
- Dasgupta, P., & Stiglitz, J. (1980). Industrial structure and the nature of innovative activity. *The Economic Journal*, 266-293.
- Döring, T., & Schnellenbach, J. (2006). What do we know about geographical knowledge spillovers and regional growth?: a survey of the literature. *Regional Studies*, 40(3), 375-395.
- Drucker, J., & Goldstein, H. (2007). Assessing the Regional Economic Development Impacts of Universities: A Review of Current Approaches. *International Regional Science Review*, 30(1), 20-46.
- EC. (1995). *Green Paper on Innovation*. Brüssel: Europäische Kommission.
- EC. (2001a). *Benchmarking Industry-Science Relations - The Role of Framework Conditions - Final Report*. Brüssel: Europäische Kommission.
- EC. (2001b). *Promoting innovation through patents - Green Paper on the Community patent and the patent system in Europe*. Brüssel: Europäische Kommission.
- EC. (2008). *Towards a European Research Area - Science, Technology and Innovation - Key Figures 2007*. Brüssel: Europäische Kommission.
- Eckey, H.-F., Kosfeld, R., & Türck, M. (2006). Abgrenzung deutscher Arbeitsmarktregionen. *Raumforschung und Raumordnung*, 64, 299-309.
- Etzkowitz, H. (2003). Research groups as 'quasi-firms': the invention of the entrepreneurial university. *Research Policy*, 32(1), 109-121.
- Etzkowitz, H., & Klofsten, M. (2005). The innovating region: toward a theory of knowledge-based regional development. *R&D Management*, 35(3), 243-255.
- Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations. *Research Policy*, 29(2), 109-123.
- Etzkowitz, H., Webster, A., Gebhardt, C., & Terra, B. R. C. (2000). The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm. *Research Policy*, 29(2), 313-330.
- Feldman, M. P., & Lichtenberg, F. R. (1997). The Impact and Organization of Publicly Funded Research and Development in the European Community. *NBER Working Paper 6040*.
- Feller, I. (1990). Universities as engines of R&D-based economic growth: They think they can. *Research Policy*, 19(4), 335-348.
- Florida, R. (2002). The economic geography of talent. *Annals of the Association of American Geographers*, 743-755.

- Florida, R. (2004). *The rise of the creative class*: Basic Books New York.
- Friedman, J., & Silberman, J. (2003). University Technology Transfer: Do Incentives, Management, and Location Matter? *Journal of Technology Transfer*, 28(1), 17-30.
- Fujita, M., & Thisse, J.-F. (2002). *Economics of agglomeration: cities, industrial location, and regional growth*: Cambridge Univ Pr.
- Glaeser, E. L. (1999). Learning in Cities. *Journal of Urban Economics*, 46(2), 254-277.
- Glaeser, E. L., Kallal, H. D., Scheinkman, J. D., & Shleifer, A. (1992). Growth in Cities. *Journal of Political Economy*, 100(6), 1126-1152.
- Glaeser, E. L., Scheinkman, J., & Shleifer, A. (1995). Economic growth in a cross-section of cities. *Journal of Monetary Economics*, 36(1), 117-143.
- Gregorio, D. D., & Shane, S. (2003). Why do some universities generate more start-ups than others? *Research Policy*, 32(2), 209-227.
- Griliches, Z. (1979). Issues in Assessing the Contribution of R&D to Productivity Growth. *Bell Journal of Economics*, 10(1), 92-116.
- Griliches, Z. (1990). Patent Statistics as Economic Indicators: A Survey. *Journal of Economic Literature*, 28(4), 1661-1707.
- Gunasekara, C. (2006). Reframing the Role of Universities in the Development of Regional Innovation Systems. *Journal of Technology Transfer*, 31(1), 101-113.
- Henderson, J. V. (1983). Industrial Base and City Size. *American Economic Review*, 73(2), 164-168.
