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Nr.303/2008

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ISSN 0930-8334

STANDARD-SETTING AND KNOWLEDGE DYNAMICS IN INNOVATION CLUSTERS *

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Extensive research has been conducted on how firms and regions take advantage of spatially concentrated assets, and also why history matters to regional specialisation patterns. In brief, it seems that innovation clusters as a distinctive regional entity in international business and the geography of innovation are of increasing importance in STI policy, innovation systems and competitiveness studies. Recently, more and more research has contributed to an evolutionary perspective on collaboration in clusters. Nonetheless, the field of cluster or regional innovation systems remains a multidisciplinary field where the state of the art is determined by the individual perspective (key concepts could, for example, be industrial districts, innovative clusters with reference to OECD, regional knowledge production, milieus & sticky knowledge, regional lock-ins & path dependencies, learning regions or sectoral innovation systems).

According to our analysis, the research gap lies in both quantitative, comparative surveys and in-depth concepts of knowledge dynamics and cluster evolution. Therefore this paper emphasises the unchallenged in-depth characteristics of knowledge utilisation within a cluster's collaborative innovation activities. More precisely, it deals with knowledge dynamics in terms of matching different agents´ knowledge stocks via knowledge flows, common technology specification (standard-setting), and knowledge spillovers. The means of open innovation and system boundaries for spatially concentrated agents in terms of knowledge opportunities and the capabilities of each agent await clarification. Therefore, our study conceptualises the interplay between firm- and cluster-level activities and externalities for knowledge accumulation but also for the specification of technology. It remains particularly unclear how, why and by whom knowledge is aligned and ascribed to a specific sectoral innovation system.

Empirically, this study contributes with several descriptive calculations of indices, e.g. knowledge stocks, GINI coefficients, Herfindahl indices, and Revealed Patent Advantage (RPA), which clearly underline a high spatial concentration of both mechanical engineering and biotechnology within a European NUTS2 sample for the last two decades. Conceptually, our paper matches the geography of innovation literature, innovation system theory, and new

We owe considerable gratitude to the participants of the *Workshop on Open Innovation*, May 22-23, 2008, Cambridge (UK), Programme on Regional Innovation, The Cambridge-MIT Institute; *European Summer School on Industrial Dynamics* (ESSID 2008), Sept 01-06, 2008, Centro di Studi Micaelici e Garganici, Monte Sant'Angelo, Foggia; *FZID*, CC Innovation & Knowledge, Doctoral Colloquium, July 17, 2008, University of Hohenheim, Stuttgart; and *Knowledge Economy*: Chances and Challenges for SMEs, October 9-10, 2008, ESB Research Institute, Reutlingen.

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ideas related to the economics of standards. Therefore, it sheds light on the interplay between knowledge flows and externalities of cluster-specific populations and the agents' use of such knowledge, which is concentrated in space. We find that knowledge creation and standard-setting are cross-fertilising each other: although the spatial concentration of assets and high-skilled labour provides new opportunities to the firm, each firm's knowledge stocks need to be contextualised. The context in terms of 'use case' and 'knowledge biography' makes technologies (as represented in knowledge stocks) available for collaboration, but also clarifies relevance and ownership, in particular intellectual property concerns. Owing to this approach we propose a conceptualisation which contains both areas with inter- and intra-cluster focus. This proposal additionally concludes that spatial and technological proximity benefits standard-setting in high-tech and low-tech industries in very different ways. More precisely, the versatile tension between knowledge stocks, their evolution, and technical specification & implementation requires the conceptualisation and analysis of a non-linear process of standard-setting. Particularly, the use case of technologies is essential. Related to this approach, clusters strongly support the establishment of technology use cases in embryonic high-tech industries. Low-tech industries in contrast rather depend on approved knowledge stocks, whose dynamics provide better and fast accessible knowledge inputs within low-tech clusters.

Keywords: innovation clusters, standard-setting, knowledge externalities and flows, knowledge alignment, mechanical engineering, biotechnology

JEL: D89, L22, M20, O32

1 Introduction

Extensive research has been conducted on how firms and regions take advantage of spatially concentrated assets and also why history matters to regional specialisation patterns. In brief, it seems that innovation clusters as a distinctive regional entity in international business and also the geography of innovation are of increasing importance to STI policy, innovation systems and competitiveness studies.

To put it simply, literature can be separated into qualitative, often appreciative and economic categories respecting the indicator-based research community. In qualitative studies, the phenomenon of a new role of regional and metropolitan settings for competence-building, inter-firm cooperation and excellence within competition has been stressed. For instance, besides the Italian "industrial district" concept, literature has also put emphasis on "technical districts", "innovative milieus" (Groupe de Recherche Européen sur les Milieux Innovateurs), "learning regions",[1] and different cluster approaches.[2] Moulaert and Sekia (2003) aggregate industrial districts, innovative milieus, new industrial spaces, innovation clusters, learning regions, and regional innovation systems under the collective term 'territorial innovation models'(TIM).[3] Unfortunately, attempts to differentiate between these agglomerated phenomena are not sufficient. Additionally, contemporary literature has introduced several expressions such as competence clusters, excellence clusters, competence networks, science parks, technology parks, science cities, technopoles, and many more.[4] Some expressions are introduced for political purposes without detailed recourse to economic theory, and are STI policy oriented. A prominent group of researchers on Innovation Clusters has established a 'European Cluster Observatory' published by the Stockholm School of Economics (http://www.clusterobservatory.eu/; particularly see the item 'Cluster Mapping').[5] Furthermore, 'The Cluster Initiative Greenbook' and the so-called new 'Redbook' are published in Stockholm as well (Sölvell et al., 2003; Sölvell, 2008). On clusters & competitiveness in development countries see the so-called 'Bluebook' (Ketels/Lindqvist/Sölvell, 2006).[6] On clusters & innovation also note OECD (1999a).

Our conceptual approach includes systems of innovation theory, the geography of innovation literature and the economics of standards. Thus, spatially concentrated systems (innovative clusters) are crucial. As literature indicates, economics researchers and economic

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1 Cooke (1998); Asheim (1995); Moulaert/Sekia (2003: 293).

2 Asheim/Coenen (2004); Asheim/Isaksen (2002); Cooke (1998); Cooke/Memedovic (2003).

3 Moulaert/Sekia (2003: 291-294).

4 Hu (2007: 77).

5 "The Observatory offers rich data on geographical patterns of specialisation across cluster categories, national and regional portfolios of clusters, cluster organisations, and national and regional policies and programmes related to innovation and clusters. In addition, a cluster library offers case materials and various articles on clusters, competitiveness and cluster policy." (http://www.clusterobservatory.eu/, European Cluster Observatory)

6 Also see http://www.isc.hbs.edu/econ-clusters.htm, Institute for Strategy and Competitiveness at Harvard Business School, Clusters and Cluster Development; and http://www.competitiveness.org/, TCI Network, The Competitiveness Institute, Barcelona.

geographers are deeply involved in both the qualitative and quantitative-orientated research communities. Other disciplines such as economic sociology rather contribute qualitative case findings. Economic prosperity and innovation from strong regions are not necessarily solely a question of R&D intensity and high-tech patents.[7] Some regions might strive to become global excellence service centres, others to become leading export sites of particular high-tech or high-end products, or at least of low-tech production. The literature on regional economics and sociological literature indicate that strategy is to some extent bounded to regional history: regional opportunities are shaped by beliefs and mental lock-ins of local policymakers, qualifications of the labour pool, and evolved ties between local firms.[8]

In economics, studies on regional innovation systems have highlighted externalities and policy implications of strong regional settings. Besides territorial systems, several sub-groups have contributed to agglomeration economics and spillovers in different but complementary ways. The concept of technological proximity and externalities is essentially modelled within the literature on Endogenous (New) Growth Theory and contributions to the Knowledge Production Function.[9] Most contributions, however, refer to the legacy of Marshall (1920), Young (1928), Arrow (1962) and Romer (1986).[10] The assumption of economies external to the firm but internal to the industry finally achieved recognition as 'Marshall-Arrow-Romer-(MAR-) externalities'.[11] Numerous studies have applied these MAR externalities, also known as intra-industry advantages, to get a better understanding of industry concentration, industry dynamics and the existence and development of metropolitan cities with specialised industry profiles. We will use spillovers for approaching cluster-specific knowledge dynamics, and thus standard-setting. Although the ICT revolution created new knowledge infrastructures, some economic activities still prefer geographical concentration and agglomerated industries.[12] Moreover, there is still a fruitful debate concerning the influence of geographical, technological, organisational and social proximity. This economic question is discussed in respect of the ongoing tendencies towards interconnected and footloose firms because of the World Wide Web.[13] It is, however, an accepted and salient phenomenon that increasing spatial distance tends to squeeze the frequency of economic activities and interactions among organisations and individuals. This is essential for our conceptualisation. For this reason, intellectual and innovative activities seem to be heavily influenced by technological and geographical proximity as we assume that spatial proximity favours technological spillovers and knowledge externalities. Thus, firms and entrepreneurial entities within clusters participate from an agglomerated knowledge pool because of geographically

7 For instance, based on computations for the aggregation level of German „Länder“, Leydesdorff/Fritsch (2006) have shown that the contribution of medium-tech industries provides a good predictor of properties of the innovation system in a given region.

8 Iammarino (2005) and Hanusch/Pyka (2007).

9 See Christ (2007) and Christ (2009a and 2009b) for a detailed overview and discussion of knowledge externalities, pecuniary externalities and knowledge dynamics in a spatial context.

10 Hanusch/Pyka (2007: 277).

11 MAR externalities correspond to the contributions of Marshall (1891), Arrow (1968) and Romer (1986, 1990).

12 Fagerberg (2006: 21); Gertler (2003: 75-99).

13 Cooke (2001: 965); Malmberg/Maskell (2005: 1).

bounded knowledge externalities. These knowledge externalities share similarities with club goods in a geographical sense: non-rivalry and excludability.[14] Polanyi (1966) introduced the crucial distinction between tacit (implicit) and codified (explicit) knowledge. This concept offers a feasible explanation of the main differences between spatially concentrated innovation systems.[15] Furthermore, the conceptualisation of tacit knowledge represents a main difference from the concept of national systems of innovation. Additionally, the concept of tacit knowledge is more or less equivalent to the well-established concept of localised knowledge spillovers and externalities within endogenous growth theory.[16]

According to our analysis, the research gap lies in both quantitative, but comparative, surveys and in-depth concepts of knowledge dynamics and cluster evolution. It is not the static analysis of agglomeration effects in which we are interested but rather the underlying mechanisms of these effects over time which remain unchallenged. Note, however, that some studies have recently made remarkable contributions to a somewhat dynamic perspective on regional innovation systems respecting innovation clusters.[17] Our study aims to contribute to the emerging dynamics and evolutionary perspective on regional systems of innovation and innovation clusters.[18] Therefore the paper emphasises the unchallenged in-depth characteristics of knowledge utilisation within a cluster's collaborative innovation activities. More precisely, it deals with knowledge dynamics in terms of matching different agents´ knowledge stocks via knowledge flows, common technology specification (standard-setting), and knowledge spillovers. The means of open innovation and system boundaries for spatially concentrated agents in terms of knowledge opportunities and the capabilities of each agent still remains to be clarified. Therefore, our study conceptualises the interplay between firm- and cluster-level activities and externalities for knowledge accumulation, but also for specification of technology. It remains particularly unclear how, why and by whom knowledge is aligned and ascribed to a specific sectoral innovation system.

The structure of our paper is as follows: first, we illustrate in chapter 2 the spatial concentration of biotechnology and mechanical engineering within European regions. We take patents as indicator for technology assets owned by the clusters' agents and represented by knowledge stocks. Therefore, we conduct a patent count analysis. The chapter gives several descriptive calculations of indices (Appendix A), e.g. knowledge stocks, GINI coefficients, Herfindahl indices, Revealed Patent Advantage (RPA), which clearly underline a high spatial concentration of both mechanical engineering and

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[14] Christ (2007) offers a detailed overview of the concept of tacit knowledge and externalities. See also Malmberg/Maskell (1999: 172); Asheim/Gertler (2005: 291); Cooke/Memedovic (2003: 9); DeBruijn/Lagendijk (2005: 1154); Gertler (2003: 75-99); and Audretsch/Feldman (1999: 410).

