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From the Ivory Tower to the Marketplace: Knowledge Organisations in the Development of Biotechnology Clusters

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Abstract. In the emerging knowledge economy, universities are adopting a key role as producers of scientific knowledge and skills, and they are experiencing far reaching changes in their tasks. Their main mission is no longer confined to education and research, but increasingly also covers technology transfer and commercialisation activities. The aim of this paper is to examine to what extent this phenomenon could also be observed in Austria, a country which is not a pioneer regarding the development of the knowledge economy. Moreover, we are interested in the particular mechanisms of knowledge transfer. We differentiate between four key tasks of universities, including their roles as "antennae" for receiving external knowledge, sources of highly skilled labour, cooperation partners for the industry and seedbeds for new firm formation. Focusing on the biotechnology sector we will demonstrate that an opening of the ivory tower and a move of Austrian universities towards the market place has occurred. Furthermore, we will show that these changes to some extent have been policy-driven in nature.

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1. Introduction

In the emerging knowledge economy universities are recognised as critical contributors to economic prosperity (Mowery and Sampat 2005) and key institutions of innovation systems (Coenen, 2006; Edquist, 2005; Gunasekara, 2006). Over the past two decades, universities and other public research organisations have experienced substantial changes in their tasks and roles. Their main mission seems no longer to be confined to education and research, but increasingly also covers technology transfer and commercialisation activities (Vincent-Lancrin, 2006). In most developed countries, increasing attention is paid to the economic utilisation of publicly funded research. This holds particularly true for high-technology sectors with an analytical knowledge base, where scientific knowledge is of utmost importance in the innovation process (Asheim and Gertler, 2005; Laestadius, 1998; Tödtling et al., 2006). The advent of the "entrepreneurial university" (Etzkowitz et al., 2000; Etzkowitz, 2004; Etzkowitz and Klofsten, 2005) in the Western world is widely discussed and documented in the literature. This paper investigates whether this phenomenon, which has been observed in high-technology countries (US, UK) and regions (e.g. Silicon Valley, Boston, Cambridge), also exists in countries such as Austria, where up until the very recent past universities have not yet fully realised their new functions. Such evidence would signal a broad trend towards entrepreneurial universities going beyond "islands of high-technology". Focusing on the biotechnology sector we address the following questions:

- What are the key functions of public research organisations for fostering the development of biotechnology clusters in Austria?
- Which changes could be observed in Austria in this respect?
- What are the main mechanisms for knowledge transfer?
- What is the role of policy agents in promoting a more direct and proactive contribution of universities to cluster growth and innovation in biotechnology?

In Section 2 we provide a short literature review on the conceptualisation of the knowledge economy. In Section 3 we deal with the changing role of universities and identify four core functions of public knowledge generating institutions: We deal with the task of universities as "antennae" for receiving and absorbing external knowledge, examine their importance as sources of highly skilled labour, discuss various forms of university-industry partnerships, and address the role of academia as a seedbed for new firm formation. Section 4 presents empirical results from a research project on the Austrian biotechnology sector focusing on these aspects. Drawing on 31 interviews with university researchers and representatives from the policy and supporting sector, we demonstrate that an opening of the ivory tower and a move of Austrian universities towards the market place has occurred. Furthermore, we will show that these changes have to some extent been policy-driven in nature. Finally, in Section 5 we summarise the main findings and draw some conclusions.

2. The emerging knowledge economy

In the emerging knowledge economy, universities are important contributors to the production of scientific knowledge, skills and economic growth (Mowery and Sampat 2005). They are acknowledged as crucial elements of national and regional innovation systems (Coenen, 2006; Edquist, 2005; Gunasekara, 2006; Lundvall, 2006). Before discussing the changing role of universities we will briefly conceptualise the knowledge economy.

In the meantime there exists a rich literature on the rise of the knowledge economy (OECD 1996, 2001, Drucker 1998, David and Foray 2003, Smith 2002, Cooke et al. 2007). The emergence of the knowledge economy is inextricably linked to ongoing processes of globalisation, deregulation and liberalisation, and as a consequence of these tendencies, innovation is becoming increasingly important as a competitive strategy (Lundvall and Borrás 1999, Archibugi and Lundvall, 2002). Another key driving force has been the diffusion of modern information and communication technologies (ICT), which enables new forms of information exchange and storage and facilitates the codification of knowledge (Soete 2002). Knowledge has always been at the heart of economic development, growth, and innovation. The knowledge economy in its more recent understanding is about a continuing transformation towards more knowledge intensive activities rather than a radical change or rupture of economies and societies. It refers to an economy where productivity and growth are less dependent on natural resources than they are on the capacity to improve the quality of human capital and factors of production, to create new knowledge and ideas and to incorporate them into equipment and people (David and Foray 2003). The growth and prosperity of national and regional economies depend to an ever increasing extent on the generation, dissemination and application of new knowledge and on innovation.

There are different perspectives when it comes to grasping the nature of the knowledge economy (Smith, 2002). First, it is argued that knowledge as input is becoming more significant both in quantitative and qualitative terms. This is reflected in growing levels of knowledge-related investment, such as R&D, education, software and information technologies (OECD, 2001). Second, it is claimed that knowledge as a product is increasingly important. This view rests on the observation that knowledge intensive business services and high technology industries have grown strongly over the last years. Companies which belong to these sectors are often established on the basis of new ideas, incorporating and applying new knowledge into products. According to a third perspective it is particularly codified knowledge as opposed to tacit personal skills that has become more significant (Cowan et al., 2000). It is also claimed that the knowledge economy rests on technological progress in ICT, allowing for new forms of knowledge management and exchange. Castells (1996) proposed an alternative view of the knowledge economy, emphasising that "the action of knowledge upon knowledge itself [is] the main source of productivity". Thus, the mere use of knowledge is not enough; knowledge creation is also necessary in order for an industry to be regarded as knowledge based. As Cooke (2002, p. 4f) puts it: "Knowledge economies are not defined in terms of their use of scientific and technological knowledge, including their willingness to update knowledge and creatively forget old knowledge through learning. Rather, they are characterised by exploitation of new knowledge in order to create more new knowledge". Each of the above perspectives has weaknesses if applied separately as tools to understand the knowledge economy (Smith, 2002). Combined, however, they may shed light on the complex phenomenon of the knowledge economy from different angles, and they are also intimately linked to each other.

