

Universities' functions in knowledge transfer: a geographical perspective

Martina Fromhold-Eisebith · Claudia Werker

Received: 18 January 2011 / Accepted: 22 February 2013 / Published online: 9 March 2013
© Springer-Verlag Berlin Heidelberg 2013

Abstract Universities' functions in knowledge transfer have been thoroughly investigated by scholars from different disciplines in the last decades. However, a complete picture of universities' contribution to regional, national and international knowledge transfer is still missing. In this paper, we pull together the strings of various scholarly works produced by economic geographers, economists, regional scientists and others, thereby taking stock of achievements and shortcomings and elaborating avenues for further scientific work. We analyse the various functions of universities by using four conceptual frameworks, namely the regional innovation systems approach, the new production of technology theory, the triple helix model and social network theory. These different frameworks help to integrate the functions of universities into local-regional, national and international relationships theoretically. Empirically, universities' relationships have been investigated by case studies, surveys and increasingly by social network analysis. Our exercise results in a critical discussion of a predominantly regional focus of investigation. Looking at knowledge transfer from a regional, national and international perspective leads to a different way of developing theoretical concepts and matching them with empirical tools. In particular, we find that social network analysis and its theoretical basis, i.e., social network theory, will give more body to understanding knowledge transfer functions of universities.

JEL Classification O30 · O33 · O38 · R19

M. Fromhold-Eisebith · C. Werker
Department of Geography, Chair of Economic Geography, RWTH Aachen University,
Templergraben 55, 52056 Aachen, Germany

C. Werker (✉)
Department of Technology, Policy and Management, Section Economics of Innovation,
Delft University of Technology, Delft, The Netherlands
e-mail: c.werker@tudelft.nl; c.werker@geo-rwth.aachen.de

1 Introduction

For decades, universities have been considered as potential engines of innovation-driven development (Goddard et al. 1994; Malecki 1997; Feldman and Link 2001; Bercovitz and Feldman 2006; Gunasekara 2006; Power and Malmberg 2008). With the help of theoretical reasoning and empirical testing, scholars have examined aspects of knowledge provision and use, like institutional changes and learning processes of universities (Etzkowitz 2004; Srinivas and Viljamaa 2008), different kinds of knowledge interaction and transfer channels (Scharinger et al. 2001, 2002; D'Este and Patel 2007; Fritsch et al. 2007; Jensen et al. 2007) or regional economic implications of collaborations (Bekkers and Bodas Freitas 2008; Drucker and Goldstein 2007; Kauffeld-Monz and Fritsch 2008; Varga 2009; Uyarra 2010). Growing expectations in universities as engines of regional innovativeness have entailed the mushrooming of new institutions and policies for strengthening university–industry–government linkages and their outcomes (Bozeman 2000; Boucher et al. 2003; Debackere and Veugelers 2005; D'Este and Patel 2007; Wright et al. 2008; Geuna and Muscio 2009). Universities are now counted on as active contributors to the regional innovation system and economic development (Godin and Gingras 2000; Bercovitz and Feldman 2006; Benneworth and Arbo 2007; Srinivas and Viljamaa 2008; Caniëls and van den Bosch 2011). They shift towards the ‘entrepreneurial university’ that does not only contribute to regional but also to national and international innovation (Etzkowitz 2004; Bramwell and Wolfe 2008; Goldstein 2010) by translating academic research into commercial outputs in terms of a ‘third mission’ besides scientific research and teaching (Etzkowitz and Leydesdorff 2000).

For adequately analysing universities’ functions in knowledge transfer, we suggest to develop theoretical concepts together with empirical tools measuring them. In contrast to a focus on regional impact that marks many recent studies (Boucher et al. 2003; Gunasekara 2006; Drucker and Goldstein 2007; Uyarra 2010; Caniëls and van den Bosch 2011), we employ an extended geographical view considering universities’ functions as being shaped by regional, national and international orientations. In doing so, we can draw on a number of reviews on universities and their geographical context written in the last decade, which have analysed institutional, social or political factors embedding or disembedding universities, eventually influencing the development of their region of location (Bercovitz and Feldman 2006; Drucker and Goldstein 2007; Power and Malmberg 2008; Caniëls and van den Bosch 2011). Taking into account the various, at times contradictory mechanisms via which universities are linked to regional economic processes (Uyarra 2010), and the debate on whether and under which conditions universities actually contribute to regional innovation (Power and Malmberg 2008), we aim at achieving a more comprehensive understanding of relevant mechanisms: We suggest that universities’ integration into scale-crossing collaboration systems contributes to regional innovation. In order to more clearly disentangle universities’ functions in knowledge transfer from a geographical perspective, we further suggest better matching theoretical conceptualization and empirical measurement.

Analysing universities’ functions in knowledge transfer confronts us with the complex interplay of a university’s self-determined or superimposed role, its potential or expected input to regional innovativeness, and characteristics of the surrounding

economy that shape absorptive capacities of regional players. This seems to make it virtually impossible to include all of this into a concise account of universities' regional relationships of knowledge-intensive collaboration. The intricate question of how the 'region' of a university can be unequivocally distinguished must be answered. Based on this, we need to find out why there are quite a few cases where the knowledge flows from the university to regional partners fall short of expectations (Bramwell and Wolfe 2008; Fromhold-Eisebith 1992, 2006). We suggest that this has to do with:

1. unrealistic assumptions about what a university can contribute to innovation-oriented regional development through knowledge transfer because knowledge flows are usually not confined to geographical borders and may only show effects after decades, as well as
2. inappropriate theoretical or empirical approaches applied to capturing relevant systems of relationships and their geographies.

In our paper we will show that knowledge transfer has a local-regional, national and international dimension, calling for further advancement of theory and empirics in order to better understand and capture factors that shape universities' impact on regional development. Two main objectives provide the guideline of argumentation: first, we review which roles and functions have been devoted to universities, drawing on relevant concepts (Sect. 2). From these debates, a set of qualities is derived that should mark a university's integration into collaborative linkages in order to make them effective, including scale-crossing geographical aspects. Second, we discuss various empirical approaches that have been applied to assessing a university's integration into systems of relationships, revealing methodological achievements and shortcomings (Sect. 3). Based on that, we consider how a university's knowledge transfer can adequately be investigated by matching theory and empirics or by further developing and tailoring theoretical and empirical approaches (Sect. 4). We wrap up with some suggestions on how future research may benefit from our results (Sect. 5).

2 Universities' functions in knowledge transfer: theoretical approaches

In order to assess how university–industry interactions may expediently be investigated empirically, we first need to clarify what exactly universities (faculty, students and researchers) are supposed to contribute to knowledge transfer. Thus, we need to point out various aspects that determine the functions of universities in this regard. This clarifies the kinds of relationships to be looked at, the types of agents to be included, the sort of outcomes to be taken into consideration and, last but not least, the aspects of geography and proximity to account for. From a conceptual angle, the universities' role and function has been associated with different explanatory approaches (c.f. Drucker and Goldstein 2007). In the following, we pick four approaches: the first three have made the main theoretical contributions to universities' role in knowledge transfer. These are the Regional Innovation Systems Approach (RIS), the New Production of Knowledge Theory (NPK), the Triple Helix Model (THM) and Social Network Theory (SNT). While the RIS Approach chiefly conceptualizes universities' embedding in regional settings of knowledge generation and use, the NPK Theory and the THM take a more general view on the (geographical) impact of universities. Despite their

contributions to analysing universities in knowledge networks, neither the NPK nor the Triple Helix has disentangled normative with positive elements (Shinn 2002; Hessels and van Lente 2008). Moreover, the aforementioned approaches as well as the RIS approach have not provided a systematically empirical approach (Shinn 2002; Hessels and van Lente 2008; Edquist 2005). We suggest that the three approaches are best suited to guide empirical analysis. We include SNT as fourth approach as it is a powerful means of understanding social relationships in various contexts that has developed a strong empirical toolbox, i.e., social network analysis.