[15] Lundvall (2007: 103);

[16] Polanyi (1966). For an overview, see additionally Hanusch/Pyka (2007: 282); Senker (1995: 426); Gertler, (2003: 77); Winter (2005: 35); Malmberg/ Maskell (1999: 172); or Malmberg/Maskell (2005: 4).

[17] Brenner (2001); Bröcker et al. (2003); Lagnevik et al. (2003); Nooteboom (2005); Shao et al. (2008).

[18] As the dynamic and evolutionary analysis of innovation clusters is a heterodox, badly-defined field, references provided can only be examples and are incomplete.

biotechnology within a European NUTS2 sample for the last two decades.[19] In order to explain these findings, chapter 3 first introduces different concepts of innovation systems, primarily sectoral and regional innovation systems. Second, we conceptualise new opportunities for firms in innovation clusters in terms of open innovation respecting open systems and also a knowledge production function. New ideas on the in-depth relationship between knowledge and standard-setting dynamics within clusters are presented in chapter 4. Our paper matches the geography of innovation literature with new ideas related to the economics of standards. Chapter 5 draws some conclusions.

2 Dynamics and Spatial Concentration in High- versus Low-technology Industries: Mechanical engineering and Biotechnology in Europe

2.1 Mechanical engineering

With respect to possible structural differences between low- versus high-tech sectors and clusters, we provide both a non-HT (mechanical engineering) and a high-tech (biotechnology) analysis.[20] In terms of standard-setting (see chapter 4.3) we argue that mechanical engineering and biotechnology are different as regards the maturity versus novelty question of contextualised knowledge. The extent of novelty shapes both the logics of technology specification and the process of sectoral innovation system evolution or creation. We therefore assume that high-tech agents create technology new to existing industries, whereas non-high-tech agents advance given technology or create technology new in only a specific industry context. Note that owing to varieties in novelty of the created knowledge and standards, we suggest two different kinds of specification and implementation processes beyond the linear model of standard-setting. Recent literature has often looked at standard-setting cases in information technologies & industries software where given standards are advanced (i.e. MOST25 to 50 to 150)[21] or where new standards refer to previous standards in order to replace them (i.e. UMTS[22], XML[23]). Therefore, standard-setting processes in high-tech fields are well known for the combination of new

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[19] See Appendix A for detailed classification of empirical indicators and indices. Appendix B highlights the complete NUTS codes.

[20] For terminology concerning high versus medium versus low-technology fro instance see Hatzichronoglou (1997).

[21] FlexRay, AUTOSAR, Media Orientated Systems Transport (MOST), CAN and LIN are standards widely used for field bus technology in automobiles. MOST can be considered as a kind of infotainment backbone which connects consumer electronics and Ethernet in the car. The above standards are established and maintained by industry consortia. Labels 25, 50 and 150 are those of the MOST standard vintages and each vintage adds new bandwidth or features to the standard.

[22] Universal Mobile Telecommunications Service (UMTS) builds on the Global System for Mobile (GSM) standards. The technology is also often labelled as 'third-generation' broadband technology. Hence, a UMTS use case for mobile phones was well established from the beginning. For an overview about the UMTS standard, see Rapeli (1995), Dahlman and colleagues (1998) and Halonen and colleagues (2003).

[23] XML can be taken as an evolution of HTML (see Tolksdorf, 1999) but it is now also used for several other documents such as office document types/'docx', component description in productions technologies or Web 2.0 applications. Additionally, see chapter 4.3 where we argue for replication of success mechanisms in low-technology standard-setting.

technology and for approved context and 'use case'[24] knowledge. The combinations we look at, namely new technology in combination with new knowledge on the one hand, and given or third industries' technology in combination with approved own knowledge on the other hand, are less focused in standard-setting and standardisation studies. Within this paper, 'standards' will be defined as technical specifications or business agreements about how technologies respecting business will be shaped. A specification of a standard selects one from various implementation alternatives respecting business models. Our paper particularly deals with the collaborative de facto specification of technical industry standards.

Mechanical engineering and production technologies are non-high-technology industries where high-norm activities and the ability to absorb other sectors' technology and standards are crucial. Briefly, integrators need to coordinate activities to control the innovation system. This has been described in detail by Gerybadze/Slowak (2008). Mechanical engineering is said to be a German strength. Exemplifying, this chapter will analyse how far the German mechanical engineering industry is concentrated in space. Additionally, it shows concentration measures for the European NUTS2 level (Appendix B). EUROSTAT NUTS2 classification will serve as a proxy for regional innovation systems' boundaries, whereas patents signal technology competence. We conduct a sectoral patent count to evidence spatial concentration of technology in geographical space. For this purpose we use EPO patent data of the EUROSTAT REGIO database (NewCronos), especially the recorded patent applications (per million employees and total number). These data have been regionalised to NUTS2 inventor locations (postal code, city name). In our view, the NUTS2 classification of EUROSTAT can be used for a European cluster analysis and patent data observation because of guaranteed data availability and harmonisation – at least for the period between the mid-nineties and today. As this chapter will show, the regions Stuttgart (de11), Rhone-Alpes (fr71), Ile-de-France (fr10), Lombardia (itc4), and Emilia-Romagna (itd5), among others, are important in terms of innovative activity for particular technology segments.[25]

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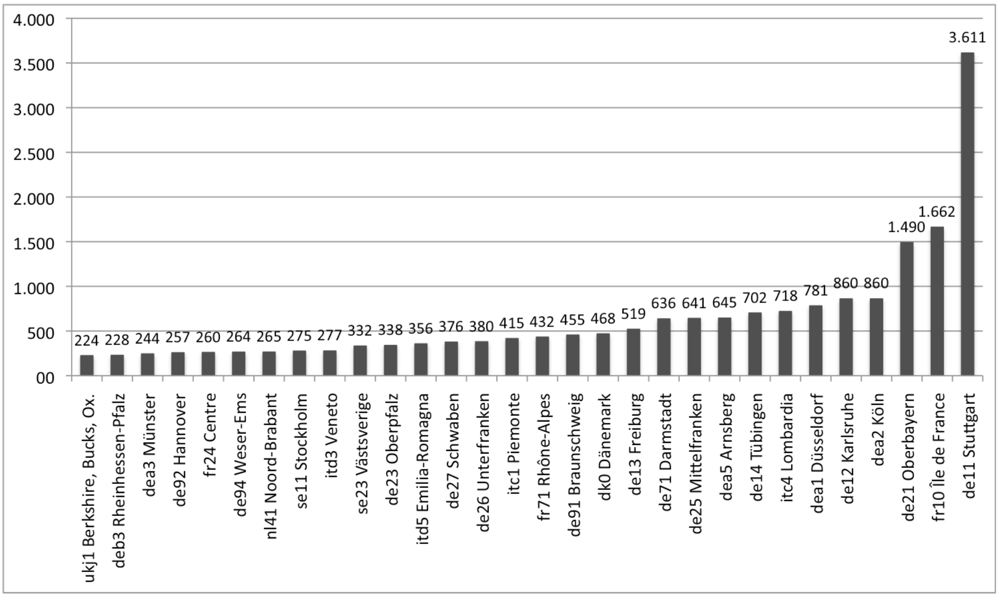
[24] For the medium/ low industry of industrial automation, the creation of a use case has been conceptualised as follows:

'As industrial automation represents a medium/low-tech industry, use cases are well-established. Field buses serve the automation of production processes and motions in factories and process plants. Therefore, in contrast with embryonic/immature industries such as cell cloning, the construction of a meaningful use case is not part of the standard-setting process … User organisations specify how and why a set of standards shall be used. They create a generic case of industry-specific use and industry-tailored services, but they also integrate third industries' open standards if those deliver new features to industry (creation of use case). For instance, industrial wireless technology / industrial WiFi takes from consumer-IT standards and allows for automation systems where cabling cannot be easily maintained (e.g. reefer vessels). Leading integrator firms such as Siemens therefore sell integrated, industry-specific process plant & factory solutions. The less there is a well-defined business for a standard and the higher the rate of technical change, the more the creation of a use case becomes a crucial part of the standard-setting process itself' (Slowak, 2008).

[25] Note that IPC class F addresses not only mechanical engineering but implicitly many other industries as well. Furthermore, niche markets like machinery tools or new segments of mechanical engineering such as 'mechatronics & productronics' may interfere with several other IPC classes. Also note that markets in mechanical engineering technologies interfere with other markets downstream and upstream the particular innovation chain case by case. Finally, cluster data, particularly for emerging new technology fields, differ substantially in terms of depth, public availability and access.

Owing to a high observable unequal distribution of knowledge in the field of mechanical engineering (see following tables and figures) in terms of the spatial distribution of (accumulated) patent applications to the EPO, IPC F, we conclude that this technology field (IPC F) – and consequently the underlying knowledge - is highly concentrated in a few regional NUTS2 entities within the European landscape. Thus, the spatial concentration of this proxy gives some indication about sector-specific knowledge stocks and knowledge dynamics. Figure 1 shows the 30 best-performing regions in the field of mechanical engineering; we accumulated the annual IPC F patent applications (inventor locations) from 1977 to 2003 to control for existing, inter-temporal knowledge stocks.

Figure 1: Accumulated EPO Patent applications IPC F (Mechanical engineering) – 30 Best-Performing NUTS2 regions, 1977-2003



Source: Own calculation and illustration. EUROSTAT database; Regional science and technology statistics, Mechanical engineering patent applications to the EPO by priority year at the regional level (April 2008).

The figure also shows that the best-performing regions are still heterogeneous in terms of their patenting performance. Although the EPO data of EUROSTAT are partially incomplete for the whole period from 1977 until 2003, we still argue that the accumulated value represents an adequate and sufficient proxy for knowledge stocks.[26] Thus, the top five regions with the highest rate of application are Stuttgart (de11), Ile-de-France (fr10), Oberbayern (de21), Köln (dea2) and Karlsruhe (de12). Between 1990 and 2003 Düsseldorf (dea1) performed better than Karlsruhe (de12). From this result, we assume a high level of cluster-specific knowledge in mechanical engineering in the observed NUTS2 entities. Additionally, this first simple descriptive analysis underlines the outstanding position of German NUTS2 regions.