An interesting contribution has been made by Raspe and van Oort (in this volume) who suggest the concept of a knowledge region to give due emphasis to the role of the spatial context of the knowledge economy and to better understand the impact of locational knowledge characteristics on firm performance. Their definition of a knowledge region rests on several

dimensions, stressing the importance of the presence of knowledge workers and high and medium tech firms, a high share of R&D employees, and high levels of technical as well as non-technical innovation. Also prominent is the sectoral perspective, i.e. the view that the knowledge economy can be identified by referring to the growth of high technology sectors such as biotechnology and ICT and knowledge based services. These industries strongly rely on science, R&D, and knowledge as a key input. They are characterised by strong growth and firm formation, a high innovation activity regarding products and processes, and they make extensive use of both internal and external knowledge sources (Keeble and Wilkinson, 2000). These industries often have strong links to universities, e.g. through spin-offs, co-operations or joint use of facilities. It is, however, important to note that the knowledge economy is not confined to the sectors mentioned above. In many medium and low technology sectors such as food, materials or textiles, learning and innovation are also vital (Lundvall and Borrás, 1999). We find knowledge and innovation to play an increasingly important role in these industries, as can be seen from rising levels of qualifications or from innovation expenses more broadly defined (OECD 2001, European Commission 2003).

3. The changing role of universities and other public research institutions

Throughout the Western world, the science system has undergone far reaching reforms over the past two decades. The traditional teaching and research university is being transformed into an "entrepreneurial university" (Etzkowitz et al., 2000; Etzkowitz, 2004; Etzkowitz and Klofsten, 2005), reflecting a growing and more direct role of academia as engine of innovation dynamics and economic development. Promoting academic entrepreneurship has been high on the political agenda since the mid 1990s (see, for instance, OECD, 2003). Universities and other public research organisations have been encouraged to enter into relationships with industry in order to stimulate the production of more practical, applied research outputs (Godin and Gingras, 2000; Simpson, 2004; Vincent-Lancrin, 2006). The ever increasing significance of universities for technological and economic progress (Goncalves and Papon, 2004) can particularly be observed for high-technology regions and knowledge intensive economic activities such as biotechnology or information technology, where scientific inputs are acknowledged as essential for the innovation process (Asheim and Gertler, 2005; Cooke et al., 2007; Laestadius, 1998; Tödtling et al., 2006).

There are two main conceptual approaches to the changes of the science system and the strong role of universities and other public research institutions for economic dynamics. According to Gibbons et al. (1994) and Nowotny et al. (2001, 2003), the process of knowledge production has changed radically from a traditional disciplinary model, Mode 1, where knowledge was produced in universities with limited social or other external influence, to a more recent Mode 2, which is characterised by a transdisciplinary inquiry. Transdisciplinary inquiry involves not only scientists but also other stakeholders working together to find solutions in a context of practical application. The second approach reflecting on the new role of universities is provided by the triple helix model (Etzkowitz and Leydesdorff, 2000; Etzkowitz et al., 2000). Here it is argued that universities are increasingly being transformed into entrepreneurial agents, encompassing a "third mission" in addition to research and teaching. Universities are translating research into economic development through various forms of knowledge transfer.

Thus, both the proponents of "Mode 2 of knowledge production" and the advocates of the triple helix model, point to an enhanced role of public research organisations as a source of economic prosperity and to a growing significance of interfaces between universities and the private sector. The emergence of the "entrepreneurial university", however, is not universally embraced (Renault, 2006). It has also provoked strong concerns and criticism among some scholars. Lerner (2005) points to the fear that commercial activities may subvert the core academic missions of universities. According to Nelson (2004) the increasing commercialisation efforts by universities pose a threat to academic freedom, independence, autonomy and basic research. Similarly, Lundvall (2006) argues that the key roles of universities to generate basic knowledge and to provide critical views and reflections in the emerging learning economy might be undermined by a too strong orientation on commercialisation and marketing of knowledge.

Although not acclaimed by all observers, the third mission of academic actors outlined above has become a reality in recent years. The United States clearly have the lead in this regard. Mowery et al. (2001) state that universities are at the heart of the commercial leadership of the United States in key science-based sectors. Compared to the US, university-industry interfaces in Europe have lagged behind due to a number of reasons such as the lack of incentives for and legal obstacles against faculty collaboration with companies or cultural predispositions against academic involvement with commerce. In the mean-

time, not only in the US but also in Europe, "academic capitalism" is advancing. This is particularly apparent in high-technology sectors such as biotechnology, which is the focus of this paper. Excellent universities and research organisations have been found to constitute the core of strong biotechnology clusters (Galambos and Sewell, 1996).

Universities contribute in various ways to the evolution of high-technology clusters. Lawton Smith and De Bernardy (2000, p. 93) suggest a rather comprehensive typology of influences of universities in this context, comprising the following dimensions:

- location (spin-offs)
- innovation (technology transfer, information resources, localisation of foreign technology, technological spill-over)
- labour (mix of labour skills, training), and
- identity (contribution to cultural characteristics of the region, refocusing of region/spatial and technical segmentation or integration, prestige, participation in territorially organised policy processes).