All four theoretical approaches help us pointing out how broad the range of relevant determinants and linkage types is. This refers to the mission of the university itself (Sect. 2.1), which we take up first as the overarching goal-giving set-up. Then, we turn to the three processes where universities are major contributors to knowledge transfer: their knowledge transfer linkages to regional partners (Sect. 2.2), their ability to generate human capital and spin-off entrepreneurship (Sect. 2.3), and their function as node of extra- and intra-regional relationships (Sect. 2.4). Eventually, the fifth function captures the universities' overall and aggregated contribution to (regional) economic development (Sect. 2.5). By pulling together these strings, we offer a synthesis of perspectives on universities' relational and functional features as this has not been compiled before.

2.1 The mission of universities

Since the 1980s, the mission of universities has undergone significant changes (Goddard et al. 1994). This bears a crucial impact on the universities' embedding in collaborations and the geography of relationships. A university's mission shapes its attitudes towards basic and applied research and towards teaching by focusing either on academic excellence or practical applications or on a combination of both. Moreover, it affects the balance between self-determined and externally contracted R&D as well as the preference for either public or private partners. The choice, for instance, between industrial collaborations in basic or applied research has significant implications for the nature of interaction and the value created for the university (Perkmann and Walsh 2009). While the universities' mission in the knowledge economy and society appears to have generally shifted towards the 'entrepreneurial university' (Etzkowitz 2004; Mansfield and Lee 1996), changes differ for different countries and regions.

Conceptually, mainly two approaches mark the debate on the transforming representation of universities: the NPK Theory (Gibbons et al. 1994; Nowotny et al. 2001) and, logically connected to that, the THM (Etzkowitz and Leydesdorff 2000; Shinn 2002). Both of them suggest that universities reorient towards the commercialization of created knowledge. The NPK Theory discusses the role of universities in relation to 'Mode 1' and 'Mode 2' of knowledge production (Nowotny et al. 2003; Hessels and van Lente 2008). In contrast to 'Mode 1', which focuses on academic basic research, the agency of individuals, scientific peers and a hierarchical university-centred government system, 'Mode 2' emphasizes the transdisciplinary nature of knowledge production, which emerges from a wider range of organizations (also government agencies, public R&D laboratories, private firms, etc.). They form communities which

collectively generate application-oriented knowledge according to social contexts and recombine different fields of research in new ways. 'Mode 2' bears a heterarchical organization of knowledge production shaped by the dynamic structures of temporary networks of experts.

Consequently, universities are ready to interact more with non-academic partners (Estabrooks et al. 2008; Nagle 2007), which makes regional collaboration more important, spurred by advantages of physical and social proximity (Gunasekara 2006). Universities seek more contact with industry in order to commercialize research outputs, access complementary skills and profit from interactive learning processes. Conversely, technology-driven firms recognize universities as important sources of knowledge that may enhance competitiveness and innovation (Cohen et al. 2002; Freel 2003; Laursen and Salter 2004; Weijnen and Bowmans 2006; Bekkers and Bodas Freitas 2008; van Beers et al. 2008; Eom and Lee 2010). In particular, universities of technology have successfully increased the spillover and commercialization of academic knowledge (Audretsch and Lehmann 2005), because they have traditionally been acting in 'Mode 2'.

The THM similarly emphasizes the relationships of universities with other partners, explicitly also including the government (Etzkowitz and Leydesdorff 2000; Leydesdorff 2005a,b). The notion symbolizes the opening up of universities towards the outside world, their reorientation away from purely inward-looking activities of isolated research and academic teaching (Shinn 2002). In this vein, the Triple Helix of trilateral university–industry–government interaction illustrates the readiness of university faculty and graduates to proactively engage in technology transfer, augmenting the agency traditionally occupied by the private sector (Leydesdorff 2005a,b). In a network of loosely coupled reciprocal relations, universities organize the production and commercialization of knowledge interactively with partners, balancing requirements of independence and interdependence (Hessels and van Lente 2008).

Accordingly, research that aims at capturing geographical dimensions of university linkages needs to take account of the mission of the investigated organization. Depending on its mode of knowledge production as well as its chosen position in triple helix constellations, the focus of external collaboration of the university and the kinds of partners may differ, shaping the geographical reach of relationships.

2.2 Universities as regional knowledge providers

In line with the changing mission of universities, expectations have grown concerning their function as providers of knowledge transfer to regional partners (Florax 1992; Charles 2003; Varga 2009; D'Este and Iammarino 2010). Theoretically this is linked with the THM, the RIS Approach and SNT. A range of other concepts emphasize the advantages of regionalized knowledge-intensive collaboration as well but do not focus on the role of universities in the first instance, such as Learning Region, Creative Milieu or Cluster (Charles 2007; Fromhold-Eisebith 2009). Universities are imagined to contribute to regional innovation-oriented development through a set of predominantly local linkages.

Important conceptual assumptions that matter for empirical investigations relate, above all, to potential types of collaborations (Bekkers and Bodas Freitas 2008; Fromhold-Eisebith and Schartinger 2002; Malecki 1997; Schartinger et al. 2001, 2002). Various channels may be used, such as technology transfer via contract research or collaborative R&D, rarely associated with patenting or licensing agreements; the less costly variant of consultancy work by faculty members for firms; the use of technical equipment of the university by firms; the transfer of knowledge embedded in university graduates employed by firms; the attraction of R&D-oriented corporate investments from outside; science-based further education for company employees; knowledge transfer occurring in the context of sophisticated technical supplies by firms to the university (in case equipment needs to be constructed tailor-made to specific scientific requirements), or, more simply, the provision of information to users outside of the university (e.g. through libraries). It has to be pointed out that partners not only include private manufacturing or service firms, but also parts of public administration that represent an often overlooked recipient of human capital and consulting services from universities.

The Triple Helix framework has helped to discover through which channels knowledge transfers from universities to industrial or administrative partners seem possible (Benneworth and Arbo 2007; Bercovitz and Feldman 2006; Malecki 1997; Feldman and Massard 2002; Gunasekara 2006; Leydesdorff 2005a,b). It has also raised the agents' awareness of some typical barriers that hamper effective academia–industry interaction and collective innovations (Bruneel et al. 2010). These obstacles concern, for instance, differing expectations of universities and firms with regard to the nature of collaborative R&D (long-term, scientifically challenging projects versus short-term provision of solutions to technical production problems) as well as discrepancies of the language and basic terminology obstructing the understanding between university faculty and company employees. Because of such obstacles to knowledge transfer, government interventions and support measures are required, which reduce barriers and foster prospective fields of university–industry collaboration. Accordingly, the three kinds of agents need to locally interact in specific ways in order to bear the desired effects. It must be pointed out that not only public institutions but also academic organizations themselves engage in technology transfer promotion (Debackere and Veugelers 2005; Wright et al. 2008; Geuna and Muscio 2009).

The inclusion of government agency into the Triple Helix framework in particular suggests a focus on regional linkages of the university, since administrative borders and regions of responsibility provide some framework for action. Public organizations engage in fostering knowledge transfer from universities because they want the benefits to stay in their own constituency. This reverberates similar claims made with regard to the function of universities in RIS (Charles 2006; Fritsch and Schwirten 1999).

Traditionally, universities have been centre stage in the RIS approach (cf. Werker and Athreye 2004). Generally spoken, an innovation system comprises the relationships between innovative agents, public or private supporting organizations, and the institutional setting. It acknowledges that networks can be more than the sum of individual agents (Lundvall 1992; Nelson 1993; Edquist 2005) and that agents organize their activities beyond markets and hierarchies (Powell 1990; Kogut 2000). On the regional level, the innovation systems approach explains the geographical distribution

of innovation activities by combining knowledge infrastructure with innovative behaviour (Cooke et al. 2004; Werker and Athreye 2004).

Universities can play a crucial role in providing knowledge for regional partners. There are some famous success stories that have been thoroughly investigated, such as Silicon Valley with Stanford University (e.g. Saxenian 1994). Neither the firms nor the university alone would have been able to trigger off such dynamics. The RIS where a well-equipped university, rooted in military tradition, co-evolved with highly performing start-ups supported by uniquely developed institutions suited to its needs (e.g. venture capital) made Silicon Valley a success (Saxenian 1994). Within the European Union, Oxford and Grenoble did particularly well for the same kinds of reasons (Lawton Smith 2003). Conversely, these success stories hint at problems of non-success stories, i.e., when universities are part of the regional infrastructure but do not provide knowledge for the region. According to the innovation systems approach, non-success has basically three causes: one, missing or malfunctioning agents, two, missing or malfunctioning relationships between agents, three, absent or inappropriate institutions (e.g. Metcalfe 2005; Klein-Woolthuis et al. 2005). This does by no means imply that a missing or malfunctioning agent, e.g., no university in the region, leads to failure. A region might still thrive without a university as long as the functions that the RIS requires are provided, e.g., by a private research agency (Bergek et al. 2008).