- Henderson, J. V. (1986). Efficiency of Resource Usage and City Size. *Journal of Urban Economics*, 19(1), 47-70.
- Henderson, J. V. (1994). Externalities and Industrial Development. *NBER Working Paper 4730*.
- Henderson, R., Jaffe, A., B., & Trajtenberg, M. (1998). Universities as a source of commercial technology: A detailed analysis of university patenting. *Review of Economics & Statistics*, 80(1), 119-127.
- Hülsbeck, M., & Lehmann, E. E. (2007). Entrepreneurship Policy in Bavaria: Between Laptop and Lederhosen. In D. B. Audretsch (Ed.), *Handbook of Research on Entrepreneurship Policy*. Cheltenham: Edward Elgar.
- Jacobs, J. (1969). *The Economy of Cities*. New York: Random House.
- Jaffe, A., B. (1989). Real Effects of Academic Research. *American Economic Review*, 79(5), 957-970.
- Jaffe, A., B., Trajtenberg, M., & Henderson, R. (1993). Geographical Localization of Knowledge Spillovers by Patent Citations. *Quarterly Journal of Economics*, 108(3), 577-598.
- Keilbach, M. C. (2000). *Spatial knowledge spillovers and the dynamics of agglomeration and regional growth*: Springer.
- Link, A. N., & Siegel, D. S. (2005). Generating science-based growth: an econometric analysis of the impact of organizational incentives on university industry technology transfer. *European Journal of Finance*, 11(3), 169-181.
- Lockett, A., Wright, M., & Franklin, S. (2003). Technology transfer and universities' spin-out strategies. *Small Business Economics*, 20(2), 185-200.
- Long, J. S. (1997). *Regression Models for Categorical and Limited Dependent Variables*. Thousand Oaks, London und Neu Delhi: SAGE Publications.
- Marshall, A. (1890). *Principles of economics*: Macmillan and co.

- Maskell, P., & Malmberg, A. (1999). Localised learning and industrial competitiveness. *Cambridge Journal of Economics*, 23(2), 167-185.
- Mowery, D. C., Sampat, B. N., & Ziedonis, A. A. (2002). Learning to patent: Institutional experience, learning, and the characteristics of U.S. university patents after the Bayh-Dole Act, 1981-1992. *Management Science*, 48(1), 73-89.
- Mowery, D. C., & Ziedonis, A. A. (2002). Academic patent quality and quantity before and after the Bayh-Dole act in the United States. *Research Policy*, 31(3), 399-418.
- Müller, P. (2006). Exploring the knowledge filter: How entrepreneurship and university-industry relationships drive economic growth  
*Research Policy*.
- Murmann, J. P., & Landau, R. (1998). On the Making of Competitive Advantage: The Development of the Chemical Industries in Britain and Germany Since 1850. *Chemicals and Long-Term Economic Growth: Insights from the Chemical Industry*, 27-70.
- Nelson, R. R. (1986). Institutions Supporting Technical Advance in Industry. *American Economic Review*, 76(2), 186-194.
- Nelson, R. R. (1994). The Co-evolution of Technology, Industrial Structure, and Supporting Institutions. *Ind Corp Change*, 3(1), 47-63.
- O'Shea, R. P., Allen, T. J., Chevalier, A., & Roche, F. (2005). Entrepreneurial orientation, technology transfer and spinoff performance of U.S. universities. *Research Policy*, 34(7), 994-1009.
- O'Shea, R. P., Allen, T. J., & Morse, K. (2005). *Creating the Entrepreneurial university: The Case of MIT*. Paper presented at the Academy of Management Conference. from [http://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=783866](http://papers.ssrn.com/sol3/papers.cfm?abstract_id=783866).
- Owen-Smith, J., & Powell, W. W. (2003). The expanding role of university patenting in the life sciences: assessing the importance of experience and connectivity. *Research Policy*, 32(9), 1695-1711.