It is beyond the scope of this paper to examine all these roles of research organisations in cluster development. We concentrate on four main functions of universities and deal with their roles as

- "antennae" for receiving external knowledge,
- sources of highly qualified labour,
- knowledge providers in university-industry linkages, and
- incubators for academic spin-off companies.

In the following, we will discuss these four roles of universities and other public research institutes in more detail.

3.1. Universities as "antennae" for receiving external knowledge

A key task of universities and other publicly funded research institutions consists in absorbing, accumulating and storing knowledge that has been produced elsewhere (Fritsch, 2003; Fritsch and Schwirten, 1999; Fritsch and Schwirten, 2002). Universities, thus, take over the role of an "antenna" (Fritsch, 2003) for receiving external scientific knowledge that is not available locally. There are several mechanisms underlying this important function of public research organisations; e.g. the reading of literature, participation in conferences, as well as international scientific collaborations (Vincent-Lancrin, 2006). Therefore, various forms of international scientific linkages are crucial underpinnings for the inflow of new knowledge that has been generated abroad. It should not be neglected, however, that the local or regional levels are also significant spaces for scientific interaction. Local connections between universities and other public research organisations are relevant, because they represent eminent channels for the local circulation of external competences, expertise and knowledge (Lundvall, 2006). Scientific contacts, both at the local and global level, can be seen to be of utmost importance in the emerging knowledge economy, reflecting a growing need for specialisation and interdisciplinary research. Collaboration and cooperation within academia is, however, not the only relevant factor in identifying the foundations of innovation. Dynamic regions and clusters rest on extensive knowledge flows between the science system and the business sector. In the following, we will deal with three core mechanisms that are relevant here.

3.2 Universities as sources of highly skilled labour

In the past years a considerable body of work has enhanced our understanding of the critical role played by human capital and talent in spurring (regional) development and growth. Human capital has been recognised to constitute a key factor for economic prosperity (Romer, 1990). Lucas (1988) put forward the argument that the spatial concentration of (skilled) labour generates strong external economies, and that such externalities increase productivity and growth. In the meantime there exists a large number of empirical studies providing evidence for the strong relationship between talent and the growth of cities and regions (Florida, 2002; Florida, 2005; Glaeser, 2004; Glaeser and Saiz, 2004, Hogan and Hoffman in this volume).

Universities are considered as a key source of highly skilled labour, providing trained researchers and engineers for the industrial sector (Lawton Smith and De Bernardy, 2000; Martin and Salter, 1996; Pavitt, 2005). The production of trained personnel corresponds to the traditional educational mission of academic institutions. The movement of well educated talent into industrial occupations represents a powerful mechanism for the diffusion of scientific research (Mowery and Sampat, 2005) and regional collective learning (Keeble, 2000). Qualified scientists, engineers and managers are acknowledged to constitute a key element in biotechnology clusters in particular (Casper and Karamanos, 2003; Casper and Murray, 2005). A survey of Californian firms revealed that the availability of qualified workers is the most important location factor for companies in this sector (Audretsch, 2003). Keeble (2000), drawing on a comparative study of sev-

eral European high-technology milieux, notes that the movement of talent within high-technology clusters is essential for the transfer of embodied expertise and a deepening and broadening of the regional pool of knowledge. He adds that "local universities with their continuous output of young qualified scientists and engineers, may play a particularly significant role in this regard, with graduate and postgraduate recruitment by local firms helping local dissemination and commercial application of new scientific knowledge derived from university research" (Keeble, 2000, p. 209f.). Combining these arguments, it can be stated that the conventional mission of universities as providers of human capital remains crucial for fostering the development of high-technology clusters. In recent years, however, many academic institutions have been expected to play an even more active role in innovation and development by entering into co-operative relations with industry and spinning off new ventures.

3.3. University-industry linkages

There is strong evidence that collaborative ventures between academic institutions and industry are increasing in number, size and complexity (Goncalves and Papon, 2004), reflecting a new function of universities that goes beyond teaching and the carrying out of (basic) research for its own sake. This seems to be the case in science-based sectors with an analytical knowledge base in particular, where universities play an essential role as knowledge providers and co-operation partners for industrial companies (Asheim and Gertler, 2005; Laestadius, 1998; Tödtling et al., 2006). Such relationships can take different forms, including informal networks, formal R&D co-operation, co-authorship, the shared use of laboratory facilities and contract research (Mowery and Sampat, 2005; Pavitt, 2005), pointing to a broad spectrum of mechanisms of technology transfer and joint production of new knowledge.

The trend towards an increased significance of university-industry linkages has been actively promoted by policy agents. Many governments have set up programmes and measures to strengthen the relationships between universities (and other public research organisations) and private companies, in order to enhance the contributions of university research to the innovation performance and economic growth of regions and nations (Mowery and Sampat, 2005).

Looking specifically at the biotechnology sector, there is considerable empirical evidence that university-industry relations are highly relevant in that sector (see, for example, Audretsch and Stephan, 1996; Gertler and Levitte, 2005; McKelvey, 2004; Metha, 2004; Rothaermel and Deeds, 2006). Several studies have documented the existence of a wide array of such links (Lynskey, 2006; Murray, 2002; Murray, 2004; Porter et al., 2005; Tödtling and Trippl, 2007; Trippl and Tödtling, 2007). The complexity and rapid expansion of the knowledge base in the field of biotechnology, and the wide dispersion of relevant sources of expertise (Powell, 1998; Powell et al., 1996) are key reasons for the strong interaction found between the academic and industrial spheres. The growing significance of university-industry ties is the outcome of an increased focus on knowledge transfer and the economic exploitation of scientific discoveries and the skills and research resources of public knowledge generating organisations. The recent rise of academic spin-off companies signals that universities and other public research organisations are nowadays pursuing strategies to commercialise their knowledge in even more direct ways.