SNT is deeply rooted in sociology and has only during the last decade been applied to questions of knowledge transfer and the role of universities in a regional context (Bergman 2009; Fritsch and Kauffeld-Monz 2010). Social networks are a social construct and can span across boundaries of regions and even across the world (Ter Wal and Boschma 2009). This rather broad approach investigates the individual and social structure of networks. Agents and their relationships are mapped, structured and carefully analysed (cf. Freeman 2004; Huber 2009; Moody 2001; Wassermann and Faust 1994). Researchers of universities can provide knowledge via different kinds of linkages, namely their PhD students, their collaborators and their promoters (Verspagen and Werker 2004). These linkages can reach into universities, other research agencies, firms or governmental agencies. There are indications that, in line with the findings of triple helix, collaboration between researchers from different spheres can be very fruitful. For the Italian microelectronics sector, Balconi and Laboranti (2006) showed that it is important to have strong ties between researchers from industry and universities in order to achieve high scientific performance. While SNT is very strong regarding its empirical methods (see Sect. 3), it requires substantial elaboration regarding the theoretical underpinnings (Grabher and Powell 2005; Huber 2007, 2009).

2.3 Universities' potential to foster and generate human capital and entrepreneurship

Generating human capital and entrepreneurship are very important functions of universities. The two effects are related and have been particularly investigated with the help of SNT and the innovation systems approach.

Creating human capital has traditionally been a core function of universities (e.g. Gunasekara 2006; Drucker and Goldstein 2007; Faggian and McCann 2009). Human

capital is knowledge embodied in faculty, students and researchers, i.e., an accumulation of their expertise, skills and abilities that they acquire through experience or education at the university. When investigating the role of human capital, it becomes clear that these types of agents contribute in two specific ways to economic change in general and regional development in particular (Murray 2004): First of all, well-respected researchers connected to other academic researchers or other researchers in firms signal the quality of the underlying science as well as of the university itself. Second, while embodied knowledge is difficult to transfer between people and organizations (cf. Jensen et al. 2007), it can be relatively easily transferred via the labour market, i.e., by hiring students or university staff by non-university organizations (Faggian and McCann 2009). In particular, human capital can be transferred beyond the region the university is located in and therefore has a national and international impact in knowledge transfer as well.

Universities can particularly contribute via entrepreneurship education. As regional development might be hampered by a lack of competent individuals to manage projects and become entrepreneurs, universities can help overcoming this bottleneck by teaching individuals to increase their motivation and ability to innovate and to become an entrepreneur. Like shown for the cases of five Swedish universities, recently learning-by-doing activities in groups and networks have gained importance (Rasmussen and Sorheim 2006). This has also to do with the fact that universities' initiatives serve multiple goals relating to the objective of commercializing university research output (see Sect. 2.1).

Spin-offs are a particular case of enterprises. Here, the entrepreneur stems directly from the university—either as graduate, faculty or researcher. Sometimes, he/she even stays part of it, in particular faculty working at the university while being involved with a company that commercializes research results. The crucial contribution to regional success by spin-offs is based on the commercial exploitation of knowledge previously acquired by the founder while studying or working at the university. This has been emphasized by policy makers and academic scholars alike (Charles 2002; Benneworth and Charles 2004; Shane 2004; van Geenhuizen and Soetanto 2004; Bercovitz and Feldman 2006; Boucher et al. 2003; Gunasekara 2006). Underscoring this interest, impulses of entrepreneurship seem to represent the most regionally oriented economic effect of universities (Feldman and Massard 2002; Malecki 1997). Reasons lie in the social embedding of the entrepreneur in the region, where he/she not only spent the time of study but often also worked in university-based projects, established friendships and founded a family (Fromhold-Eisebith 1992). Universities, however, differ in their propensities to generate start-ups due to a set of various interacting factors, namely their discipline focus (with advantages for engineering sciences), their orientation towards third-party-funded R&D and the existence of support schemes that raise students' awareness of entrepreneurship opportunities (Di Gregorio and Shane 2003).

By driving and stimulating regional entrepreneurship, universities link various modes of knowledge and technology transfer and cause a growing bias on the region of location (Feldman and Massard 2002; Malecki 1997). Founding an enterprise already combines the commercialization of academic knowledge with the transfer of qualified human capital in the form of the entrepreneur(s). Subsequently, some supportive influence of universities on their spin-off companies prevails also after the young

enterprises have grown up. Quite regularly, firms profit from continuing contact to their former academic supervisors or colleagues in terms of information flows, and they source interns, student workers or employees through this channel, use testing or measuring equipment of the university, or enter R&D collaborations (Fromhold-Eisebith 1992; Rothaermel and Thursby 2005). This renders spin-off entrepreneurship particularly an effective means of regionalized academia–industry collaboration. It thus deserves specific attention in empirical research on factors that shape the geography of university relationships.

2.4 Universities as nodes of intra- and inter-regional linkages

The necessity for universities to be internationally connected is often overlooked in debates on their function as knowledge providers for economic uses (for an exception see Pike and Charles 1995). The geography of university relationships, however, needs to include far reaching and proximate linkages in order to support regional industrial development. Fortunately, in recent years, the debate on the universities' role as drivers of regional development has started to loose some of its 'regional fixation'. While government support clearly advocates a regional focus, the two other groups, i.e., universities and industry, do not necessarily share that view but target wider spatial horizons. Neither do university faculty select their research partners mainly according to physical proximity nor do companies choose their technology and knowledge suppliers just by picking the nearest option, which eventually creates fairly complex and volatile geographies of knowledge production (Ibert 2007; Cunningham and Werker 2012). Although distance matters to some extent by virtue of social contacts, accessibility and trust, also remote relationships represent crucial assets of universities. This holds true especially with respect to the scientific networks into which university researchers are integrated. The world of academic exchange is, by nature, highly internationalized and must be so in order to bring together the top people and best ideas on a global scale.

Some scholars have emphasized the importance of connecting the local circulation of knowledge with inputs from outside. The initially geographically quite restrictive concept of RIS, for instance, has been opened up towards incorporating influences from different spatial scales: the system is now expected to integrate local 'sticky' and global 'ubiquitous' knowledge (Asheim and Isaksen 2002). Similarly, clusters should not only consist of 'local buzz', but also possess 'global pipelines' in order to remain flexible (Bathelt et al. 2004). The contrasting views of these two approaches with regard to the nature of external knowledge acquisition already set the scene for an interesting debate about broadly available versus narrowly channelled knowledge supplies. They underscore how important it is to regard various interacting scales when thinking about the universities' impact on economic development.

Universities may be conceived as particularly suitable conduits for combining the external sourcing of knowledge with its local integration and circulation. In this sense, they are well-endowed agents for bridging between scales of innovation systems (Fromhold-Eisebith 2007; Power and Malmberg 2008). Faculty members are well embedded in international scientific communities, which offers options both to

establish selective ‘pipelines’ and to broadly source ‘ubiquitous’ knowledge from academic events, such as conference participations abroad. When some of this externally acquired information also feeds into local linkages of application-oriented collaboration, maybe channelled through acquainted spin-off enterprises, this can substantially enrich the regional knowledge base.

Concerning research on the geography of university relationships, this requires to include all scales and not to focus only on the regional one. Probably, there is some correlation between the scale of linkages, the kind of partner organizations, and the purpose and outcome of exchanges with the university, which deserve further exploration.

2.5 Regional outcomes of universities’ relationships

The main reason why universities’ linkages to partners have received widespread scientific attention is that they are conceived as conduits for stimulating regional economic effects (Florax 1992; Goddard et al. 1994; Uyerra 2010). This is why public agents intervene and specifically support localized university–industry collaboration, and this is also the main motivation for university-related policies (Audretsch and Lehmann 2005; Wright et al. 2008). Expectations relate, above all, to a rise of the innovativeness and, hence, the economic competitiveness of firms (Malecki 1997; Beise and Stahl 1999; Feldman and Massard 2002; Power and Malmberg 2008). In detail, universities are expected to increase the regional knowledge base, corporate technological innovation based on knowledge transfer, and investments, in line with creating atmospheric benefits in terms of leadership and an academic milieu (Drucker and Goldstein 2007).