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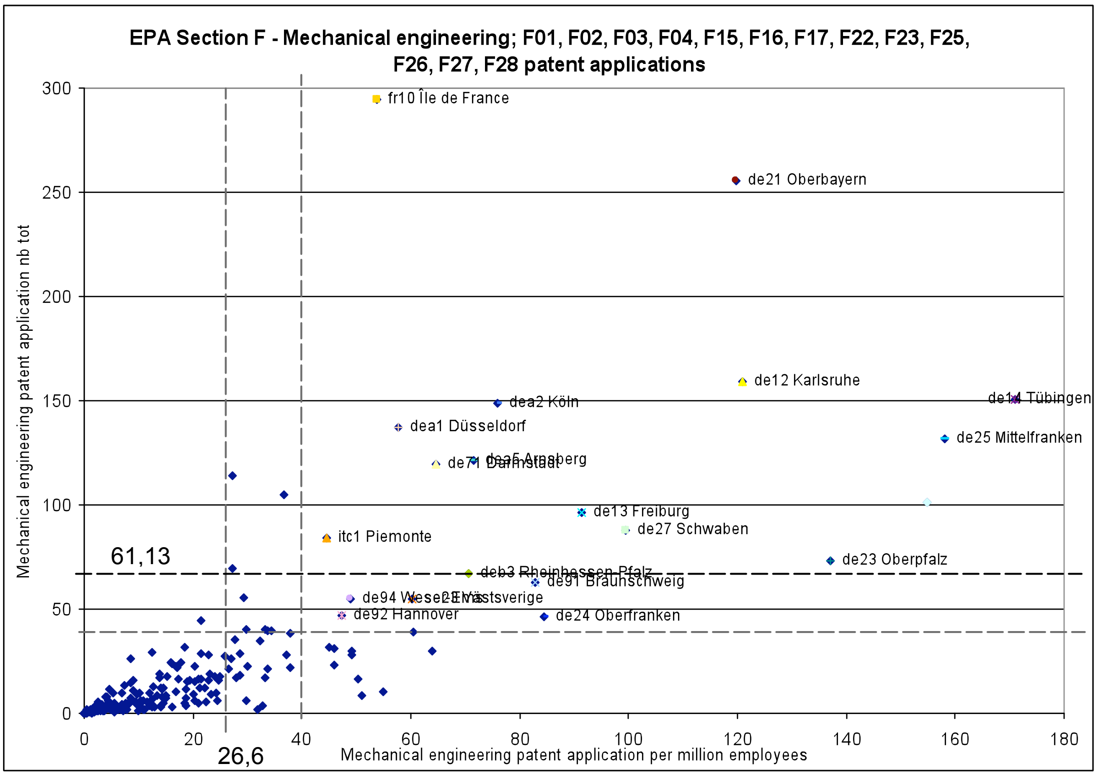
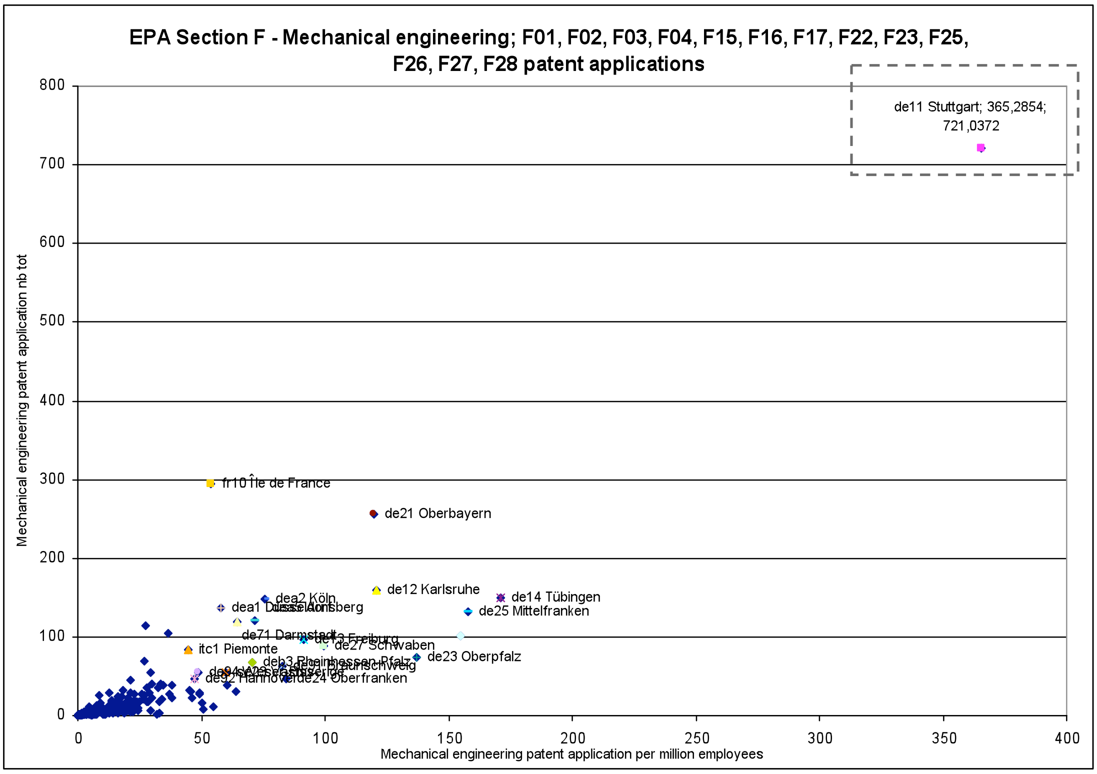
[26] Data for the best-performing regions were nearly fully available. The chart clearly shows an unequal distribution.

Figure 2: Mechanical engineering in 254 EU regions (NUTS) – Relative and Absolute Strength, Year 2002





Source: Own calculation and illustration. EUROSTAT database: Regional science and technology statistics; Patent applications to the EPO by priority year at the regional level (February 2008). For section F see Appendix C. Legend: Average number (nb tot): 61,13 patents (2002); average number (pat. appl. per mio employees): 26,68.

Figure 2 centres data points (x,y) for absolute and relative patent applications in mechanical engineering. As is shown, the leading clusters with specialised knowledge pools (represented by patent applications) are located in Germany.

Additionally, Stuttgart (de11) seems to be the leading cluster in mechanical engineering; its absolute (nb tot) and relative (per mio employee) patent applications are outstanding compared with other technologically advanced regions.

If we assume that the intensity of knowledge externalities increases with the (absolute) size of the knowledge stock, leading regions would benefit the most. Chapters 3 and 4 centre on this issue. Thus, we assume geographically concentrated sectoral innovation systems and innovative clusters to be more competitive, if absolute patenting activity exceeds those of other regions. In the above figure, strong patenting activity is given, if patent applications of a spatially concentrated (regional) innovation system exceed the average applications of all regions in the sample (critical mass). The leading regions (de11, de12, de21, fr10, dea1, dea2, de13, itc1, de23, de27, de25) in Figure 2 are determined by absolute and relative strength in IPC F patenting, which is additionally complemented by higher employment shares as highlighted in various descriptive regional analyses.[27]

Table 1 illustrates two possible scenarios in terms of knowledge stock changes; stability or high dynamics of knowledge accumulation in the field of mechanical engineering. Stuttgart (de11) particularly has always been within the top five groups, but outperformed the previously higher ranked regions Ile-de-France (fr10) and Oberbayern (de21). The German region Mittelfranken (de25) entered the top 20 in 1995 and achieved seventh place in 2002. Other regions like Lombardia (itc4) have always been strong, but their development has been volatile. The region of Inner London (uki1) dramatically fell between 1980 and 1985 (from sixth to eighteenth place). Since 1995 the UK has had no any position in the top 20, which indicates some structural downsizing of patenting in the field of mechanical engineering. The Herfindahl index (HHI), and our calculated GINI coefficients for the top ten and top 20 regions in IPC F patenting show spatially concentrated patenting.

The following Figure 3 and Table 1 show the concentration of patents in mechanical engineering (IPC F) (biotechnology, see next chapter) for 241 European regions according to the EUROSTAT NUTS classification.

[27] We do not consider employment structures and other cluster-specific resources in this paper, because the conceptual contribution is essentially related to knowledge stocks and standard-setting.

Table 1: Machinery in Europe: Patent Application Ranking (nb tot); Mechanical engineering - IPC Section F20; 20 Best Performing European NUTS2 Regions

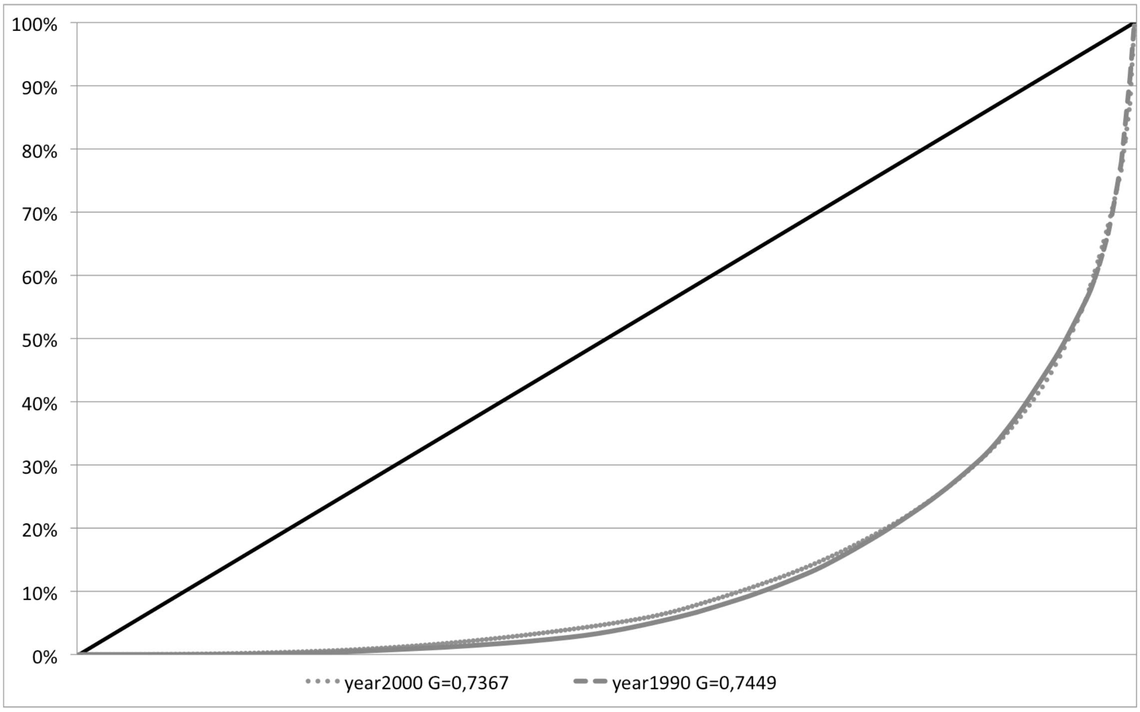
RANK	1980		1985		1990	
	observed regions:	172	observed regions:	183	observed regions:	213
	nb tot applications:	1552,88	nb tot applications:	2479,83	nb tot applications:	3149,82
	average (172):	9,03	average (183):	13,55	average (213):	14,79
	average (top10):	67,44	average (top10):	109,03	average (top10):	135,29
	average (top20):	45,76	average (top20):	73,04	average (top20):	89,61
	Share top 10/172	0,43	Share top 10/183	0,44	Share top 10/213	0,43
	Germany in top 10:	7	Germany in top 10:	7	Germany in top 10:	7
	France in top 10:	2	France in top 10:	2	France in top 10:	2
	HHI (top10)	0,14	HHI (top10)	0,13	HHI (top10)	0,13
	HHI (top20)	0,08	HHI (top20)	0,08	HHI (top20)	0,08
	normalized HHI (top20)	0,03	normalized HHI (top20)	0,03	normalized HHI (top20)	0,03
	GINI (top10)	0,29	GINI (top10)	0,32	GINI (top10)	0,31
	GINI (top20)	0,35	GINI (top20)	0,37	GINI (top20)	0,22
1	fr10 Île de France	172,25	fr10 Île de France	228,87	fr10 Île de France	288,65
2	de21 Oberbayern	91,63	de21 Oberbayern	219,83	de11 Stuttgart	225,02
3	dea2 Köln	81,06	de11 Stuttgart	136,45	de21 Oberbayern	210,42
4	de11 Stuttgart	68,61	dea2 Köln	117,75	de71 Darmstadt	129,83
5	dea1 Düsseldorf	66,16	dea1 Düsseldorf	100,12	dea2 Köln	122,79
6	uki1 Inner London	48,07	de71 Darmstadt	71,35	dea1 Düsseldorf	113,59
7	de71 Darmstadt	40,32	de12 Karlsruhe	63,45	itc4 Lombardia	82,59
8	fr71 Rhône-Alpes	40,02	de14 Tübingen	61,59	fr71 Rhône-Alpes	64,04
9	dea5 Arnsberg	34,49	se11 Stockholm	46,75	de12 Karlsruhe	63,04
10	de14 Tübingen	31,83	fr71 Rhône-Alpes	44,12	de30 Berlin	52,90
11	de12 Karlsruhe	29,76	deb1 Koblenz	42,82	de14 Tübingen	51,27
12	dk0 Dänemark	27,50	de13 Freiburg	41,75	itc1 Piemonte	50,23
13	ukg3 West Midlands	26,43	itc1 Piemonte	39,74	se11 Stockholm	44,39
14	ukj2 Surrey, East and West S	25,41	itc4 Lombardia	39,47	dk0 Dänemark	44,00
15	ukg1 Herefordshire, Worcest	23,07	itd5 Emilia-Romagna	38,49	de13 Freiburg	43,83
16	se11 Stockholm	22,66	dea5 Arnsberg	36,13	ukg1 Herefordshire, Worcest	43,78
17	ukd3 Greater Manchester	22,38	ukg3 West Midlands	34,46	itd5 Emilia-Romagna	42,90
18	uki2 Outer London	22,35	uki1 Inner London	34,21	uki2 Outer London	40,83
19	itc4 Lombardia	21,83	se12 Östra Mellansverige	31,80	fr24 Centre	39,12
20	de13 Freiburg	19,44	uki2 Outer London	31,60	ukh1 East Anglia	39,00