3.4 Universities as incubators for spin-offs

Over the last years, there has been a considerable rise in the formation of university spin-out firms (Cooke, 2002; Locket et al., 2005; Keeble and Wilkinson, 2000), reflecting new routes of commercialisation of publicly funded research and inventions. This applies particularly to industries which draw on an analytical knowledge base (biotechnology, information technology, etc.), where scientific knowledge represents a key input in the innovation process. Substantial public resources are increasingly committed to supporting "science entrepreneurship" (Lehrer and Asakawa, 2004), as in most industrialised countries, policy initiatives have been launched to promote university spin-offs (Bower, 2003; Meyer, 2003; Rasmussen et al., 2006; van Loy et al., 2003; Wright et al., 2006).

In the meantime, there exists a large amount of literature on academic spin-offs indicating that new firm formation by academic scientists is driven by a set of factors, including resources for opportunity search and intellectual property protection, the capabilities of technology transfer organisations, and the extent of science and engineering funding (Lockett and Wright, 2005; O'Shea et al., 2005). Furthermore, additional factors like the entrepreneurial climate, the innovative milieu of the region, the network capabilities of academic firms (Walter et al., 2006) and the density and strength of university-firm linkages (Rothaermel and Thursby, 2005) seem to play a significant role.

In most cases, science-based start-ups face serious challenges in their development, brought about by a narrow range of competencies and a too strong focus

on technical aspects (Meyer, 2003). As academic founders emanate from a non-commercial environment, they often lack market knowledge and contacts, management skills, business experience and awareness (Bower, 2003; Niosi, 2006). Another key factor for the success of start-ups is access to venture capital (Wright et al., 2006). Looking specifically at the biotechnology sector, it has been revealed that new venture creation is a crucial ingredient for innovation and the emergence and dynamic development of clusters in this field (see, for example, Audretsch, 2003; Feldman and Francis, 2003; Feldman and Francis, 2004; Feldman et al., 2005; Fuchs and Krauss, 2003). Research has shown that university researchers do not only act as consultants and members of scientific advisory boards of science based start-up firms, but also play a pivotal role as founders of new companies in biotechnology. In other words: Universities and other public research institutes have become a main source of new technology-based firms in this sector (Cooke, 2002; Lehrer and Asakawa, 2004; Tödtling and Trippl, 2007; Trippl and Tödtling, 2007).

4. The case of biotechnology in Austria

Austria is not a pioneer in developing entrepreneurial universities and interaction between academia and industry. This is mainly due to the country's strong specialisation in medium technology sectors and the dominance of a coordinated market economy model. In the past, knowledge flows from academia to the business sector remained limited. Recently, however, there is evidence of growing university-industry interfaces. This is clearly documented in the work by Schartinger et al. (2001, 2002), who studied university-industry links in Austria in the late 1990s. The authors conducted a postal survey involving 443 firms (yielding 99 responses) and 834 university departments (421 responses). The most frequent types of interaction that university departments were engaged in were the supervision and financing of PhDs and master's theses (38%), lectures by firm members (35%), contract research (32%) and joint research (31%) (Schartinger et al., 2001). The interaction most frequently engaged in by the firms was clearly the employment of graduates (67%), followed by the supervision and financing of PhDs and master's theses (42%), and contract research (32%). Determinants also differed between the two types of actors. Larger and younger firms, as well as those with fewer cultural barriers for research cooperation had more interaction. With respect to university departments, size, as well as field influenced their level of cooperation. The technical science field was particularly prone to interaction with firms.

The sectoral pattern of university-industry links partly reflects the industry specialisation found in Austria (Schartinger et al., 2002). Sectors with strong university-industry interaction comprise chemicals, instruments, vehicles as well as energy production, basic metals and paper. From the services it was R&D, banking, insurance and computer services. Important determinants for university-industry interaction in this second study were the size of the sector and the scientific field, and their knowledge proximity. Natural sciences and technical sciences had more interaction than social sciences and humanities. On the industry side a high share of medium sized firms and a high R&D intensity were favouring factors. In the following we will address two questions; can this trend towards stronger university-industry linkages in Austria also be observed for the biotechnology sector, and what are the major types of interaction?

The rise of the biotechnology industry in Austria is a rather recent phenomenon (see Tödtling and Trippl, 2007; Trippl and Tödtling, 2007). The sector features a strong specialisation in "red" biotechnology and comprises 115 biotechnology related companies (BIT and LISA, 2004). The Austrian biotechnology industry exhibits a strong tendency towards spatial concentration. No less than 77 firms (67 % of the Austrian total) are located in the region of Vienna, while smaller clusters can be found in Styria (10 firms), Lower Austria (10 firms) and Tyrol (9 firms). Table 1 provides an overview of the structuring of the biotechnology clusters in the provinces of Vienna, Styria and Tyrol. These clusters will be examined in the following.

Vienna is the key biotechnology centre of Austria, not only regarding the number of firms, but also with respect to the presence of scientific excellence. The region hosts five universities, several hospitals and a range of other public and private research institutes: the Institute of Molecular Pathology (IMP), which is Boehringer Ingelheim's cancer research centre, the Novartis Research Institute (NRI), and the Antibiotic Research Institute Vienna (ABRI), owned by Biochemie Kundl (part of Sandoz R&D). Recently, the Austrian Academy of Sciences has established two new institutes, including the Institute of Molecular Biotechnology (IMBA) and the Research Centre for Molecular Medicine (CeMM). In addition, five co-operative research centres involving university institutes and firms have been set up (see below). Finally, a technical college for biotechnology has also been established in order to improve the supply of specialised and highly skilled labour. The scientific base in Tyrol is made up of three universities, the Tyrolean Cancer Research Institute, and the Institute for Biomedical Aging Research of the Austrian Academy of Sciences.