- Payne, A. A., & Siow, A. (2003). Does Federal Research Funding Increase University Research Output? *Advances in Economic Analysis & Policy*, 3(1), 1018-1042.
- Phan, P. H., & Siegel, D. S. (2006). The Effectiveness of University Technology Transfer: Lessons Learned from Quantitative and Qualitative Research in the U.S. and the U.K. *Foundations and Trends® in Entrepreneurship*, 2(2).
- Powers, J., & McDougall, P. (2005). University start-up formation and technology licensing with firms that go public: a resource-based view of academic entrepreneurship. *Journal of Business Venturing*, 20(3), 291-311.
- Pregibon, D. (1980). Goodness of link tests for generalized linear models. *Applied Statistics*.
- Rip, A. (2002). Regional Innovation Systems and the Advent of Strategic Science. *Journal of Technology Transfer*, 27(1), 123-131.
- Romer, P. M. (1986). Increasing returns and long-run growth. *The Journal of Political Economy*, 94(5), 1002.
- Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(S5), 71.
- Rosenberg, N. (1963). Technological change in the machine tool industry, 1840-1910. *Journal of Economic History*, 414-443.
- Rothaermel, F. T., Agung, S. D., & Jiang, L. (2007). University entrepreneurship: a taxonomy of the literature. *Industrial and Corporate Change*, Advance Access published July 18 2007, 1-101.

- Sampat, B. N., Mowery, D. C., & Ziedonis, A. A. (2003). Changes in university patent quality after the Bayh Dole act: a re-examination. *International Journal of Industrial Organization*, 21(9), 1371-1390.
- Saxenian, A. (1994). *Regional advantage: culture and competition in Silicon Valley and Route 128*: Harvard University Press.
- Scherer, F. M. (1965). Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions. *The American Economic Review*, 55(5), 1097-1125.
- Scherer, F. M. (1982). Inter-industry technology flows in the United States. *Research Policy*, 11(4), 227-245.
- Siegel, D. S., Waldman, D. A., Atwater, L. E., & Link, A. N. (2003). Commercial knowledge transfers from universities to firms: Improving the effectiveness of university-industry collaboration. *Journal of High Technology Management Research*, 14(1), 111-133.
- Smith, D., & Florida, R. (1994). Agglomeration and Industry Location: An Econometric Analysis of Japanese-Affiliated Manufacturing Establishments in Automotive Related Industries. *Journal of Urban Economics*, 36, 23-41.
- Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, 65-94.
- Thursby, J. G., Fuller, A., & Thursby, M. C. (2009). US faculty patenting: inside and outside the university. *Research Policy*, 38(1), 14-25.
- Thursby, J. G., Jensen, R., & Thursby, M. C. (2001). Objectives, Characteristics and Outcomes of University Licensing: A Survey of Major U.S. Universities. *Journal of Technology Transfer*, 26(1-2), 59-72.
- Uzawa, H. (1965). Optimum technical change in an aggregative model of economic growth. *International Economic Review*, 18-31.
- Varga, A. (2000). Local academic knowledge transfers and the concentration of economic activity. *Journal of Regional Science*, 40(2), 289-309.
- Yip, K. Y., Patel, P., Kim, P. M., Engelman, D. M., McDermott, D., & Gerstein, M. (2008). An integrated system for studying residue coevolution in proteins. *Bioinformatics*, 24(2), 290-292.
- Youtie, J., & Shapira, P. (2008). Building an innovation hub: A case study of the transformation of university roles in regional technological and economic development. *Research Policy*, 37(8), 1188-1204.
- Zucker, L. G., & Darby, M. R. (1996). Star Scientists and Institutional Transformation: Patterns of Invention and Innovation in the Formation of the Biotechnology Industry. *Proceedings of the National Academy of Science*, 93(23), 12709-12716.
- Zucker, L. G., Darby, M. R., & Armstrong, J. S. (2002). Commercializing knowledge: University science, knowledge capture, and firm performance in biotechnology. *Management Science*, 48(1), 138-153.