RANK	1995		2000		2002	
	observed regions:	213	observed regions:	240	observed regions:	236
	nb tot applications:	3569,74	nb tot applications:	6035,9	nb tot applications:	6117,88
	average (213):	16,76	average (240):	25,15	average (236):	25,92
	average (top10):	142,77	average (top10):	254,41	average (top10):	254,34
	average (top20):	98,04	average (top20):	171,36	average (top20):	175,60
	Share top 10/213	0,40	Share top 10/240	0,42	Share top 10/236	0,42
	Germany in top 10:	8	Germany in top 10:	8	Germany in top 10:	8
	France in top 10:	1	France in top 10:	1	France in top 10:	1
	HHI (top10)	0,14	HHI (top10)	0,15	HHI (top10)	0,15
	HHI (top20)	0,08	HHI (top20)	0,09	HHI (top20)	0,09
	normalized HHI (top20)	0,04	normalized HHI (top20)	0,04	normalized HHI (top20)	0,04
	GINI (top10)	0,32	GINI (top10)	0,31	GINI (top10)	0,31
	GINI (top20)	0,36	GINI (top20)	0,37	GINI (top20)	0,35
1	de11 Stuttgart	352,58	de11 Stuttgart	760,87	de11 Stuttgart	760,87
2	fr10 Île de France	285,09	fr10 Île de France	331,21	fr10 Île de France	342,17
3	de21 Oberbayern	163,00	de21 Oberbayern	319,32	de21 Oberbayern	312,12
4	dea2 Köln	124,88	dea2 Köln	197,33	de12 Karlsruhe	183,52
5	dea1 Düsseldorf	112,58	de12 Karlsruhe	180,73	dea1 Düsseldorf	170,07
6	de71 Darmstadt	90,60	itc4 Lombardia	170,63	dea2 Köln	166,27
7	de12 Karlsruhe	80,39	dea1 Düsseldorf	163,44	de25 Mittelfranken	164,09
8	de14 Tübingen	75,91	dea5 Arnsberg	146,69	de14 Tübingen	156,45
9	dk0 Dänemark	75,11	de25 Mittelfranken	136,99	itc4 Lombardia	149,96
10	de25 Mittelfranken	67,54	de14 Tübingen	136,90	dea5 Arnsberg	137,83
11	itc1 Piemonte	62,31	de71 Darmstadt	126,41	de71 Darmstadt	127,76
12	dea5 Arnsberg	60,39	dk0 Dänemark	97,53	de13 Freiburg	122,36
13	fr71 Rhône-Alpes	58,90	fr71 Rhône-Alpes	95,25	dk0 Dänemark	115,67
14	itc4 Lombardia	57,48	itd5 Emilia-Romagna	92,43	de26 Unterfranken	105,39
15	de13 Freiburg	56,45	de13 Freiburg	84,59	de27 Schwaben	101,30
16	se23 Västsverige	55,46	de27 Schwaben	81,87	itc1 Piemonte	98,58
17	fr24 Centre	55,08	de91 Braunschweig	81,39	fr71 Rhône-Alpes	78,59
18	se12 Östra Mellansverige	46,33	de26 Unterfranken	79,43	de23 Oberpfalz	76,10
19	se11 Stockholm	42,49	se23 Västsverige	73,74	deb3 Rheinhessen-Pfalz	74,60
20	de26 Unterfranken	38,19	itc1 Piemonte	70,44	de91 Braunschweig	68,24

Source: Own calculation and illustration. EUROSTAT database; Regional science and technology statistics. Patent applications to the EPO by priority year at the regional level (February 2008).

The GINI values (Figure 3) are calculated for the periods 1989 to 1992 (mean, year 1990) and 1999 to 2002 (mean, year 2000). The values clearly show a high concentration of patenting in mechanical engineering; this concentration did not decrease between 1990 and 2000; additional analyses of several years contribute to this result. A total of 4.1% of all 241 observed regions, which are the ten best-performing regions, have contributed on average with 41.5% of all IPC F patents between 1999 and 2002. The top 20 have effected 56.5% of overall patenting. The 1990 average values are rather similar: 42.3% of all patenting was done by the top ten and 55.2% by the top 20 regions. Thus we suggest high externalities and also high potentialities for localised knowledge accumulation and standard-setting in clustered entities. The concentration coefficients are also high for the selected sample; $CC^{1990} = 0.748$; $CC^{2000} = 0.739$.

Figure 3: Mechanical engineering – Spatial Distribution of EPO-Patent Applications (nb tot) for 241 European Regions



Source: Own calculation; data from EUROSTAT database; average values and GINI coefficients are computed for 1990 (1989-1992) and 2000 (1999-2002).

In addition to the GINI values as concentration measures of technological knowledge, we calculated the region-specific Revealed Patent Advantage (RPA) for 251 NUTS regions (mostly NUTS2).[28] As shown in this table, patent application in mechanical engineering (IPC F) shows heterogeneous RPA values for the analysed sample of European regions. Values range from +94.00 (ee) to -99.99 (fi20).

[28] The RPA sample is larger than the GINI sample owing to higher data availability; we calculated the RPA for the year 2002. Other years showed similar structures of technological advantage.

Table 2: Revealed Patent Advantage (RPA) in IPC F

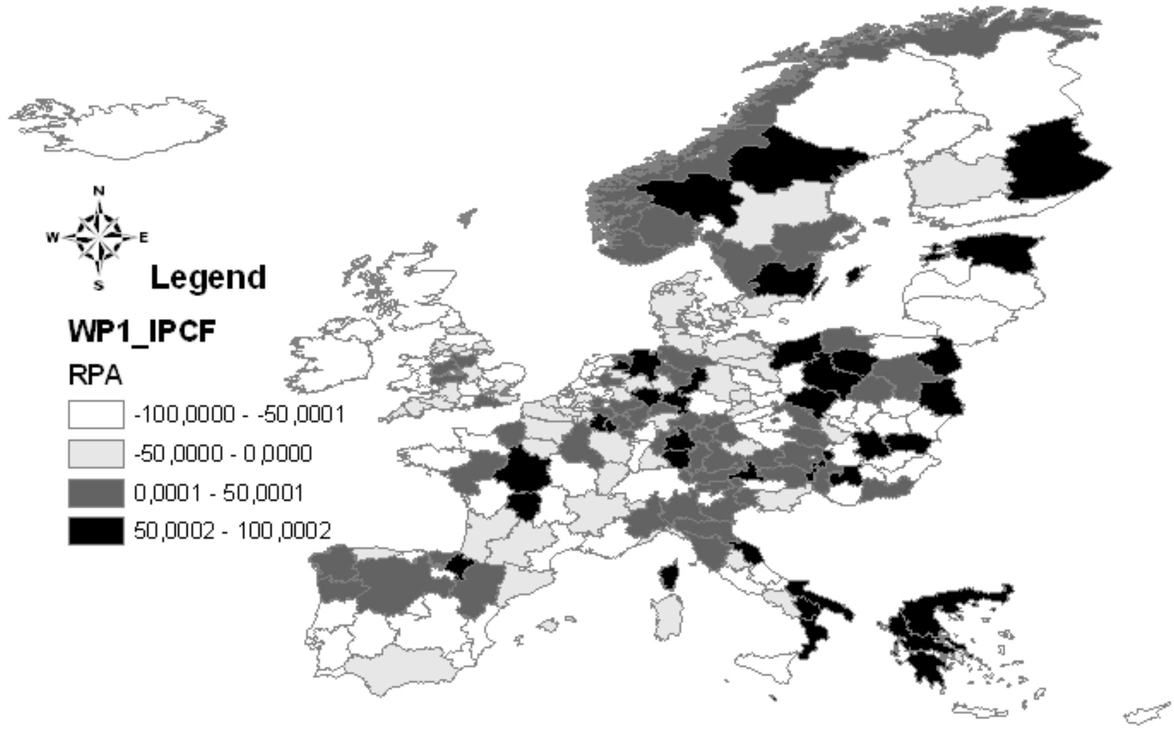
ID	NUTS	RPA_2002	ID	NUTS	RPA_2002	ID	NUTS	RPA_2002	ID	NUTS	RPA_2002
1	be	-35,44	64	def0	-44,90	127	ite3	57,82	190	sk	62,83
2	be10	-35,38	65	deg0	-55,63	128	ite4	-71,58	191	sk01	68,78
3	be21	-20,23	66	ee	67,64	129	itf1	-75,83	192	sk02	-87,18
4	be22	7,49	67	ie	-67,93	130	itf2	-99,63	193	sk03	72,93
5	be23	-81,52	68	gr	23,17	131	itf3	-0,64	194	sk04	78,36
6	be24	-92,11	69	gr1	70,43	132	itf4	86,01	195	fi	-57,49
7	be25	-43,05	70	gr2	51,24	133	itf5	85,05	196	fi13	60,60
8	be31	-74,75	71	gr3	-1,19	134	itf6	67,73	197	fi18	-75,14
9	be32	-41,27	72	gr4	-51,90	135	itg1	-89,91	198	fi19	-30,50
10	be33	44,43	73	es	-31,36	136	itg2	-40,18	199	fi1a	-68,31
11	be34	62,56	74	es11	22,54	137	cy	-100,00	200	fi20	-100,00
12	be35	-25,95	75	es12	-8,37	138	lv	-100,00	201	se	-11,20
13	cz	-6,30	76	es13	-99,55	139	lt	-100,00	202	se11	-58,19
14	cz01	23,62	77	es21	12,13	140	lu	59,11	203	se12	20,34
15	cz02	-99,55	78	es22	68,99	141	hu	-60,38	204	se21	57,71
16	cz03	-99,55	79	es23	-99,56	142	hu10	-66,82	205	se22	-26,63
17	cz04	-99,55	80	es24	9,60	143	hu21	62,26	206	se23	17,24
18	cz05	3,47	81	es30	-59,61	144	hu22	7,84	207	se31	-13,71
19	cz06	22,40	82	es41	18,46	145	hu23	-99,51	208	se32	56,89
20	cz07	-28,46	83	es42	-99,56	146	hu31	-99,51	209	se33	-52,26
21	cz08	-99,54	84	es43	-99,56	147	hu32	-99,51	210	uk	-43,57
22	dk	-16,91	85	es51	-43,26	148	hu33	9,99	211	ukc1	-19,08
23	dk0	-16,91	86	es52	-59,05	149	mt	90,68	212	ukc2	-76,61
24	de	25,01	87	es53	-0,22	150	nl	-58,50	213	ukd2	-69,63
25	de11	77,50	88	es61	-11,79	151	nl11	38,72	214	ukd3	-42,13
26	de12	35,99	89	es62	-99,56	152	nl12	-59,36	215	ukd4	-12,80
27	de13	-5,04	90	es70	-3,37	153	nl13	51,03	216	ukd5	-57,57
28	de14	51,63	91	fr	-16,13	154	nl21	-6,46	217	uke1	-30,51
29	de21	0,14	92	fr10	-0,57	155	nl22	12,48	218	uke2	-83,95
30	de22	-3,67	93	fr21	4,58	156	nl23	-95,66	219	uke3	-17,84
31	de23	37,80	94	fr22	-2,88	157	nl31	-61,40	220	uke4	-25,11
32	de24	26,09	95	fr23	20,38	158	nl32	-60,55	221	ukf1	10,48
33	de25	41,23	96	fr24	52,19	159	nl33	-59,15	222	ukf2	-8,01
34	de26	42,72	97	fr25	-51,54	160	nl34	-67,24	223	ukg1	0,50
35	de27	34,52	98	fr26	-51,14	161	nl41	-77,41	224	ukg2	34,28
36	de30	-80,63	99	fr30	-36,14	162	nl42	-64,82	225	ukg3	-1,69
37	de41	-44,76	100	fr41	-30,75	163	at	19,90	226	ukh1	-69,27
38	de42	-57,48	101	fr42	-67,25	164	at11	77,78	227	ukh2	-74,89
39	de50	-67,77	102	fr43	-22,90	165	at12	7,15	228	ukh3	-39,63
40	de60	-44,56	103	fr51	15,90	166	at13	-88,46	229	uki1	-68,37
41	de71	-32,45	104	fr52	-73,78	167	at21	-59,73	230	uki2	-43,27
42	de72	6,94	105	fr53	-72,70	168	at22	0,97	231	ukj1	-64,97
43	de73	67,77	106	fr61	-12,55	169	at31	44,97	232	ukj2	0,29
44	de80	-20,08	107	fr62	-27,37	170	at32	76,20	233	ukj3	-78,87
45	de91	55,41	108	fr63	55,87	171	at33	39,78	234	ukj4	-42,90
46	de92	17,48	109	fr71	-29,44	172	at34	37,20	235	ukk1	-40,24
47	de93	10,63	110	fr72	-92,52	173	pl	31,88	236	ukk2	-28,68
48	de94	56,35	111	fr81	-56,52	174	pl11	49,42	237	ukk3	-27,93
49	dea1	-3,85	112	fr82	-68,08	175	pl12	14,14	238	ukk4	-8,95
50	dea2	19,91	113	fr83	86,24	176	pl21	-96,85	239	ukl1	-94,41
51	dea3	-3,62	114	fr9	-99,99	177	pl22	-96,85	240	ukl2	-84,01
52	dea4	-11,21	115	it	14,03	178	pl3	78,01	241	ukm	-94,41
53	dea5	52,09	116	itc1	37,03	179	pl4	64,03	242	ukn0	-57,68
54	deb1	36,95	117	itc2	-4,57	180	pl5	54,67	243	is	-63,34
55	deb2	16,86	118	itc3	-20,20	181	pl6	58,18	244	no	10,87
56	deb3	-59,96	119	itc4	9,67	182	pt	-27,73	245	no01	-51,64
57	dec0	43,89	120	itd1	17,97	183	pt11	40,80	246	no02	74,87
58	ded1	-9,71	121	itd2	-79,63	184	pt15	-89,84	247	no03	42,31
59	ded2	-58,39	122	itd3	10,60	185	pt16	-89,83	248	no04	11,99
60	ded3	-39,89	123	itd4	34,63	186	pt17	-89,83	249	no05	28,69
61	dee1	-11,34	124	itd5	23,12	187	pt18	-89,76	250	no06	37,32
62	dee2	-16,58	125	ite1	12,01	188	pt3	-89,84	251	no07	23,11
63	dee3	6,67	126	ite2	-3,94	189	si	-14,59			