Table 1. Structuring of biotechnology clusters in three Austrian regions (number of firms)

	Vienna	Styria	Tyrol
Multinational Companies	6	1	1
Dedicated Biotech Firms	25	2	7
Specialised Suppliers	19	4	1
Other Suppliers	10	3	0
Other Firms	2	0	0
Sales & Distribution Firms	15	0	0
Total	77	10	9

Source: Own inquiries

Furthermore, there is one co-operative research centre located in the region (see below). The province of Styria hosts three universities and two recently established co-operative research organisations carrying out bio-scientific research (see below).

As we have argued elsewhere, until recently the Austrian science sector in the field of biotechnology was not used to commercialising its scientific expertise. The most important reasons for this weakness in academic entrepreneurship include a lack of tradition, culture and incentives at universities to commercialise scientific results on the one hand, as well as a weakly developed public support infrastructure on the other (Trippl and Tödtling, 2007).

In the following we will demonstrate that in the recent past substantial changes have set in, reflecting a more active role of Austrian universities in economic development. Our results are based on qualitative face-to-face interviews. The interviews were conducted for two research projects: "Collective Learning in Knowledge Economies: Milieu or Market?" (2002-2004), funded by the Austrian Science Fund, and "Cluster development and policy in the Vienna biotechnology sector" (2005-2006), funded by the Jubilee Fund of the City of Vienna for the Vienna University of Economics and Business Administration. In the three regions of Vienna, Tyrol and Styria 17 interviews were conducted with university institutes, other public and semi-public research organisations and cooperative research centres. Furthermore, some 14 interviews were carried out with policy agents, supporting institutions at universities and other organisations that aim at promoting knowledge transfer from universities to the industry.

4.1. Scientific collaborations at global & local levels

As outlined in Section 3, international scientific contacts are a key channel for getting access to knowledge, expertise and competences which have been developed elsewhere. The scientists included in our sample reported rather intensive collaboration with international research organisations. For the majority of them, contacts with international partners – mainly from Europe and the United States – are more important than local ones. Almost all interview partners noted that the key reason for establishing contacts with foreign universities has been the specific complementary knowledge possessed by them. Not surprisingly, in the majority of cases, joint publications have been found to constitute the crucial aim of scientific interaction. Other motives for entering into relations with international universities included joint problem solving, getting new ideas and intellectual discussions.

Notwithstanding the significance of the international level as space for scientific interactions, the local and national levels also turned out to play a prominent role. At these scales, it is also the access to complementary knowledge that is decisive for cooperating with specific partners. Additionally, as is the case when it comes to international interaction, joint publications have been identified as the most essential goal of collaboration with the national and regional science systems. Since a few years such interactions are actively promoted by public policy in the context of the "Austrian Genome Research Programme", which has led to a local bundling of scientific competences and the achievement of critical mass in this field (see Table 2). As is also revealed in Table 2, this policy initiative

Table 2. Collaboration stimulated by the Austrian Genome Research Programme

Project	Partners (location)
COOPERATIVE PROJECTS:	
Epigenetic Plasticity of the Mammalian Genome	▪ Research Institute of Molecular Pathology IMP (Vienna) ▪ Center f. Molecular Medicine, Austrian Academy of Sciences (Vienna) ▪ Institute of Medical Biochemistry, Medical University Vienna
Ultra-sensitive Proteomics and Genomics	▪ Instit. for Biophysics, University Linz (Upper Austria) ▪ Profactor Produktionsforschungs GmbH (Upper Austria) ▪ Fuzzy Logic Laboratorium, University Linz (Upper Austria) ▪ Lambda GmbH (Upper Austria) ▪ Instit. of Genetics and General Biology, University Salzburg ▪ Instit. of Immunology, Medical University Vienna ▪ Elisabethinen Hospital Linz (Upper Austria)
Genomics of Lipid-Associated Disorders	▪ Instit. for Molecular Biology, Biochemistry and Microbiology, University Graz (Styria) ▪ Instit. f. Genomics and Bioinformatics, Technical University Graz (Styria) ▪ Dep. of Biochemistry, Technical University Graz (Styria) ▪ Instit. of Medical Biochemistry and Medical Molecular Biology, Medical University Graz (Styria) ▪ Dep. of Medical Biology and Human Genetics, Medical University Innsbruck (Tyrol) ▪ Instit. for Molecular Biology, Biochemistry and Microbiology, University Graz (Styria)
Genomic Approaches to Tumor Invasion and Metastasis	▪ Boehringer Ingelheim Austria (Vienna) ▪ Medical University Vienna ▪ Clinical Instit. of Clinical Pathology, Medical University Vienna ▪ University Clinics for Dermatology, Medical University Vienna
PILOT PROJECTS:	
Functional analysis using the "screen-out" method	▪ Instit. of Animal Breeding & Genetics, University of Veterinary Medicine Vienna ▪ Dep. of Vascular Biology and Thrombosis Research, Medical University Vienna ▪ Research Institute of Molecular Pathology IMP (Vienna)
A Comprehensive Disease Bank for Functional Genomics	▪ Instit. of Pathology, Medical University Graz (Styria) ▪ Instit. for Virology, University of Veterinary Medicine Vienna ▪ Instit. of Cancer Research, Medical University Vienna ▪ Dep. of Internal Medicine, Medical University Graz (Styria) ▪ Oridis Biomed GmbH (Styria)
Functional genomics of childhood malignancies	▪ Children´s Cancer Research Institute (Vienna) ▪ Tyrolean Cancer Research Institute (Tyrol)
Cancer in the Hematopoietic System	▪ Instit. for Molecular Biotechnology IMBA, Austrian Academy of Sciences (Vienna)
Proteomics in Tumor Biology	▪ Instit. of Analytical Chemistry and Radiochemistry, University Innsbruck (Tyrol) ▪ Dep. of Anatomy, Histology, and Embryology, Medical University Innsbruck (Tyrol)