Not all of the desired outcomes, however, easily materialize, and some of them are extremely difficult to measure (Benneworth and Arbo 2007). While some indicators on regional innovative output, productivity or export performance may suit to capture university-induced effects, there is always the problem how to separate influences by the university from the plethora of other factors that determine regional economic dynamics (Drucker and Goldstein 2007). In any given case, the university is but one out of many organizations that shape the fate of a region. In fact, often developments are to a much larger extent subject to external forces of economic globalization than regional ones. Furthermore, analysing overall regional outcomes inevitably requires predetermining the university’s region of influence. This may only reflect the opinion of the public part of the triple helix, whereas the other two parties rather look at wider spatial reach.

When concrete economic impacts can be followed back to certain interactions of the university with regional partners, like the launching of a particular new product that was developed jointly by the university and a firm close by, the causal relationship may be clear. Yet, the logical link between university relationships and regional outcomes is often hampered by ambiguity. Not every university–industry collaboration bears tangible results. Sometimes economic manifestations materialize only many years after technology transfer took place, and often the financial volume of a cooperation project is not equivalent to the value created for the involved firm (Fritsch et al. 2007).

Accordingly, the question of how the impact of a university's knowledge-related activities actually shows in regional development is not yet solved (Benneworth and Arbo 2007; Drucker and Goldstein 2007). It is even more difficult to determine the results of its knowledge transfer on the national and international level.

Consequently, investigations of universities' relationships should bear in mind that the interaction triggers some effects and that those effects may affect a range of variables. The question which types of collaboration, in which discipline, produce the strongest outcomes is particularly interesting in this context (for the case of Italian microelectronics see Balconi and Laboranti 2006). No less important are geographical issues, like interdependencies between proximity, kinds of relationships and impact (Cunningham and Werker 2012).

3 Universities' functions in knowledge transfer: empirical approaches

In line with theoretical reasoning, empirical analysis advances the understanding of the geographical dimensions of universities' relationships. In the following, we depict empirical methods usually used in this context. We discuss to which extent these methods seem appropriate for capturing the universities' functions and the geography of their relationships.

Different kinds of data can be used to map and analyse universities' relationships, in particular data stemming from interviews and from surveys (e.g. Krätke and Brandt 2009; Soetanto and van Geenhuizen 2009) and publication, patent and funding data (e.g. Cantner and Graf 2006; D'Este and Iammarino 2010; Graf 2010; Crespi et al. 2011; Maggioni et al. 2011). Data from interviews are usually limited in number and therefore difficult to generalize. However, it is very detailed in nature, which often leads to a better and more thorough understanding. Survey data on regional university–industry–government linkages try to capture a fairly comprehensive picture based on written surveys among a larger number of research institutes or local firms (Soetanto and van Geenhuizen 2009; Graf 2006). Graf (2010), for instance, showed that universities contribute to the success of regions as gatekeepers by transferring internal and external knowledge, thereby supporting the view of universities as nodes of inter- and intra-regional knowledge transfer (see Sect. 2.4).

While scholars can gain detailed and comprehensive insights from surveys, they have to take into consideration four limitations (c.f. Ter Wal and Boschma 2009; Kleinknecht et al. 2002): One, the longer and more comprehensive the questionnaire, the lower the response rate, which restricts the validity of findings. A short questionnaire, in contrast, falls short of including necessary differentiations. Two, the terms used in the questionnaires can get misinterpreted or mean something different to different respondents, like the notions of relationship or collaboration. Three, carrying out a survey costs a lot of time and can often only involve a selective sample. Four and most notably, surveys often predetermine the geography of the university's collaborations. As the embedding of a university combines various spatial scales, approaches should flexibly allow such features to emerge from investigation. The sampling method of a survey, however, already pre-defines the 'region' of the university: addressed agents are usually chosen according to their location within certain administrative boundaries.

In similar ways, also information gained through university-centred surveys is usually evaluated against a predetermined assumption of what the 'region' actually is (in terms of 'regional share' of partners or collaborations).

With the help of publication, patent and funding data scholars can draw a comprehensive picture of regional collaboration network of universities. Looking at this kind of data comes with the usual caveats (Kleinknecht et al. 2002; Nelson 2009; Ter Wal and Boschma 2009). In particular, publication and patent data do not cover unpublished research activities, thereby underestimating the efforts of small- and medium-sized companies as well as of industries which traditionally rely on secrecy to keep their ideas from being copied. Moreover, the affiliations mentioned on the papers or patents may not be the places where the actual research was done, either due to change of affiliation or due to policies to only list the headquarters' address. The use of funding data (on R&D collaborations of university and industry) captures a certain type of collaboration efforts, which may not be representative of the overarching pattern of the university's knowledge transfer (D'Este and Iammarino 2010).

The complex collaboration systems between universities, companies and public agencies (see Sect. 2) are associated with equally complex geographies of knowledge transfer. They are shaped by the interdependent influences of physical, institutional and social proximity (Boschma 2005; Ponds et al. 2007), the focus of R&D and teaching at the university, its compliance with political strategies of innovation-oriented regional development, the absorptive capacities of regional and extra-regional partners, and other factors. This offers quite some scope to employ and refine empirical approaches and methods, notably case studies, econometrics, scientometrics and bibliometrics as well as social network analysis. In the following, we focus on advantages or shortcomings with regard to an adequate assessment of university–industry relationships.

The history of empirical research on university–industry collaboration and induced impacts has been marked by a growing number of individual case studies (Drucker and Goldstein 2007; Tornatzky 2001). Data, for instance, on R&D project partnerships are used to depict spatial patterns of technology transfer or to determine a region's share as a recipient of respective knowledge flows (Schartinger et al. 2001, 2002; Fromhold-Eisebith and Schartinger 2002; Fromhold-Eisebith 2006). Different processes can be addressed, like project collaborations, the use of technical equipment at the university by firms and the employment of alumni, which takes account of the diversity of services supplied by the university (Fromhold-Eisebith 1992; Fritsch et al. 2007; Graf 2006). Apart from sourcing and evaluating secondary data, information is usually collected via expert interviews or surveys of research institutes or regional firms. Reasoning may as well draw on a predominantly qualitative information base that consists of documents and experts' statements (Acworth 2008; Bramwell and Wolfe 2008). This way, various case studies provide evidence of highly place-specific constellations of agents, institutions and outcomes.

Without doubt, case studies have important merits. Conditions, agents and processes that characterize a university or sets of compared universities can be investigated in some depth, using a combination of various indicators and data (Drucker and Goldstein 2007). Many of the features depicted above, which influence the university's knowledge-driven interaction with its partners, can adequately be captured only by combining qualitative and quantitative information from different

sources. This applies to describing the role of a university, its ascribed function in a triple helix setting as well as the evolution and nature of its embedding in various categories of regional and extra-regional collaborations. In order to clearly identify the conditions under which a university operates and the various fields in which some impact on knowledge-driven economic development seems possible, a range and depth of information is required that can only be produced through a case study approach.

Case studies that use a mix of interview and survey methods are particularly well suited to investigate the mission of universities. They allow to source qualitative information which not only address facets of identity chosen by the university itself, but also roles inflicted on the organization by external peers (such as policy makers). Case studies can reveal the mostly highly idiosyncratic nature of respective constellations. This methodological approach seems also appropriate for collecting information on regional knowledge transfer and, to a lesser extent, on the generation of human capital and entrepreneurship by the university. Descriptive analyses bear the advantage of combining insights from a variety of information sources, which matches with the heterogeneous nature of regional relationships of the university. This approach helps to identify the specific characteristics of regional university–industry relationships.

Case study analysis, however, can only cover a small number of examples. Consequently, in descriptive investigation, the chosen case stands somehow isolated. It is hardly possible to judge whether this is a successful example of university–industry relationships or not, or whether this university is typical for its kind or rather specific. Points of reference are missing and generalizing is difficult. There is no broader picture produced of overarching features of university relationships. Most importantly, we cannot read from individual cases how the patterns of regional and extra-regional linkages of universities typically look like, which connect far reaching and proximate knowledge flows. Another caveat relates to difficulties to read information on actual economic impacts of university relationships on included partners from case studies. While it is possible to source information on different kinds of partners and collaborations, the instigated economic outcomes can hardly be assessed from that.