Source: Own calculation and illustration. EUROSTAT database; IPC F patent applications in year 2000; inventor location.

The RPA thus supports our argument that knowledge stocks vary enormously in a spatially disaggregated context; second, the table clearly shows that the national level (NUTS0) suppresses regional innovative performance, e.g. be34 (NUTS2) v. be (NUTS0). The extreme variety exists for nearly every country within the IPC F sample. National RPA values are in general lower than values for leading sub-national regions. Interestingly, some Eastern

European regions hold a high RPA value although overall patenting is at a very low level. Thus, we assume highly specialised knowledge owing to specialised clustering (Table 2 and figure 4).

Figure 4: Revealed Patent Advantage in IPC F, Year 2002



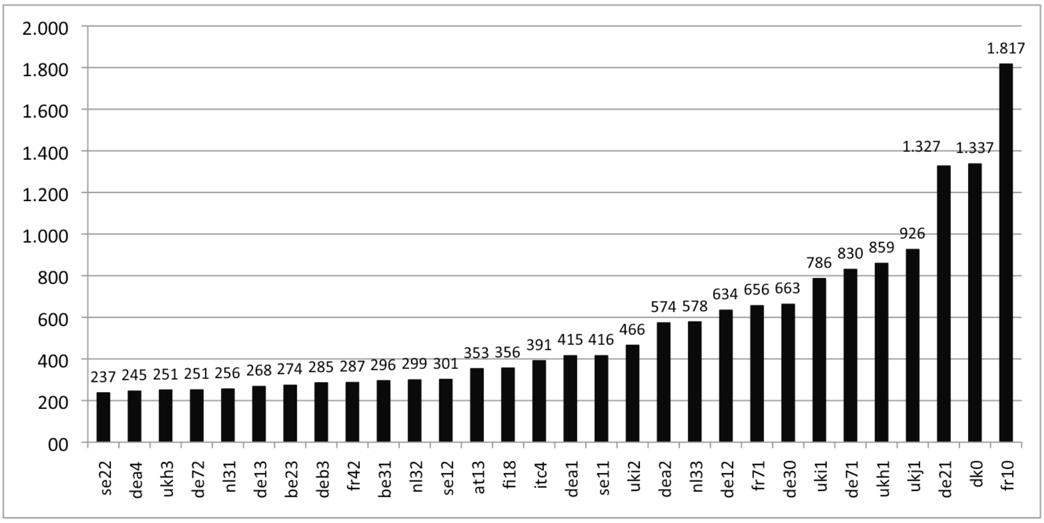
Source: Own illustration; Shape file from EUROSTAT; illustration with ArcGIS

2.2 Biotechnology

During the last twenty years, economists have observed a tremendous increase in patent applications, firm foundation and expansive growth rates, an increase in spin-offs, investment and employment in the field of biotechnology. Besides the overall European development and modifications in European STI policy, we suggest particularly that national and regional initiatives and programmes like the German 'BioRegio' contest, 'BioProfile' and 'BioFuture' initiatives boosted and influenced economic activities in biotechnology. In addition, the 'Kompetenzcluster' and 'Kompetenznetze' initiatives of the German Federal Ministry gradually propelled spatial biotech-concentration and technology competence.

The following Figure 5 highlights the 30 best-performing regions in Europe in the field of biotechnology. EUROSTAT concordance offers aggregated data for biotechnology. Similarly to mechanical engineering, the heterogeneity within the analysed group is very great. Ile-de-France (fr10), Denmark (dk0) and Oberbayern (de21) hold nearly nine to ten times more patents compared with lower ranks within the top 30, e.g. se22, dea4, ukh3. The leading three regions do nearly 30% of overall patenting of the top 30 group, which overall adds up to nearly 56.57% of all 241 regions.

Figure 5: Accumulated EPO Patent applications in Biotechnology – 30 Best-Performing NUTS2 regions, 1977-2002



Source: Own calculation and illustration. EUROSTAT database; Regional science and technology statistics, Mechanical engineering patent applications to the EPO (IPC F) by priority year at the regional level (April 2008).

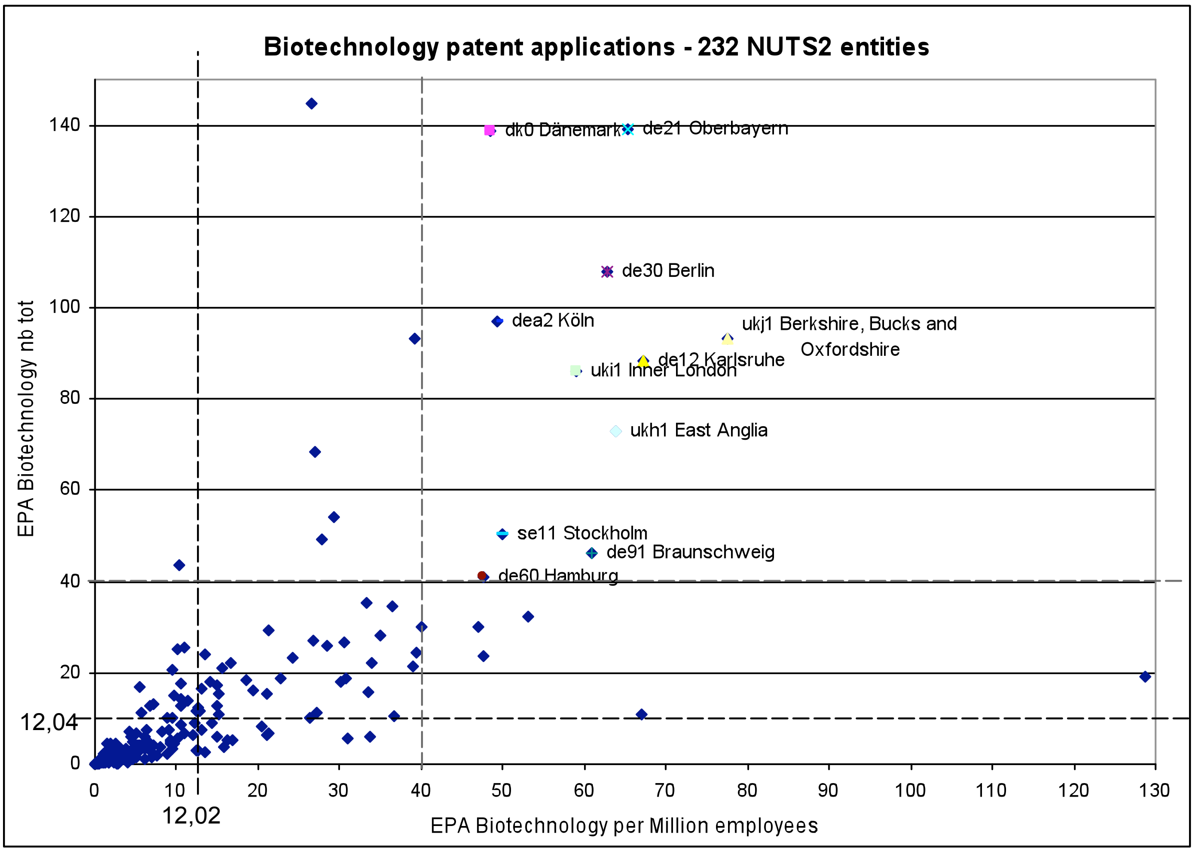
We assume that open innovation determines progress in biotechnology.[29] Compared with mechanical engineering, and built upon our argument for cluster-specific knowledge stocks and inter-temporal knowledge externalities, we think that technological externalities are essential for the evolution of biotechnology in a disaggregated spatial context. Whereas specialised production clusters are heavily influenced by MAR externalities and intra-industry knowledge externalities, we rather assume the importance of inter-industry externalities (Jacobian externalities) and knowledge diffusion in the case of biotechnology. Most of the accomplished studies and research projects in the field of (dynamic) knowledge externalities mention the diverse importance of externalities/spillovers and their different effects on (localised) growth, spatial knowledge production, and (localised) knowledge diffusion. This idea is related to place-specific industrial lifecycles. Owing to the fact that biotechnology is a cross-section technology, which is influenced by and influences many different industries and sub-sectors, we suppose that the inter-industry model of spillovers is more adequate than the MAR model. Second, biotechnology represents an embryonic and fast-growing technology/ industry where competition is still very high and the degree and level of standardisation should still be lower than in the case of mechanical engineering. As a consequence, we expect much more competition, a higher rate of invention, shorter technology lifecycles and more venture capital-based funding than for mechanical engineering.

[29] Open innovation as a paradigm promotes the exploration and exploitation of many paths to the market. This active search for and advancement of multiple use cases and opportunities of value creation is important in order to establish biotechnology within innovation systems so that the early innovators capture profitable innovation rents.