Table 2 (continued). Collaboration stimulated by the Austrian Genome Research Programme

Project	Partners (location)
NETWORKS:	
Bioinformatics Integration Network	▪ Instit. for Genomics and Bioinformatics, Technical University Graz (Styria) ▪ Tyrolean Cancer Research Institute (Tyrol) ▪ Research Institute of Molecular Pathology IMP (Vienna) ▪ Instit. for Theoretical Chemistry and Structural Biology, University of Vienna ▪ Instit. for Chemistry, University Graz (Styria)
Austrian Proteomics Platform	▪ Dep. of Anatomy, Histology, and Embryology, Medical University Innsbruck (Tyrol) ▪ Instit. for Medical Chemistry, University of Veterinary Medicine Vienna ▪ Research Institute of Molecular Pathology IMP (Vienna) ▪ Instit. of Pharmaceutical Chemistry & Pharmaceutical Technology, University Graz (Styria) ▪ Instit. of Analytical Chemistry and Radiochemistry, University Innsbruck (Tyrol) ▪ Dep. of Anatomy, Histology, and Embryology, Medical University Innsbruck (Tyrol)

Source: Own inquiries

has also stimulated the joint production of new knowledge and the circulation of scientific competence and expertise at the interregional level.

4.2 Links between research organisations & industry

After our brief discussion of scientific interaction we now deal with different types of relationships between research organisations and private companies. Our results indicate that a transformation of Austrian universities into more outward-looking and entrepreneurial facilities has occurred. Their role is no longer restricted to the provision of highly skilled labour, but increasingly includes being a cooperation partner of industry and acting as incubator for spin-offs.

Universities as sources of highly qualified labour. The production of highly skilled labour represents a key function performed by universities in the Austrian biotechnology sector. Particularly in the region of Vienna, this more traditional function of academic knowledge organisations has been crucial for the emergence of the local biotechnology industry. Between the 1950s and 1980s the availability and easy recruitment of scientists has been among the main reasons for the arrival of large multinational pharmaceutical companies such as Boehringer Ingelheim, Novartis and Baxter (Oosterwijk et al., 2003). As we have argued elsewhere (Tödtling and Trippl 2007), the attraction and "anchoring" of these companies to the region have been vital for the gradual evolution of the Vienna biotechnology cluster. The provision of graduates still represents an essential function of universities in Austria. Academia directly contributed to the development and growth of the three biotechnology clusters investigated here. Many of the academic institutions included in our sample reported that their alumni have found jobs in subsidiaries of multinational corporations located in the region. This holds true in particular for the Vienna biotechnology cluster, where the movement of trained personnel from universities to companies such as Baxter, Boehringer Ingelheim and Novartis constitutes an important mechanism for regional collective learning, as it leads to the dissemination of new scientific knowledge at the local level. It is, however, not only in the Vienna biotechnology industry that local economic dynamics are linked to the educational mission of universities. This type of knowledge transfer from academia to industry has also been found to be of major significance in the smaller biotechnology clusters identified in the regions of Tyrol and Styria. In Tyrol, Biochemie Kundl is a key employer of university graduates. This illustrates a main aspect of the situation; big pharmaceutical companies are the main absorbers of highly skilled young scientists in the Austrian biotechnology sector. Labour mobility from universities to the dedicated biotechnology firms located in the regions we have investigated is not yet very intensive. This finding can be related to the fact that many of these companies are still very young and fairly small. Thus, the fact that the development of the biotechnology sector in Austria is still in

the early stages, has to be regarded as an important reason why dedicated biotechnology firms only to a limited extent, exploit the knowledge and skills embodied in the graduates of academic institutions. Importantly, our interviews have shown that several academic knowledge organisations maintain close contacts with their former students now employed in local firms. These relations are manifold, ranging from more informal exchange of information and ideas to joint activities in formal university-industry partnerships. The good personal knowledge that professors and the graduates have from each other, facilitates the exchange of knowledge in cooperative endeavours enormously and helps to overcome interaction barriers between universities and industry. As one interview partner from the university scene put it: "These alumni have a good understanding of the research that is done at our institute, they are familiar with our philosophy. There is reciprocal trust, which is a very important point, and communication with them is so easy." In the recent past in Vienna, the educational system has become further differentiated. Two technical colleges for biotechnology and bioengineering have been established to meet the growing demand for skilled technicians. Some important actors from the industry have been involved in specifying the content of teaching and representatives from local firms also give lectures. Given this close interaction between the industry and the technical colleges, it is likely that the colleges' output of qualified workers is fine-tuned to the needs of the local companies.

University-industry partnerships. A key function of universities and other research organisations that has become important in the past decades is that of partners of pharmaceutical and biotechnology firms in various university-industry relationships. The Austrian biotechnology sector clearly demonstrates that universities do not only accomplish their traditional function as human capital providers. They are also becoming increasingly involved in cooperative projects. This reflects a more modern and active role of knowledge institutions in spurring industrial innovation in the Austrian biotechnology clusters studied here. A closer look at the university-industry partnerships reveals that the Austrian university institutes in our sample have built up a range of ties to local and international companies. At the local level, different types of industrial actors seem to represent important partners of knowledge organisations. First, there is evidence that big pharmaceutical companies, in particular Baxter, Novartis and Boehringer Ingelheim Austria, exploit the scientific capabilities and expertise of the universities by engaging in co-operative projects with them. Second, links between academic research institutions and small dedicated biotechnology firms have also been found. Finally, very close contacts between universities and their spin-off firms could be identified (see below).