Econometrics, scientometrics and bibliometrics have been used for turning theoretical models into ones that can be confronted with empirical data. It is fair to say that econometric analysis is always useful when it comes to research questions that are analysed with larger datasets. This method suits for investigating certain channels of regional and inter-regional knowledge transfers, the human capital and entrepreneurship effects of universities and other selected categories of regional outcomes in systematic ways. As the results rely on broad databases, they are also easily generalizable, even leading the way to simulations of university–industry interactions (Ahrweiler et al. 2011).

The limits of econometrics, scientometrics and bibliometrics lie both with the kind of data available and with the theoretical concepts drawn upon: they rely substantially on the underlying theory. Statistically and mathematically based methods need theory to build hypotheses about causal relationships explaining the university's linkages and their regional impacts. Even if there is a proper model, it is not always possible to find data on which to build indicators which adequately represent the underlying theoretical concepts. Often the inclusion of geographical aspects of universities' relationships is limited to a calculated 'spatial gradient of influence' (Drucker and Goldstein 2007),

which ignores the relevance of spatial economic structure. Econometric approaches mainly focus on the question which regional economic impact is actually created by universities, including issues of human capital mobility (see overviews by [Acs et al. 1992](#); [Drucker and Goldstein 2007](#); [Faggian and McCann 2009](#)). They look at certain output indicators, such as patents and patent citations, and try to find some evidence of local knowledge spillovers of the university ([Anselin et al. 1997](#); [Crespi et al. 2011](#)). Some econometric analyses also rely on interview-based surveys and calculate correlations between indicators of innovation-driven regional development and selected university features, such as research funding or expenditures, degrees awarded, publications and citations, numbers of scientists, and simple or distance-weighted counts of institutions. This serves to identify which qualities of universities matter most for creating economic effects ([Goldstein and Drucker 2006](#)).

Scientometric and bibliometric analysis uses indicators mapping citations between researchers by using large databases like, for example, the Social Science Citation Index (SSCI) in order to draw the relationships between different agents (cf. a critical appraisal [Leydesdorff 2002](#)). This approach is also used to trace university–industry collaboration by analysing co-authored publications of university scientists and researchers in the private sector ([Abramo et al. 2009](#); [Zucker and Darby 2007](#); [Cunningham and Werker 2012](#)). While the results offer some interesting insights, for instance, on particularly ‘fruitful’ fields of interaction (like medicine, chemistry and biotechnology), the geographical picture drawn of university–industry collaboration has to be interpreted with caution. This has mainly to do with the data used, because patent and publication data are biased towards large organizations and ‘star scientists’ and do not always reflect the correct affiliations.

The method of social network analysis has been underpinned by sociological theory including not only the concept of social networks but also the concept of social capital. The concept of social networks is more encompassing and looks at the social structure of agents and their relationships with others (e.g. [Wassermann and Faust 1994](#)). In contrast, the concept of social capital is more focused and looks into questions like whether and how investment in the social structure pays off (e.g. [Burt 2001](#); [Lin 1999](#)). As both concepts have originally been used for sociology and have been employed and adapted for research on innovative networks only later ([Fromhold-Eisebith 2004](#)), it is not surprising that they need more clarification in this context. However, a network-based approach of social capital would help by defining social capital more clearly as resources embedded in social networks, which can be accessed and/or used by agents ([Huber 2009](#)). Generally spoken, the method of social network analysis has a lot of potential for enriching literature on regional and inter-regional linkages by using different approaches of economic geography and economics ([Ter Wal and Boschma 2009](#)).

Techniques of social network analysis help to map and structurally analyse agents and their relationships ([Freeman 2004](#); [Huber 2007, 2009](#); [Moody 2001](#); [Wassermann and Faust 1994](#)). Social network analysis is an interdisciplinary methodology emerging from sociology that has been further developed with inputs from mathematics and statistics. It has been widely applied, e.g., in economics, management science and organization studies ([Knoke and Yang 2008](#)), including studies on networking structures within universities ([Lee and Wee 2007](#)). It is sometimes combined with

scientometric and bibliometric approaches, which somehow blurs the distinction between approaches depicted here. Social network analysis has been increasingly considered as being a suitable tool to investigate knowledge transfer in a geographical dimension (Grabher and Powell 2005; Huber 2007; Krätke and Brandt 2009), human capital and entrepreneurship as well as inter- and intra-regional linkages (Murray 2004). The reason is that social network analysis allows us to focus on the structure of networks and the relationships of agents, thereby including socio-cultural factors into our analysis.

4 Universities' functions in knowledge transfer: promising theoretical and empirical approaches

Answering questions about the geographical dimensions of universities' relationships is by nature a multidisciplinary task combining the views of economics and economic geography, sociology, anthropology or management science. The overview of the theoretical analyses of the functions of universities and their geographical dimensions (Sect. 2) mirrors this multidisciplinary nature. In Table 1, we summarize our assessment of major logical relationships between theoretical approaches and the functions of universities. With our assessment, we want to show that theoretical frameworks differ in their abilities to suitably address universities' functions and the geography of relationships, with no approach alone capturing the complete picture.

A number of empirical methods address the university's functions and the multi-scalar geographies of their relationships, inducing regional knowledge transfer (see Sect. 3). In Table 2, we summarize our assessment about suitable empirical approaches to measure the functions of universities. Our results indicate that none of the empirical approaches seem appropriate to cover all of the relevant university functions. Each of them has its strengths and weaknesses in different fields. This provides some options for expediently combining them in further research.

Table 1 Contribution of theoretical approaches to explaining and describing universities' functions

	New production of knowledge theory	Triple helix	Regional innovation systems	Social network theory
Mission of universities	++	+	+	-
Regional knowledge transfer	++	++	++	-
Generation of human capital and entrepreneurship	++	++	+	+
Node of intra- and inter-regional linkages	-	+	+	+
Regional outcomes	+	+	+	-

(++ = important contribution, + = partial contribution, - = no contribution)

Table 2 Contribution of empirical approaches to explaining and describing universities' functions

	Case study analysis	Econometrics, scientometrics and bibliometrics	Social network analysis
Mission	++	-	-
Regional knowledge transfer	++	++	+
Generation of human capital and entrepreneurship	+	+	-
Node of intra- and inter-regional linkages	+	++	++
Regional outcomes	-	+	-

(+++ = important contribution, + = partial contribution, - = no contribution)

4.1 The mission of universities

Theoretically, the mission of universities can best be captured by the NPK Theory, the Triple Helix and RIS Approaches: goal setting of universities plays a crucial role in their theoretical considerations. Social network analysis might contribute to analysing the mission of universities as well, because it could shed light on the positioning of universities in knowledge networks. However, there is still some substantial theoretical clarification necessary to do so. In particular, positive and normative aspects of universities' missions have to be disentangled. Based on this, it would be possible to find out what the sources of the normative aspects are, e.g., political decisions or a societal understanding of the functions of universities in knowledge transfer. Empirically, only case study analysis seems feasible and suitable as the mission of universities does not lend itself to be calculated. In our opinion, the NPK Theory has provided substantial insights into the mission of universities. We suggest to make more use of the insights of Triple Helix and RIS in order to guide case study analysis. With the help of these approaches, deeper insight into universities' mission regarding relationships and involvement with governmental agencies and other stakeholders on a regional, national and international level would be possible. This can answer questions such as: Do universities' missions include goals regarding their role in the national and global innovation systems? Do these missions look at other universities only as their peers, collaborators or competitors?

4.2 Universities as regional knowledge providers

The NPK Theory, the Triple Helix or RIS approach and, to some extent, SNT have highlighted various aspects of the important issue of the universities' knowledge transfer. Empirically, case studies or econometric, scientometric and bibliometric analysis have been mostly used. Less was done with social network analysis so far. However, social network analysis provides excellent measures that go beyond investigating scale and scope of knowledge transfer, in particular when analysing the structure and identifying the key players in knowledge networks. While SNT is closest to this empirical tool, we expect most insights when one of the other approaches guides the analysis, because they have a rich body of insights into the role of universities as knowledge providers, e.g., by giving meaning to centrality measures by helping defining gatekeeper roles of universities in knowledge networks.