As Figure 5 shows, biotech patent applications increased considerably between 1977 and 2003. The decrease of the total application number after 2002 is related to lags in the patent database; this effect is visible for all IPC classes.[30]

Figure 6 builds upon data for the year 2002, and highlights biotechnology patent applications for 232 NUTS geographical entities. The figure shows perfectly that biotechnology is highly concentrated in the European landscape. We divided and separated the regions by a minimum value of 40 patent applications per million employees (per mio empl.) and 40 applications in total number (nb tot), which forms a group of leading regions.

Figure 6: Biotechnology in 232 EU Regions (NUTS2 classification) – Relative and Absolute Knowledge Strength, Year 2002



Source: Own calculation and illustration. EUROSTAT database; Regional science and technology statistics, Biotechnology patent applications to the EPO by priority year at the regional level (February 2008). See Appendix D for a detailed IPC definition of biotechnology. Average number (nb tot): 12,04 patents (2002); average number (pat. appl. per mio employees): 12.02.

Although the accumulated number of patent applications at NUTS2 level shows an unequal distribution, we assume that biotechnology is less concentrated in absolute and relative terms (patenting per mio employees) than mechanical engineering and other medium-high- and low-tech industries. Within the top ten and top 20 regions, the GINI values for

[30] EPO biotechnology patents are based upon the OECD biotechnology classification (IPC classification). See Appendix D for further details.

biotechnology show higher changes opposed to patenting in IPC F (Table 3). In addition, the measured stock of patent applications seems to highlight the fact that regional systems of innovation in biotechnology in the observed spatial sample are more dynamic than in the former analysed case of mechanical engineering (Herfindahl indices; GINI coefficients). This result could be because biotechnology resembles a cross-sectoral technology which is still in an embryonic, steep growth stage, influenced by strong market dynamics and STI policy. In our view, it is quite interesting to observe that several German regions could gain within the top ten spatial entities in terms of patent applications. Additionally, Table 3 shows that the average number of patent applications within the top ten performers is eight times higher than the average value within all observed entities. We conclude that the strong position and fast development of German regions is essentially influenced by, for example, the German 'BioRegio' competition and other STI policy initiatives. Our comparison of German NUTS2 regions with leading European regions in Table 3 clearly shows the dramatic catching-up process of German NUTS2 entities, measured by the EPO patent application number with respect to other European regions. If, as we suppose, we can take patent applications as a proxy for cluster-specific knowledge and technology diffusion, we would argue that the observed regions increased their technology competence. Moreover, we assume a quasi (place-specific) knowledge narrowing and cumulative deepening.[31] The measured absolute (and accumulated) quantity of patent applications (nb tot) resembles in our opinion a good measure of absolute cluster strength, concerning cluster-specific knowledge stocks. When we compare absolute and relative patent application data, we can develop ideas about the absolute and relative strength of the regional areas in inter-regional comparison.

In addition, the top three regions in Table 3 did not change that much in the observed period of 1998 to 2002: Ile-de-France (fr10), Dänemark (dk0) and Oberbayern (de21). We observe higher dynamics in the lower positions, e.g. Braunschweig (de91), Köln (dea2), Essex (ukh3), and Berlin (de30). Additionally, we calculated the Herfidahl Index (HHI) and GINI indices (Table 3), which indicate a high and increasing concentration. Some regions gained in the ranking (Berlin, de30), whereas others dramatically lost position (Essex, ukh3). We are also aware, however, of time lags using patent data (e.g. lag of granting, truncation problems, etc.).

[31] EPO patent application documents must include patent citations. If we were to analyse EPO patent applications and underlying patent citations, we would get an idea and additional information about the most important and essential patents and their spatial location.

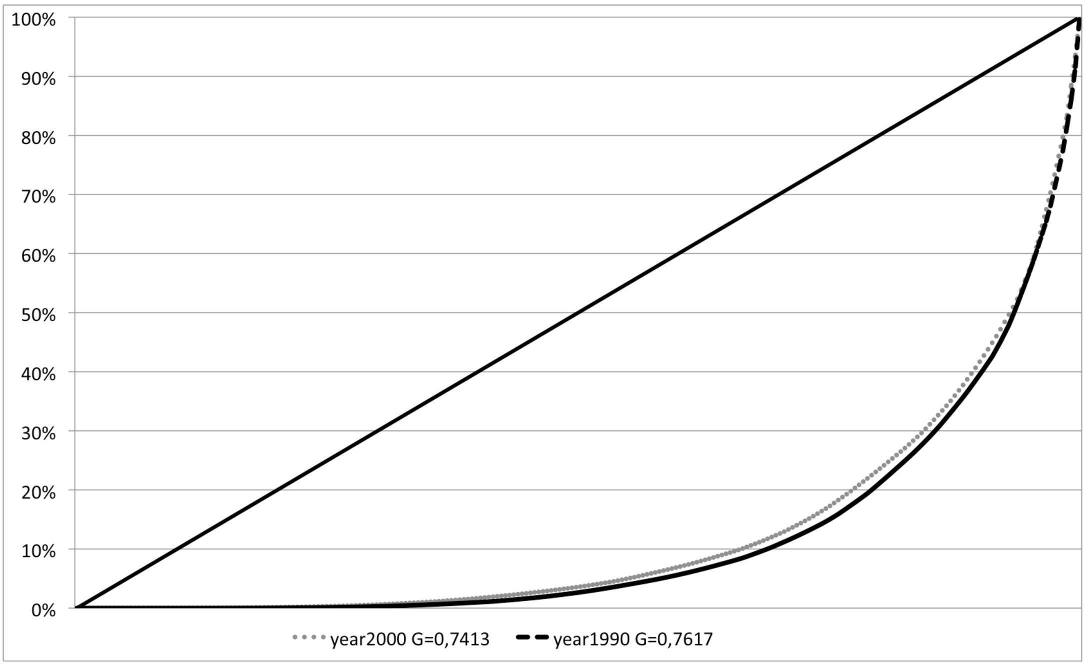
Table 3: Biotechnology in Europe: Patent Application Ranking (nb tot); 50 Best-Performing European NUTS2 Regions

	1985			1990			1995			2000			2002		
	average top10		17,10	average top10		31,09	average top10		48,85	average top10		104,83	average top10		106,11
	average top 20		11,55	average top 20		22,76	average top 20		34,71	average top 20		76,38	average top 20		75,85
	average 50		6,36	average 50		12,39	average 50		20,19	average 50		43,72	average 50		43,87
	applications (50)		318,16	applications (50)		619,52	applications (50)		1009,68	applications (50)		2185,83	applications (50)		2193,75
	share top10 fr:		10%	share top10 fr:		10%	share top10 fr:		20%	share top10 fr:		20%	share top10 fr:		10%
	share top10 de:		50%	share top10 de:		20%	share top10 de:		30%	share top10 de:		40%	share top10 de:		40%
	share top10 uk:		20%	share top10 uk:		40%	share top10 uk:		20%	share top10 uk:		30%	share top10 uk:		30%
	share top10 it:		10%	share top10 it:		0%	share top10 it:		0%	share top10 it:		0%	share top10 it:		0%
	Herfindahl (top50):		0,045	Herfindahl (top50):		0,038	Herfindahl (top50):		0,035	Herfindahl (top50):		0,034	Herfindahl (top50):		0,032
	GINI (top10):		0,321	GINI (top10):		0,204	GINI (top10):		0,209	GINI (top10):		0,172	GINI (top10):		0,124
	GINI (top20):		0,365	GINI (top20):		0,273	GINI (top20):		0,289	GINI (top20):		0,266	GINI (top20):		0,261
	GINI (top50):		0,461	GINI (top50):		0,440	GINI (top50):		0,392	GINI (top50):		0,394	GINI (top50):		0,385
	Conc.C. (top50):		0,470	Conc.C. (top50):		0,449	Conc.C. (top50):		0,401	Conc.C. (top50):		0,402	Conc.C. (top50):		0,393
1	fr10	Île-de-Franc	37,03	fr10	Île-de-France	64,91	fr10	Île-de-France	89,51	fr10	Île-de-France	184,33	fr10	Île-de-France	144,81
2	de21	Oberbayern	30,39	dk0	Denmark	38,37	dk0	Denmark	71,92	dk0	Denmark	142,81	de21	Oberbayern	139,14
3	de71	Darmstadt	23,73	de21	Oberbayern	36,86	de21	Oberbayern	63,75	de21	Oberbayern	129,38	dk0	Denmark	138,78
4	ukj1	Berkshire, Bu	19,39	de71	Darmstadt	32,60	ukh1	East Anglia	50,30	de71	Darmstadt	102,93	de30	Berlin	107,76
5	dk0	Denmark	18,17	ukj1	Berkshire, Buc	27,50	ukj1	Berkshire, Buc	41,96	de30	Berlin	96,69	dea2	Köln	96,82
6	dea2	Köln	11,10	uki2	Outer London	24,61	uki1	Inner London	37,94	uki1	Inner London	83,77	ukj1	Berkshire, Buc	93,20
7	dea1	Düsseldorf	9,07	fi18	Etelä-Suomi	23,00	fr71	Rhône-Alpes	37,88	ukh1	East Anglia	81,41	dea1	Düsseldorf	93,08
8	uki2	Outer Londo	7,70	uki1	Inner London	22,75	nl33	Zuid-Holland	36,78	ukj1	Berkshire, Buc	79,09	de12	Karlsruhe	88,38
9	itc4	Lombardia	7,26	nl33	Zuid-Holland	20,30	de12	Karlsruhe	30,30	dea2	Köln	74,06	uki1	Inner London	86,10
10	de30	Berlin	7,14	ukh1	East Anglia	19,99	de71	Darmstadt	28,12	fr71	Rhône-Alpes	73,80	ukh1	East Anglia	73,06
11	de12	Karlsruhe	6,85	itc4	Lombardia	18,79	dea2	Köln	27,27	dea4	Detmold	71,50	fr71	Rhône-Alpes	68,60
12	fr71	Rhône-Alpes	6,50	de30	Berlin	18,48	fi18	Etelä-Suomi	23,76	de12	Karlsruhe	61,57	de71	Darmstadt	54,18
13	ukj2	Surrey, East	6,44	dea2	Köln	17,71	de30	Berlin	22,83	nl33	Zuid-Holland	58,88	se11	Stockholm	50,46
14	uki1	Inner Londor	6,40	at13	Wien	16,52	se11	Stockholm	20,82	nl31	Utrecht	50,17	nl33	Zuid-Holland	49,37
15	fr62	Midi-Pyrénée	6,15	de12	Karlsruhe	15,27	itc4	Lombardia	19,77	se11	Stockholm	45,26	de91	Braunschweig	46,07
16	se12	Östra Mellan	5,81	de11	Stuttgart	12,81	de72	Gieflen	19,40	be31	Prov. Brabant	40,42	itc4	Lombardia	43,52
17	ukh1	East Anglia	5,76	fr71	Rhône-Alpes	12,79	at13	Wien	18,51	nl32	Noord-Holland	39,48	de60	Hamburg	41,16
18	se11	Stockholm	5,70	dea1	Düsseldorf	12,62	uki2	Outer London	18,23	dea1	Düsseldorf	38,71	de13	Freiburg	35,29
19	dea4	Detmold	5,25	se11	Stockholm	10,89	ukf1	Derbyshire an	17,76	at13	Wien	37,48	deb3	Rheinhessen-I	34,76
20	se22	Sydsverige	5,19	se23	Västsverige	8,44	nl32	Noord-Holland	17,40	de14	Tübingen	35,97	nl31	Utrecht	32,48
21	de11	Stuttgart	4,85	nl32	Noord-Holland	8,43	se12	Östra Mellansv	15,55	itc4	Lombardia	31,44	se12	Östra Mellansv	30,12
22	at13	Wien	4,35	nl41	Noord-Braban	8,43	ite4	Lazio	15,40	se12	Östra Mellansv	31,01	se22	Sydsverige	30,07
23	fr42	Alsace	4,32	de60	Hamburg	8,24	ie0	Irland	14,67	be23	Prov. Oost-Vla	29,15	dee	Sachsen-Anha	29,89
24	deb1	Koblenz	4,01	fr82	Provence-Alpe	7,89	be24	Prov. Vlaams I	14,39	deb3	Rheinhessen-I	26,97	nl32	Noord-Holland	29,46
25	fi18	Etelä-Suomi	4,00	nl31	Utrecht	7,86	nl41	Noord-Braban	12,78	de13	Freiburg	25,92	at13	Wien	28,08
26	nl33	Zuid-Holland	3,94	be23	Prov. Oost-Vla	7,84	de14	Tübingen	12,19	fi18	Etelä-Suomi	25,66	nl22	Gelderland	26,96
27	be24	Prov. Vlaams	3,73	fr62	Midi-Pyrénées	7,42	be31	Prov. Brabant	12,13	dee	Sachsen-Anha	25,47	de14	Tübingen	26,83
28	ukg3	West Midlanc	3,65	se12	Östra Mellansv	7,23	fr42	Alsace	12,00	uki2	Outer London	25,32	se23	Västsverige	26,01
29	be21	Prov. Antwer	3,54	ukh2	Bedfordshire,	6,60	de13	Freiburg	11,82	se22	Sydsverige	24,95	uki2	Outer London	25,52
30	ukd3	Greater Man	3,47	itd3	Veneto	5,52	be23	Prov. Oost-Vla	11,66	fr42	Alsace	24,34	es30	Comunidad de	25,01
31	nl32	Noord-Hollar	3,39	ie0	Irland	5,50	dea1	Düsseldorf	11,27	de11	Stuttgart	23,71	be23	Prov. Oost-Vla	24,36
32	def0	Schleswig-Hc	3,03	se22	Sydsverige	5,22	fr81	Languedoc-Ro	11,14	ukh3	Essex	23,53	fr82	Provence-Alpe	24,17
33	ukj3	Hampshire a	2,94	be21	Prov. Antwerp	5,10	de91	Braunschweig	11,12	be24	Prov. Vlaams I	23,18	de72	Gieflen	23,74
34	nl41	Noord-Braba	2,92	ite1	Toscana	5,06	nl22	Gelderland	11,11	de92	Hannover	22,64	fr81	Languedoc-Ro	23,35
35	be10	Région de Br	2,77	ukf1	Derbyshire an	4,99	fr62	Midi-Pyrénées	10,83	fr82	Provence-Alpe	22,53	def0	Schleswig-Hol	22,27
36	deb3	Rheinhessen	2,68	ukk	South West (E	4,66	deb3	Rheinhessen-I	10,77	de91	Braunschweig	21,58	de26	Unterfranken	22,26
37	be31	Prov. Braban	2,64	de92	Hannover	4,58	se22	Sydsverige	10,62	ite4	Lazio	21,23	no01	Oslo og Akersl	21,48
38	se23	Västsverige	2,62	ukd3	Greater Manch	4,48	be10	Région de Bru	10,20	nl22	Gelderland	20,33	fi18	Etelä-Suomi	21,10
39	de72	Gieflen	2,58	fr42	Alsace	4,44	no01	Oslo og Akersl	10,04	de60	Hamburg	19,85	ite4	Lazio	20,82
40	de60	Hamburg	2,27	ukf2	Leicestershire,	4,33	ukj2	Surrey, East a	9,29	ukj4	Kent	19,51	be31	Prov. Brabant	19,34
41	nl22	Gelderland	2,09	de14	Tübingen	4,32	de92	Hannover	9,25	nl41	Noord-Braban	18,22	uke3	South Yorkshi	18,91
42	be33	Prov. LiËge	2,07	deb3	Rheinhessen-I	4,28	fr82	Provence-Alpe	8,93	dea3	Münster	17,94	fr42	Alsace	18,75
43	ite1	Toscana	2,07	ite4	Lazio	4,27	ukd3	Greater Manch	8,81	se23	Västsverige	17,93	de92	Hannover	18,42
44	fr30	Nord - Pas-d	2,06	ukj2	Surrey, East a	4,24	def0	Schleswig-Hol	8,13	ukk	South West (E	17,59	dee3	Magdeburg (N	18,18
45	ukg1	Herefordshir	2,04	nl22	Gelderland	4,14	nl31	Utrecht	7,18	de72	Gieflen	17,18	nl41	Noord-Braban	18,09
46	fr53	Poitou-Chare	2,02	no01	Oslo og Akersl	4,00	de11	Stuttgart	7,17	no01	Oslo og Akersl	16,56	fr30	Nord - Pas-de	17,63
47	uke4	West Yorkshi	1,87	def0	Schleswig-Hol	3,99	ukj4	Kent	7,09	es30	Comunidad de	16,27	dea3	Münster	17,37
48	be23	Prov. Oost-V	1,78	be31	Prov. Brabant	3,83	ukj3	Hampshire an	6,76	dee3	Magdeburg (N	16,11	ukd3	Greater Manch	16,64
49	ukf1	Derbyshire a	1,74	be24	Prov. Vlaams I	3,73	ukf2	Leicestershire,	6,61	ukf1	Derbyshire an	16,02	de25	Mittelfranken	16,22
50	at31	Oberösterrei	1,71	fr81	Languedoc-Ro	3,69	ukh3	Essex	6,54	ukj3	Hampshire an	15,99	be24	Prov. Vlaams I	15,70