An analysis of the nature of the various relationships found shows that it is formal interactive cooperations between knowledge organisations and local firms that dominate. However, evidence was also found that contract research, the selling of licenses, the development of assays and diagnostic products and tests, as well as informal relationships play a role. In this context, one university professor stated: "In former times industrial companies had a clear problem and a clear goal when they built up contacts with universities. The universities carried out contract research to solve this clearly defined problem. However, things have changed. The actual questions and problems that companies face are far more complex, they can no longer be specified in detail at the beginning of the project. This demands a new form of relationship between universities and industries that is about a joint definition of the problem during the project. This leads to a shift from classical contract research to more interactive cooperative endeavours". Several of the aforementioned formal cooperation projects have been encouraged by public policy and various cooperative research centres carrying out longer-term projects have been established in this context. The overwhelming majority of these publicly funded university-industry partnerships can be found in the Vienna region, promoting collective learning in the local cluster (see Table 3). Policy efforts undoubtedly account for a part of the trend toward stronger links between universities and firms in the Austria biotech clusters.

The research organisations in our sample do not only have contacts with local firms. Most of them have also developed relationships with international companies. Large pharmaceutical firms, mainly European ones, constitute the most important partners here. There is a wide variety of types of knowledge interaction between Austrian universities and international firms, covering consulting activities, cooperation in EU projects, contract research, selling of patents as well as joint publications. Although there is increasing evidence of knowledge links between universities and companies, the interaction between the academic and industrial world is far from running smoothly and without obstruction. Several interview partners mentioned barriers such as problems of communication, a mismatch of philosophies, as well as diverging interests and incentives. A frequent problem is that the research activities conducted at universities do not meet the demand of firms.

Table 3. Cooperative research centres in biotechnology in Austria

Cooperative research centre	Academic partners	Industry partners (location)
Region of Vienna:		
Christian Doppler Lab Gene therapeutic vector development	Inst. for Virology and Biomedicine (Univ. of Veterinary Medicine Vienna)	Sanochemia (Vienna), Austrianova (Vienna)
Christian Doppler Lab: Molecular Recognition Materials	Inst. of Analytical Chemistry (Univ. of Vienna)	Merck (Germany) Astrazeneca (Sweden)
Christian Doppler Lab: Proteomics Analysis	Inst. of Biochemistry and Molecular Cell Biology (Univ. of Vienna)	IMP (Vienna)
Kplus: BMT Biomolecular Therapeutics	Dep. of Dermatology (Medical Univ. Vienna), Dep. of Vascular Biology and Thrombosis Research (Medical Univ., Centre for Nanobiotecnology (Univ. of Natural Resources and Applied Life Sciences)	Baxter (Vienna), Polymun (Vienna), Technoclone (Vienna)
K-ind: ACBT Austrian Centre of Biopharmaceutical Technology	Inst. of Applied Microbiology (Univ. of Natural Ressources and Applied Life Sciences), Inst. of Biochemistry (Univ. of Innsbruck)	Boehringer Ingelheim Austria (Vienna), Polymun Scientific (Vienna), Sandoz (Tyrol)
Region of Tyrol:		
K-ind: Medical Centre of Excellence Projects (selection)		
Dendritic Cell-Based Tumour Vaccine / Kidney	Medical Dep. of Dermatology and Venerology (Innsbruck Medical Univ.)	Sentimmun (Tyrol), V&F medical development (Tyrol), Biocrates (Tyrol)
Dendritic Cell-Based Tumour Vaccine / Skin	Medical Dep. of Dermatology and Venerology (Innsbruck Medical Univ.)	Sentimmun (Tyrol), Immumetrics (Tyrol), Biocrates (Tyrol)
Islet cells	Medical Dep. of Dermatology and Venerology (Innsbruck Medical Univ.) Dep. of General and Transplant Surgery (Innsbruck Medical Univ.)	Sentimmun (Tyrol)
Region of Styria:		
Christian Doppler Lab Genomics and Bioinformatics	Inst. for Genomics and Bioinformatics (Graz Univ. of Technology)	Sandoz (Tyrol), Eccocell (Styria), Oridis Biomed (Styria)

Source: Own inquiries

4.3.Knowledge organisations as sources of new firms

Apart from the traditional academic mission of teaching and the more modern role as cooperation partner for industrial firms, Austrian universities have lately also become an important source of new firm formation. This signals a very new role of scientists. Setting up a company in order to translate academic research discoveries into innovative commercial products is no longer frowned upon in academic departments. Academic spin-offs are essential for the development of the three Austrian biotechnology clusters investigated here; about 30 firms originating from the public research sector are located in these clusters. Although the first academic spin-off firm (Immuno) was created as early as in the 1950s, followed by two spin-outs (Technoclone and Nanosearch Membrane) in the 1980s, it was not until around the year 2000 that the academic spin-off process really gained momentum. As we have shown elsewhere, the overwhelming majority of these spin-offs are still in an early stage of development and earn no or only few revenues so far (Trippl and Tödtling, 2007). From the 15 knowledge organisations in our sample, 10 have spun off new local businesses. The majority of these firms were established between 2001 and 2004 (see Table IV). Only three companies, all located in the region of Vienna, are older, including Technoclone (founded in 1987), Polymun (1992) and Intercell (1997).