4.3 Universities' potential to generate human capital and entrepreneurship

The important university function to foster and generate human capital and entrepreneurship has been emphasized most by the NPK Theory and the Triple Helix approach. The RIS approach has also contributed. The impact of universities, however, has rarely been associated with SNT, due to the little matching potential given the current state of the theoretical body. Empirically, there have been contributions from all three empirical approaches discussed in Sect. 3. Although human capital and entrepreneurship can be captured well by empirical data (e.g. by share of population with a university degree or share of employment force being entrepreneurs), it is difficult to link these figures directly to the universities' influence (with the exception of the number of graduates). Therefore, we suggest focusing more on empirically measuring this university function. Scholars can easily derive hypotheses from the well-established theoretical body in this field. Case study analysis will be useful to find empirical data that either exists or needs to be collected and that is suitable for building appropriate indicators. In particular, we suggest to collect data on the ego-networks of (academic) entrepreneurs and spin-off companies as well as whole networks of universities and their relevant environment.

4.4 Universities' potential as nodes of intra- and inter-regional linkages

The geographical patterns of university relationships have been partly addressed by Triple Helix, the RIS Approach and SNT. Little has been contributed from the NPK Theory, which does not focus on issues of spatial scale. Empirically, none of the discussed methods appear to have really captured the issue so far, which requires to logically link spatial and functional qualities of universities' relationships. We suggest integrating Triple Helix, RIS and SNT to come up with a more encompassing approach towards universities as nodes of intra- and inter-regional linkages. In particular, we propose merging the latter two approaches, because they can overcome each others' problems: While the RIS Approach provides a rich body of qualitative reasoning but lacks a systematic way of linking it with empirical tests, SNT is weak in reasoning on regional economic implications but can be directly linked to empirical tests by tapping into social network analysis. An example would be defining different kinds of crucial agents in the innovation system, mapping and characterizing their relationships and analysing this data with the help of social network analysis.

4.5 Regional outcomes of universities' relationships

Analysing the regional outcomes of universities' relationships has an inherent problem since it is very difficult to link collaborations to regional development and growth. Theoretically, the NPK Theory, the Triple Helix and the RIS Approach have contributed to a limited extent to this question. Empirically, econometric analysis has been strongest in this matter. Generally spoken, it remains unclear whether the aforementioned methodological problems can be solved so that we refrain from specific suggestions in this respect.

5 Conclusions

Universities' relationships bear various characteristics, which is why they have been analysed by scholars from different disciplines. Here, we focus on the multifaceted, scale-bridging role of universities determining their functions for the regional economy and society. Our goal is analysing these functions more comprehensively by matching theoretical conceptualization, on the one hand, and empirical measurement, on the other hand. By doing so, we aim at a more detailed understanding of how the regional, national and international integration of universities contributes to regional innovation. As a first step, we pull together the strings of various scholarly works by economic geographers, economists, regional scientists and others, deducing five functions of universities. Based on the conceptual approaches NPK Theory, Triple Helix, RIS and SNT, we have seen the evolution of a set of various tasks and functions expected to be taken over by the universities in mature economies. Accordingly, we identify five major functions of universities that characterize geographical scale and scope of universities' collaborative relationships and their role in regional, national and international knowledge transfer. They reach from aspects determined by the university itself, in terms of its mission, over relational functions like regional knowledge transfer, the provision of human capital and entrepreneurship, and nodal linkages between different spatial scales, to broader regional impacts representing the sum of potential effects induced by the university. The geography of university relationships is shaped by all of these forces in various ways, which produces patterns of linkages that are highly specific for each regarded case. Yet, there may also be some common features across cases which hint at interesting regularities that support conceptualization.

Empirically, we can draw on case studies, surveys and increasingly social network analysis to shed more light on universities' relationships. Already now the data and empirical approaches used for capturing university relationships and their geographies cover a broad range of processes. However, we find that further advancements regarding theory and empirics would help to even better cater to the scientific requirements in future research. An orientation towards basic ideas of 'relational economic geography' offers some guideline (Bathelt and Glückler 2011), enriched by other considerations. Improvements seem possible especially with respect to the following aspects.

One, the focus of investigation should be set on the relationships of universities themselves, which actually 'produce' the geography of linkages that cannot adequately be predetermined beforehand. A combination of survey methods, case studies analysis and social network analysis seems most suitable in this regard. This way also the important social underpinnings of relationships can be included. Survey designs allow not only to map the multi-scalar reach of linkages, but also to gain additional information on qualitative aspects and implications of collaboration (Ter Wal and Boschma 2009). This eventually permits assessing the economic effects resulting from investigated relationships that affect the university's region of location and beyond. Scientometric or econometric methods seem useful to add information on the spatial patterns of specific collaboration channels and overall regional economic performance as soon as theoretical conceptualization is clearer.

Two, the relation between conceptual foundations and empirical design needs to be thoroughly reflected. This implies that research done needs to link the chosen

theoretical concept to, for instance, the method of social network analysis. In particular, it is necessary to look at SNT in order to appropriately link it to the theoretical approaches that are relevant in the context of universities' relationships. As various kinds of data can be used to build indicators, this needs to be carefully done in the light of the theoretical underpinnings provided by the NPK Theory, Triple Helix, the RIS Approach and SNT.

Three, individual case studies may not suffice to adequately investigate relevant features because they do not allow to distinguish case-specific from typical, i.e., more broadly relevant geographical characteristics of university relationships. Multi-case, comparative studies that use the same research design for multiple cases and combine a selected mix of methods as depicted above offer a much larger scope of deriving scientifically sound and value adding results. The benefits to be reaped from such a research design, however, highly depend on a thoughtful selection of cases in the light of the comparative study at hand. The cases should be marked by a combination of well-perceived commonalities, but also differences, which relate to conceptually rooted scientific objectives.

References

- Abramo G, D'Angelo CA, Di Costa F, Solazzi M (2009) University-industry collaboration in Italy: a bibliometric examination. *Technovation* 29:498–507
- Acs ZJ, Audretsch DB, Feldman MP (1992) Real effects of academic research: comment. *Am Econ Rev* 82:363–367
- Acworth EB (2008) University-industry engagement: the formation of the Knowledge Integration Community (KIC) model at the Cambridge-MIT Institute. *Res Policy* 37:1241–1254
- Ahrweiler P, Pyka A, Gilbert N (2011) A new model for university-industry links in knowledge-based economies. *J Prod Innov Manag* 28:218–235
- Anselin L, Varga A, Acs ZJ (1997) Local geographic spillovers between university research and high technology innovation. *J Urban Econ* 42:422–448
- Asheim BT, Isaksen A (2002) Regional innovation systems: the integration of local 'sticky' and global 'ubiquitous' knowledge. *J Technol Transf* 27:77–86
- Audretsch DB, Lehmann EE (2005) Do University policies make a difference? *Res Policy* 34:343–347
- Balconi M, Laboranti A (2006) University-industry interactions in applied research: the case of microelectronics. *Res Policy* 35:1616–1630
- Bathelt H, Malmberg A, Maskell P (2004) Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. *Prog Hum Geogr* 28:31–56
- Bathelt H, Glückler J (2011) *The relational economy: geographies of knowing and learning*. Oxford University Press, Oxford
- Beise M, Stahl H (1999) Public research and industrial innovations in Germany. *Res Policy* 28:397–422
- Bekkers R, Bodas Freitas IM (2008) Analysing knowledge transfer channels between universities and industry: To what degree do sectors matter? *Res Policy* 37:1837–1853
- Benneworth P, Arbo P (2007) Understanding the regional contribution of higher education institutions: a literature review. OECD education working paper 9, Paris
- Benneworth P, Charles D (2004) University spin-off companies and the territorial knowledge pool: building regional innovation competencies. DRUID summer conference on industrial dynamics, innovation and development. Copenhagen
- Bercovitz J, Feldman M (2006) Entrepreneurial universities and technology transfer: a conceptual framework for understanding knowledge-based economic development. *J Technol Transf* 31:175–188
- Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A (2008) Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. *Res Policy* 37:407–429
- Bergman E (2009) Editorial: embedding network analysis in spatial studies of innovation. *Ann Reg Sci* 43:559–565