Source: Own calculation and illustration. EUROSTAT database; Regional science and technology statistics. Patent applications to the EPO by priority year at the regional level.

The following Figure 7 finally gives some indication about the spatial equality of the patent application distribution within 241 European NUTS2 regions. The figure shows the unequal performance of European regions in the selected field of biotechnology. Similarly to the patent application ranking in Table 3 and the illustrated distribution of biotech patents in Figures 5 and 6, the paper assumes that regional set-ups and competences differ considerably. The top ten regions, which represent 4.14% of the whole sample, account for 38.0% of overall patenting in biotechnology; 8.29% of all regions (top 20) do 53.98% of all patenting. This result clearly shows an ongoing but still smaller concentration in biotechnology than in mechanical engineering. Second, we point to the fact that regional innovative performance is besides its high dynamics a path-dependent process owing to long-lasting knowledge accumulation; biotechnology shows fast-growing, spatially concentrated knowledge stocks.

Figure 7: Biotechnology – Spatial Distribution of EPO-Patent Applications (nb tot) for 241 European Regions



Source: Own calculation; data from EUROSTAT REGIO (NewCronos) database; GINI coefficients are calculated for the years 1990 (1989-1992) and 2000 (1999-2002).

As is plainly visible, a GINI near 0.75 for all 24 observed regions indicates a tremendous concentration of biotechnology and thus spatially concentrated knowledge stocks in the analysed technology field. Additionally, the concentration seems stable for a ten-year period of observation: G^{2000} = 0.74 v. G^{1990} = 0.76. The Concentration Coefficient (CC) is also high; CC^{1990} = 0.765 and CC^{2000} = 0.744. Consequently, three UK regions (ukj1, uki1, ukh1) did around 10% of overall patenting in 2000; four UK regions (ukj1, uki2, ukh1, uki1) contributed with 12.9% in 1990. We argue that these highly concentrated knowledge stocks contribute to localised knowledge diffusion and spatial effects on standard-setting owing to clustered economic valuable knowledge.

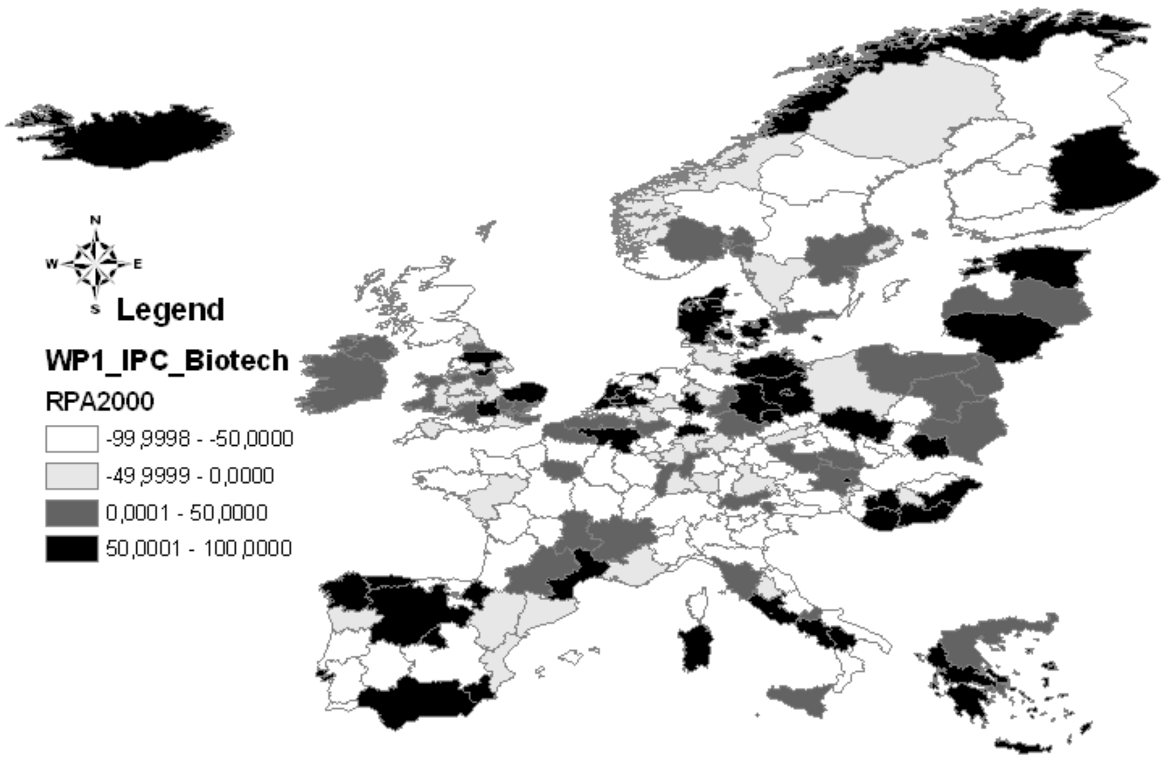
Table 4 and figure 8 highlight the RPA values for 2000 and the average value for 2000 to 2002. The following chapter will give some indications about the theoretical treatment of geography, clustering and knowledge.