Table 4. Characterisation of academic spin-offs included in the sample

Parent organisation (location)	Spin-off company (location)	Year of foundation	Number of employees
Medical University (Vienna)	Technoclone (Vienna)	1987	-
University of Natural Resources and Applied Life Sciences (Vienna)	Polymun (Vienna)	1992	24
University of Vienna (Vienna)	Intercell (Vienna)	1997	130
University of Veterinary Medicine (Vienna)	Austrianova (Vienna)	2001	16
University of Natural Resources and Applied Life Sciences (Vienna)	Nano-S (Vienna)	2003	6
Austrian Academy of Sciences (Vienna)	Appeiron (Vienna)	2003	-
Medical University Graz (Styria)	Oridis (Styria)	2001	17
University of Innsbruck (Tyrol) and Austrian Academy of Sciences (Tyrol)	Amynon (Tyrol)	2002	6
University of Innsbruck (Tyrol)	Inteligand (Lower Austria)	2003	-
University of Innsbruck (Tyrol)	AlcaSynn (Tyrol)	2004	3

Source: Own inquiries

Our results show some interesting details with respect to the academic spin-off phenomenon:

- In the Austrian biotechnology sector, the large majority of academic founders continue to hold their position as researcher or professor at the university. These people act as "border crossers" between the academic and the industrial spheres.
- The relation between the research organisation and the firm is very close. We found a wide array of such linkages, including R&D co-operations, the joint use of infrastructure, the exchange of staff, the buying of patents as well as the use of the academic networks by the spin-off firms. It can be argued that to some extent the boundaries between the academic and the industrial world have become too blurred. In some cases, the firm is even located at the university institute, resulting in unclear use of public resources.
- In most cases a lack of business skills is a dominant feature of many of these academic spin-offs.

The recent advent of research-based spin-off firms in the Austrian biotechnology sector has been essen-

tially supported by two main factors: First, successful companies such as Intercell and Igeneon have certainly played a key role in enhancing the rate of new venture creation in biotechnology. By acting as "role models" these companies inspired academic scientists to commercialise their research results by establishing new firms. Second, the intensification of the academic spin-off process must be viewed against the background of explicit policy efforts. To stimulate academic spin-offs has become an important goal of Austrian policymakers in the recent past (Austrian Council, 2005). At the national policy level, the initiative "Life Science Austria" (LISA) was launched in 1999 to support the foundation of new biotechnology companies. LISA comprises the provision of preseed capital, information and advice to firm founders concerning technological and commercial issues, a business plan competition, as well as the organisation of lectures and training sessions to enhance the commercial and managerial competencies of scientists. At the national level there is also a range of other programmes aiming to advance high technology entrepreneurship. These include the initiatives "Seed Financing" (provision of loans), "High Tech Double Equity" (acceptance of guarantees) and "uni:venture" (a fund that provides venture capital to academic spin-offs).

Regional policy agents in Austria are also engaged in pursuing strategies to create favourable conditions for academic entrepreneurship. In the recent past, academic spin-off centres geared towards promoting technology-oriented spin-offs from the science sector have been established in all three regions investigated here. These centres offer incubation space, counselling and assistance to academic founders. In the Vienna region, an additional policy initiative, "Start Up", has been introduced. The initiative aims at supporting the formation of research intensive enterprises by funding R&D projects of young companies (for a more detailed overview, see Trippl et al., 2006).

5. Summary

In the emerging knowledge economy, universities and other publicly funded research institutions have experienced essential changes in their functions. Their main mission is no longer confined to education and the carrying out of basic research, but increasingly also covers technology transfer and commercialisation activities. This paper has investigated whether the development towards entrepreneurial universities can be observed not only in high-technology countries (US, UK) and regions (Silicon Valley, Boston, Cambridge), but also in countries such as Austria, which is still characterised by the dominance of more traditional industries. Such evidence would signal a broad trend towards entrepreneurial universities going beyond "islands of high-technology". We have demonstrated that Austrian universities have slowly been changing from an ivory tower towards an economic engine. In the past years, their altruistic mission of education and the pursuit of knowledge for its own sake have been complemented by new tasks and functions. There is a variety of knowledge interaction in the Austrian economy, much of it in traditional sectors (Schartinger et al., 2001; Schartinger et al., 2002). Universities also play a key role in knowledge intensive clusters such as biotechnology. Comparing our findings with those presented by Schartinger et al. (2001) we see that in biotechnology there are more direct and interactive forms of knowledge links between academia and companies than in more traditional sectors. This is brought about because formal university-industry partnerships and academic spin-offs occupy a more important position in the area of biotechnology.

Our results reveal that in biotechnology, public knowledge organisations in Austria play multifarious roles. They are inserted in a range of international scientific collaborations, acting as "antennae" for receiving external expertise and competencies produced elsewhere. At the national and regional levels we also found intensive interaction within the scientific system, indicating a rather intense local and national circulation of academic knowledge. Furthermore, it has been shown that universities and other knowledge organisations should be regarded as key providers of qualified labour and skills. In addition, they have expanded their tasks and increased their role in innovation. The existence of university-industry partnerships and, even more importantly, the intensified process of new firm formation by university researchers signal the emergence of an entrepreneurial culture within academia. Universities have been found to play a pivotal role in seeding new biotech ventures, pointing to a direct transformation of scientific knowledge and technology into marketable products. As revealed in this article, policy interventions have been significant for promoting closer relations between academic faculties and firms and for fostering a transformation of scientific knowledge into marketable products by creating academic spin-offs.

The development from a traditional university towards an entrepreneurial university outlined here seems to be positive from the perspective of university-industry interaction, regional development and innovation. However, it should be pointed out here that universities have to maintain also their original roles (basic research, education) in order to serve their respective role in national and regional innovation sys-

tems (Lundvall, 2006). Furthermore, well-functioning university-industry links require well-defined boundaries and tasks, adequate organisations and rules. At the same time, it is necessary to have clear and consistent incentives in order to secure excellent basic research and alumni as well as knowledge interactions with firms.

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