- Boschma RA (2005) Proximity and innovation: a critical assessment. *Reg Stud* 39:61–74
- Boucher G, Conway C, Van Der Meer E (2003) Tiers of engagement by universities in their region's development. *Reg Stud* 37:887–897
- Bozeman B (2000) Technology transfer and public policy: a review of research and theory. *Res Policy* 29:627–655
- Bramwell A, Wolfe DA (2008) Universities and regional economic development: the entrepreneurial University of Waterloo. *Res Policy* 37:1175–1187
- Bruneel J, D'Este P, Salter A (2010) Investigating the factors that diminish the barriers to university-industry collaboration. *Res Policy* 39:858–868
- Burt RS (2001) Structural holes versus network closure as social capital. In: Lin N, Cook K, Burt S (eds) *Social capital: theory and research*. de Gruyter, New York, pp 31–56
- Caniëls MCJ, van den Bosch H (2011) The role of higher education institutions in building regional innovation systems. *Pap Reg Sci* 90(2):271–286
- Cantner U, Graf H (2006) The network of innovators in Jena: an application of social network analysis. *Res Policy* 35:463–480
- Charles D (2002) Universities and entrepreneurship: an international review. *North Econ Rev* 32:19–30
- Charles D (2003) Universities and territorial development: reshaping the regional role of UK universities. *Local Econ* 18:7–20
- Charles D (2006) Universities as key knowledge infrastructures in regional innovation systems. *Innov Eur J Soc Sci Res* 19:117–130
- Charles D (2007) Regional development, universities and strategies for cluster promotion. In: Scott A, Harding A, Laskey S, Burtscher C (eds) *Bright satanic mills: universities, regional development and the knowledge economy*. Ashgate, Aldershot, pp 53–68
- Cohen WM, Nelson RR, Walsh J (2002) Links and impacts: the influence of public research on industrial R&D. *Manag Sci* 48:1–23
- Cooke P, Heidenreich M, Braczyk HJ (eds) (2004) *Regional innovations systems: the role of governance in a globalized world*, 2nd edn. Routledge, London
- Crespi G, D'Este P et al (2011) The impact of academic patenting on university research and its transfer. *Res Policy* 40:55–68
- Cunningham S, Werker C (2012) Proximity and collaboration in European nanotechnology. *Pap Reg Sci* (first published online) 14.02.2012. doi:[10.1111/j.1435-5957.2012.00416.x](https://doi.org/10.1111/j.1435-5957.2012.00416.x)
- Debackere K, Veugelers R (2005) The role of academic technology transfer organizations in improving industry science links. *Res Policy* 34:321–342
- D'Este P, Patel P (2007) University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry? *Res Policy* 36:1295–1313
- D'Este P, Iammarino S (2010) The spatial profile of university-business research partnerships. *Pap Reg Sci* 89:335–351
- Di Gregorio D, Shane S (2003) Why do some universities generate more start-ups than others? *Res Policy* 32:209–227
- Drucker J, Goldstein H (2007) Assessing the regional economic development impacts of universities: a review of current approaches. *Int Reg Sci Rev* 30:20–46
- Edquist C et al (2005) Systems of innovation: perspectives and challenges. In: Fagerberg J (ed) *The Oxford handbook of innovation*. Oxford University Press, Oxford, pp 181–184
- Eom B-Y, Lee K (2010) Determinants of industry-academy linkages and their impact on firm performance: the case of Korea as a latecomer in knowledge industrialization. *Res Policy* 39:625–639
- Estabrooks CA, Norton P, Birdsall JM, Newton MS, Adewale AJ, Thornley R (2008) Knowledge translation and research careers: Mode I and Mode II activity among health researchers. *Res Policy* 37:1066–1078
- Etzkowit H, Leydesdorff L (2000) The dynamics of innovation: from National Systems and 'Mode 2' to a Triple Helix of university-industry-government relations. *Res Policy* 29:109–123
- Etzkowit H (2004) The evolution of the entrepreneurial university. *Int J Technol Glob* 1:64–77
- Faggian A, McCann P (2009) Universities, agglomerations and graduate human capital mobility. *Tijdschr Econ Soc Geogr* 100:210–223
- Feldman MP, Link AN (eds) (2001) *Innovation policy in the knowledge-based economy*. Kluwer, Boston
- Feldman MP, Massard N (eds) (2002) *Institutions and systems in the geography of innovation*. Kluwer, Boston
- Florax RJGM (1992) The university: a regional booster? Economic impacts of academic knowledge infrastructure. Avebury, Aldershot

- Freel MS (2003) Sectoral patterns of small firms innovation, networking and proximity. *Res Policy* 32:751–770
- Freeman LC (2004) *The development of social network analysis: a study in the sociology of science*. Empirical Press, Vancouver
- Fritsch M, Schwirten C (1999) Enterprise-university co-operation and the role of public research institutions in regional innovation systems. *Ind Innov* 6:69–83
- Fritsch M, Henning T, Slavtchev V, Steigemberger N (2007) *Hochschulen, innovation, region: Wissenstransfer im räumlichen Kontext*. Edition Sigma, Berlin
- Fritsch M, Kauffeld-Monz M (2010) The impact of network structure on knowledge transfer: an application of social network analysis in the context of regional innovation networks. *Ann Reg Sci* 44:21–38
- Fromhold-Eisebeth M (1992) *Wissenschaft und Forschung als regionalwirtschaftliches Potential? Das Beispiel von Rheinisch-Westfälischer Technischer Hochschule und Region Aachen*. Maas-Rhein-Institut für Angewandte Geographie, Aachen
- Fromhold-Eisebeth M (2004) Innovative milieu and social capital—complementary or redundant concepts for collaboration-based regional development. *Eur Plan Stud* 12:747–765
- Fromhold-Eisebeth M (2006) Die Universität im regionalen Innovationssystem: Anspruch und Wirklichkeit am Beispiel Salzburg. In: Reith R et al (eds) *Innovationskultur in historischer und ökonomischer Perspektive: Modelle, Indikatoren und regionale Entwicklungslinien*. Studien-Verlag, Innsbruck, pp 229–251
- Fromhold-Eisebeth M (2007) Bridging scales in innovation policies: how to link regional, national and international innovation systems. *Eur Plan Stud* 15:217–233
- Fromhold-Eisebeth M (2009) Space(s) of innovation—regional knowledge economies. In: Funke J, Meusbürger P, Wunder E (eds) *Milieus of creativity: an interdisciplinary approach to spatiality of creativity*. Springer, Heidelberg, pp 201–218
- Fromhold-Eisebeth M, Scharfetter D (2002) Universities as agents in regional innovation systems. Evaluating patterns of knowledge-intensive collaboration in Austria. In: Acs ZJ, de Groot H, Nijkamp P (eds) *The emergence of the knowledge economy: a regional perspective*. Springer, Heidelberg, pp 173–194
- Geuna A, Muscio A (2009) The governance of university knowledge transfer: a critical review of the literature. *Minerva* 47:93–114
- Gibbons M, Limoges C, Nowotny H et al (1994) *The new production of knowledge: the dynamics of science and research in contemporary societies*. Sage, London
- Goddard J, Charles D, Pike A, Potts G, Bradley D (1994) *Universities and communities*. Committee of Vice-Chancellors and Principals, London
- Godin B, Gingras Y (2000) The place of universities in the system of knowledge production. *Res Policy* 29:273–278
- Goldstein HA, Drucker J (2006) The economic development impacts of universities on regions: do size and distance matter? *Econ Dev Q* 20:22–43
- Goldstein HA (2010) The 'entrepreneurial turn' and regional economic development mission of universities. *Ann Reg Sci* 44:83–109
- Grabher G, Powell WW (2005) *Networks*. E. Elgar, Cheltenham
- Graf H (2006) *Networks in the innovation process: local and regional interaction*. E. Elgar, London
- Graf H (2010) Gatekeepers in regional networks of innovators. *Camb J Econ*. doi:10.1093/cje/beq001
- Gunasekara C (2006) Reframing the role of universities in the development of regional innovation systems. *J Technol Transf* 31:101–113
- Hessels LK, van Lente H (2008) Rethinking new knowledge production: a literature review and a research agenda. *Res Policy* 37:740–760
- Huber F (2007) *Social networks and knowledge spillovers*. Peter Lang, Frankfurt/Main
- Huber F (2009) Social capital of economic clusters: towards a network-based conception of social resources. *Tijdschr Econ Soc Geogr* 100:160–170
- Ibert O (2007) Towards a geography of knowledge creation: the ambivalences between 'knowledge as an object' and 'knowing in practice'. *Reg Stud* 41:103–114
- Jensen MB, Johnson B, Lorenz E, Lundvall BA (2007) Forms of knowledge and modes of innovation. *Res Pol* 36:680–693
- Kauffeld-Monz M, Fritsch M (2008) Who are the brokers of knowledge in a regional system of innovation? A multi-actor network analysis. Friedrich Schiller University, Max Planck Institute of Economics Jena, Jena
- Kleinknecht A, van Montfort K, Brouwer E (2002) The non-trivial choice between innovation indicators. *Econ Innov New Technol* 11:109–121

- Klein-Woolthuis R, Lankhuizen M, Gilsing V (2005) A system failure framework for innovation policy design. *Technovation* 25:609–619
- Knoke D, Yang S (2008) *Social network analysis*, 2nd edn. Sage Publications, Los Angeles
- Kogut B (2000) The network as knowledge: generative rules and the emergence of structure. *Strateg Manag J* 21:405–425
- Krätke S, Brandt A (2009) Knowledge networks as a regional development source: a network analysis of the interlinks between scientific institutions and regional firms in the metropolitan Region of Hanover, Germany. *Eur Plan Stud* 17:43–63
- Laursen K, Salter A (2004) Searching high and low: what types of firms use universities as source of innovation? *Res Policy* 33:1201–1215
- Lawton Smith H (2003) Knowledge organizations and local economic development: the cases of Oxford and Grenoble. *Reg Stud* 37:899–909
- Lee CK, Wee JF (2007) Social network analysis of four departments in the National University of Singapore. In: *Proceedings of the 3rd international conference on knowledge management 2006, creating collaborative advantage through knowledge and innovation*, London, pp 119–134
- Leydesdorff L (2002) Indicators of structural change in the dynamics of science: entropy statistics of the SCI Journal Citation Reports. *Scientometrics* 53:131–159
- Leydesdorff L (2005a) The triple helix model and the study of knowledge-based innovation systems. *Int J Contemp Sociol* 42:1–16
- Leydesdorff L (2005b) The triple helix: an evolutionary model of innovations. *Res Policy* 29:243–255
- Lin N (1999) Building a Network Theory of Social Capital. *Connections* 22:28–51
- Lundvall BA (1992) *National systems of innovation and interactive learning*. Pinter, London
- Maggioni M, Uberti TE, Usai S (2011) Treating patents as relational data: knowledge transfers and spillovers across Italian Provinces. *Ind and Innov* 18:39–67
- Malecki EJ (1997) *Technology and economic development: the dynamics of local, regional and national competitiveness*. Prentice-Hall, New York
- Mansfield E, Lee JY (1996) The modern university: contributor to industrial innovation and recipient of industrial R and D support. *Res Policy* 25:1047–1058
- Metcalf JS (2005) Systems failure and the case for innovation policy. In: Llerena P, Mireille M (eds) *Innovation policy in a knowledge-based economy*. Springer, Berlin, pp 47–74
- Moody J (2001) Peer influence groups: identifying dense clusters in large networks. *Soc Netw* 23:261–283
- Murray F (2004) The role of academic inventors in entrepreneurial firms: sharing the laboratory life. *Res Policy* 33:643–659
- Nagle M (2007) Canonical analysis of university presence and industrial comparative advantage. *Econ Dev Q* 21:325–338
- Nelson RR (1993) *National innovation systems: a comparative analysis*. Oxford University Press, Oxford
- Nelson AJ (2009) Measuring knowledge spillovers: what patents, licenses and publications reveal about innovation diffusion. *Res Policy* 38:994–1005
- Nowotny H, Scott P, Gibbons M (2001) *Rethinking science: knowledge in an age of uncertainty*. Polity, Cambridge
- Nowotny H, Scott P, Gibbons M (2003) ‘Mode 2’ revisited: the new production of knowledge. *Minerva* 41:179–194
- Perkmann M, Walsh K (2009) The two faces of collaboration: impact of university-industry relations on public research. *Ind Corp Change* 18:1033–1065
- Pike A, Charles D (1995) The impact of international collaboration on university industry links. *Ind High Educ* 9:264–276
- Ponds R, van Oort F, Frenken K (2007) The geographical and institutional proximity of research collaboration. *Reg Sci* 86:423–443
- Powell WW (1990) Neither market nor hierarchy: network forms of organization. *Res Organ Behav* 12:295–336
- Power D, Malmberg A (2008) The contribution of universities to innovation and economic development: in what sense a regional problem? *Camb J Reg Econ Soci* 1:233–245
- Rasmussen E, Sorheim R (2006) Action-based entrepreneurship education. *Technovation* 26:184–195
- Rothaermel F, Thursby M (2005) University-incubator firm knowledge flows: assessing their impact on incubator firm performance. *Res Policy* 34:305–324
- Saxenian A (1994) *Regional advantage: culture and competition in Silicon Valley and Route 128*. Harvard University Press, Cambridge, MA

- Schartinger D, Schibany A, Gassler H (2001) Interactive relations between universities and firms: empirical evidence for Austria. *J Technol Transf* 26:255–268
- Schartinger D, Rammer C, Fischer MM, Fröhlich J (2002) Knowledge interactions between universities and industry in Austria: sectoral patterns and determinants. *Res Policy* 31:303–328
- Shane S (2004) Academic entrepreneurship: university spin-offs and wealth creation. E. Elgar, Northampton
- Shinn T (2002) The triple helix and new production of knowledge: prepacked thinking of science and technology. *Soc Stud Sci* 32:599–614
- Soetanto DP, van Geenhuizen M (2009) Social networks and competitive growth: a tale of two contrasting cities. *Tijdschr Econ Soc Geogr* 100:198–209
- Srinivas S, Viljamaa K (2008) Emergence of economic institutions: analyzing the third role of Universities in Turku, Finland. *Reg Stud* 42:323–341
- Ter Wal ALJ, Boschma RA (2009) Applying social network analysis in the economic geography: framing some key analytic issues. *Ann Reg Sci* 43:739–756
- Tornatzky LG (2001) Benchmarking university-industry technology transfer: a six year retrospective. *J Technol Transf* 26:269–277
- Uyara E (2010) Conceptualizing the regional roles of universities, implications and contradictions. *Europ Plan Stud* 18:1227–1246
- van Beers C, Berghäll E, Poot T (2008) R and D internationalization, R and D collaboration and public knowledge institutions in small economies: evidence from Finland and the Netherlands. *Res Policy* 37:294–308
- van Geenhuizen M, Soetanto DP (2004) Academic knowledge and fostering entrepreneurship: an evolutionary perspective. In: Groot H, Nijkamp P, Stough R (eds) *Evolutionary approaches to innovation*. E. Elgar, London, pp 252–268
- Varga A (ed) (2009) *Universities, knowledge transfer and regional development: geography, entrepreneurship and policy*. E. Elgar, Cheltenham
- Verspagen B, Werker C (2004) Keith Pavitt and the invisible college of the economics of technology and innovation. *Res Policy* 33:1419–1431
- Wassermann S, Faust K (1994) *Social network analysis: methods and applications*. Cambridge University Press, Cambridge
- Weijnen MPC, Bowmans I (2006) Innovation in networked infrastructures: coping with complexity. *Int J Crit Infrastruct* 2:121–132
- Werker C, Athreye SS (2004) Marshall's disciples: knowledge and innovation driving regional economic development and growth. *J Evolut Econ* 14:505–523
- Wright M, Clarysse B, Lockett A, Knockaert M (2008) Mid-range universities' linkages with industry: knowledge types and the role of intermediaries. *Res Policy* 37:1205–1223
- Zucker LG, Darby MR (2007) Virtuous circles in science and commerce. *Pap Reg Sci* 86:445–470