Table 4: Biotechnology: Revealed Patent Advantage (RPA) in IPC Biotech

ID	NUTS	RPA 2000	RPA average 2000-2002	iD	NUTS	RPA 2000	RPA average 2000-2002	ID	NUTS	RPA 2000	RPA average 2000-2002
1	at	-3,76	-6,82	77	es51	-40,97	-48,05	153	nl12	-89,90	-88,58
2	at11	-47,42	-23,65	78	es52	-12,19	-19,89	154	nl13	-11,30	-4,95
3	at12	17,10	16,70	79	es53	-64,08	-23,81	155	nl21	-95,95	-95,46
4	at13	83,93	77,95	80	es61	66,42	47,25	156	nl22	57,83	60,73
5	at21	-98,80	-98,83	81	es62	81,55	83,05	157	nl23	87,91	91,50
6	at22	-62,00	-64,07	82	fi	-69,23	-67,45	158	nl31	89,21	89,28
7	at31	-93,81	-93,76	83	fi13	65,68	61,37	159	nl32	52,43	58,04
8	at32	-93,53	-92,61	84	fi18	-59,97	-58,33	160	nl33	62,45	63,44
9	at33	13,80	-2,05	85	fi19	-98,25	-98,22	161	nl34	-96,49	-94,44
10	at34	-98,02	-97,63	86	fi1a	-86,23	-81,45	162	nl41	-91,93	-93,88
11	be	53,11	54,34	87	fi2	-100,00	-100,00	163	nl42	-30,83	-31,28
12	be1	41,72	44,72	88	fr	-1,12	-2,89	164	no	-0,18	3,05
13	be2	44,42	42,79	89	fr10	14,17	14,05	165	no01	40,07	43,53
14	be3	67,77	72,32	90	fr21	-96,43	-95,87	166	no02	-94,47	-93,36
15	cz	-64,35	-68,78	91	fr22	-86,96	-86,35	167	no03	1,39	8,69
16	cz01	-13,85	-18,71	92	fr23	-91,72	-91,92	168	no04	-90,09	-91,09
17	cz02	-68,75	-90,04	93	fr24	-67,66	-61,07	169	no05	-19,15	-20,48
18	cz03	46,56	-88,14	94	fr25	-98,60	-98,82	170	no06	-32,32	-24,99
19	cz04	-19,66	5,15	95	fr26	-92,62	-92,68	171	no07	55,88	62,08
20	cz05	-93,90	-93,16	96	fr30	48,76	51,10	172	pl	9,34	-5,37
21	cz06	8,14	7,48	97	fr41	-85,09	-84,92	173	pl11	-99,94	-99,92
22	cz07	-62,69	-54,52	98	fr42	44,68	39,52	174	pl12	43,62	21,02
23	cz08	-94,49	-92,80	99	fr43	-97,93	-97,91	175	pl21	59,50	38,73
24	de	-13,39	-12,79	100	fr51	-10,61	-17,72	176	pl22	-99,87	-99,89
25	de11	-96,96	-97,24	101	fr52	-73,48	-79,20	177	pl3	2,64	-50,98
26	de12	29,71	20,16	102	fr53	-74,90	-66,60	178	pl4	-12,25	-10,01
27	de13	-27,01	-31,85	103	fr61	-66,86	-71,40	179	pl5	86,63	80,60
28	de14	-15,22	-25,39	104	fr62	9,04	5,81	180	pl6	19,49	20,81
29	de21	-3,61	2,79	105	fr63	-77,38	-76,15	181	pt	7,96	15,89
30	de22	-95,38	-95,12	106	fr71	14,26	6,58	182	pt11	-3,63	17,46
31	de23	-61,57	-58,71	107	fr72	2,01	2,56	183	pt15	-99,22	-99,36
32	de24	-69,17	-69,18	108	fr81	73,80	67,94	184	pt16	-80,95	-74,38
33	de25	-76,25	-76,54	109	fr82	-1,61	1,34	185	pt17	69,98	62,73
34	de26	-34,90	-36,28	110	fr83	-100,00	-99,99	186	pt18	-96,72	-99,78
35	de27	-95,13	-95,17	111	gr	52,15	31,28	187	se	-18,41	-7,66
36	de30	80,92	82,26	112	gr1	43,15	33,02	188	se11	-12,75	3,94
37	de4	70,77	67,29	113	gr2	57,26	47,61	189	se12	20,21	31,12
38	de50	40,10	40,37	114	gr3	35,74	9,26	190	se21	-93,67	-92,66
39	de60	46,58	39,41	115	gr4	92,85	83,10	191	se22	6,35	8,38
40	de71	-8,61	0,22	116	hu	-15,54	-10,34	192	se23	-43,88	-40,16
41	de72	50,17	51,92	117	hu1	-39,64	-33,24	193	se31	-99,81	-99,71
42	de73	-71,26	-72,00	118	hu21	56,03	39,44	194	se32	-99,93	-99,92
43	de80	76,82	78,96	119	hu22	-76,48	-44,75	195	se33	-24,07	-0,83
44	de91	44,95	44,50	120	hu23	83,64	81,16	196	uk	33,49	35,27
45	de92	-11,89	-13,55	121	hu31	-84,67	-77,39	197	ukc1	3,59	-22,75
46	de93	-73,60	-72,26	122	hu32	81,48	82,06	198	ukc2	-41,28	-29,42
47	de94	-82,08	-82,44	123	hu33	76,67	55,37	199	ukd2	11,86	9,86
48	dea1	-27,06	-21,51	124	ie	29,88	20,83	200	ukd3	-4,22	-7,61
49	dea2	5,52	7,06	125	is	89,33	89,07	201	ukd4	-58,12	-50,85
50	dea3	-46,87	-43,51	126	it	-57,01	-59,05	202	ukd5	-32,54	-26,47
51	dea4	63,78	64,42	127	itc1	-92,05	-93,13	203	uke1	-17,39	-30,94
52	dea5	-90,89	-89,65	128	itc2	-99,85	-99,86	204	uke2	50,77	50,93
53	deb1	-95,48	-95,29	129	itc3	-67,43	-65,78	205	uke3	75,42	70,66
54	deb2	-89,79	-87,57	130	itc4	-62,01	-62,15	206	uke4	-13,33	-3,91
55	deb3	-25,61	-21,38	131	itd1	-94,10	-91,05	207	ukf1	20,40	19,36
56	dec0	-46,73	-53,64	132	itd2	-99,85	-99,86	208	ukf2	-25,61	-19,38
57	ded1	-98,65	-98,46	133	itd3	-96,67	-97,12	209	ukg1	-48,73	-58,86
58	ded2	-80,02	-79,73	134	itd4	-71,05	-73,00	210	ukg2	-32,13	-26,66
59	ded3	67,37	68,29	135	itd5	-90,61	-91,10	211	ukg3	6,28	7,54
60	dee	90,65	89,76	136	ite1	41,98	28,26	212	ukh1	61,57	59,73
61	def	-16,15	-20,99	137	ite2	-3,32	10,41	213	ukh2	38,64	39,53
62	deg0	4,88	1,96	138	ite3	-89,17	-89,53	214	ukh3	25,64	20,57
63	dk	75,14	75,15	139	ite4	59,73	60,11	215	uki1	79,02	80,83
64	ee	92,99	94,00	140	itf1	-76,26	-73,91	216	uki2	4,21	11,51
65	es	20,42	12,21	141	itf2	33,83	8,03	217	ukj1	63,46	65,27
66	es11	87,18	34,09	142	itf3	63,59	59,79	218	ukj2	-16,78	-17,40
67	es12	80,37	82,71	143	itf4	-93,42	-94,30	219	ukj3	-57,06	-42,74
68	es13	-99,88	-99,95	144	itf5	86,85	84,57	220	ukj4	19,36	27,22
69	es21	-96,88	-97,56	145	itf6	-99,78	-99,87	221	ukk1	32,22	31,91
70	es22	78,29	68,36	146	itg1	5,20	2,13	222	ukk2	-62,64	-67,09
71	es23	-99,72	-99,92	147	itg2	51,28	54,14	223	ukk3	-76,46	-67,30
72	es24	-49,05	-56,40	148	lt	90,98	90,84	224	ukk4	-17,98	-37,08
73	es30	68,28	63,12	149	lu	-94,12	-91,42	225	ukl1	30,98	51,60
74	es41	80,50	78,34	150	lv	0,31	15,10	226	ukl2	-30,52	-12,06
75	es42	-99,97	-99,96	151	nl	4,35	-1,44	227	ukm	-71,27	-71,54
76	es43	-88,42	-84,62	152	nl11	86,76	85,20	228	ukn0	49,44	44,61

Source: Own calculation and illustration. EUROSTAT database; IPC Biotech patent applications (inventor location) according to EUROSTAT concordance table; year 2000 and average (2000-2002).

Figure 8: Revealed Patent Advantage in Biotechnology, Year 2000



Source: Own illustration; Shape file from EUROSTAT; illustration with ArcGIS

3 Clusters as Systems of Innovation

3.1 Technological and Sectoral Systems of Innovation

As opposed to the original national concept of systems of innovation, current SI conceptualisations conversely foster sectoral analysis, economic geography, agglomeration theory, and industrial specialisation.[32]

The emergence of different SI conceptualisations is predominantly based upon different concepts and taxonomies that differentiate, for instance, between tacit and codified knowledge, as we will discuss later. In addition, federal and local governance structures, agglomerative tendencies, and different concepts of economic externalities are conceptualised as the most essential influencers of invention and innovation in localised systems.[33] In conclusion, geographical proximity of economic entities could represent one of the major determinants of the geography of innovation, of localised knowledge diffusion and, as we assume, of de facto technological standardisation.[34]

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[32] Moulaert/Sekia (2003: 293); Gregersen/Johnson (1997: 482); Sharif (2006: 753).

[33] Feldman (1996: 71); Holbrook/Salazar (2003: 2); Cooke/Memedovic (2003: 1); Scott/Storper (2003: 581); Greunz (2005: 468); Simmie (2003: 611); Andersen et al. (2002: 185); Los/Verspagen (2007: 576-578).

[34] Lundvall (2007: 103); Carlsson (2006: 62).

Besides the hitherto dominating field of research at the nation-state level, academic literature and the policy sphere both show some really interesting modifications, conceptualisations and co-evolutions with reference to more disaggregated levels of analysis.[35] In any case, most contributions to SI underline the fact that national systems of innovation (NSI) are still of high importance and interest.[36] We reason, however, that the nation-state level approach is not really applicable and is less useful for cluster analysis and the conceptualisation of knowledge externalities. Additionally, the NSI concept does not really support open innovation and globalised knowledge creation. This drawback is primarily based on the original idea of the NSI conceptualisation in order to deal with problems and targets within the nation-state's borders. Functional boundaries of localised systems and clusters need a different perspective, which we base upon open innovation modelling and an adaptive systemic view. Owing to the hype of cluster studies and spatial modelling, the literature is increasingly enriched by several contributions that mainly focus on the geography of innovation and externalities.[37] Spatial innovation clusters like Silicon Valley (CA), Route 128 (MA) or Silicon Alley (NY) represent localised systems, agglomerations, and zones of urbanisation where technological specialisation and elementary causes of geographical agglomeration overlap. As a consequence, it is difficult to draw a clear-cut distinction between industrial and local perspectives.[38] As a result, global, continental, national, and sub-national conceptualisations of technological, organisational, institutional and economic determinants increasingly dominate the literature on SI. Some authors explicitly centre the necessity of an essential change of the perspective from a nation-state scale to geographical issues and especially to regional agglomeration appearances.[39] Therefore, these complementary SI conceptualisations and analyses represent an established method for elaborating the dynamics of spatial innovative performance, competitiveness and knowledge exchange.[40]

Several issues that relate to the nation-state level analysis of innovation were soon recognised and challenged within academic circles. Thus, the NSI concept seems to be too broad to explain sectoral and technological processes and industry specialisation.[41]

This idea goes back to Bo Carlsson and colleagues who focused to a great extent on *technological systems of innovation* (*TSI*) by centring on technology fields.[42] In this regard, most authors refer to their work *Technological Systems and Economic Performance. The Case of Factory Automation* (1993).[43] In *Differing Patterns of Industrial Dynamics: New*

35 Lundvall (2007: 100); Sharif (2006: 756).

36 This phenomenon could be explained by the fact that national entities increasingly lose policy tools whereby nation-state policy weakens.

37 Cooke et al. (1997: 476); Scott/Storper (2003: 581). For an additional overview see also Legler et al. (2006); Lundvall (2007: 112); Moulaert/Sekia (2003: 289).

38 Malerba (2005: 400); Scott/Storper (2003: 582); Saxenian (1994: 4).

39 Freeman (1995: 21); Sharif (2006: 756).

40 Lundvall (2007: 100); Edquist (2005: 198-199).

41 Nelson/Rosenberg (1993: 5).

42 Carlsson/Jacobsson (1993); Carlsson/Stankiewicz (1991); Carlsson et al. (2002); Carlsson (2006: 58).

43 Carlsson (1996); Carlsson (2006: 56).

Zealand, Ohio, and Sweden, 1978-1994, Carlsson (1996) presents his sectoral cross-country analysis on differing industrial systems results that relate to different circumstances.[44] Unsurprisingly, even Carlsson and Stankiewicz (1991) mention that technological systems show tendencies to geographical concentration. According to their ideas, agglomerative phenomena such as Route 128 and Silicon Valley represent regional and not national systems. Additionally, technological systems can also be transnational and even global. The boundaries rely on certain circumstances, such as capabilities, relationships, technologies, market requirements, interactions and even technological externalities.[45]

A similar and complementary view within the economic literature represents the *sectoral systems of innovation* (*SSI*) approach, which is mostly related to the publication by Breschi and Malerba (1997). In comparison with the national case, Breschi and Malerba focus on certain groups of firms and organisations, separated by sectoral perspectives. In *Sectoral Innovation Systems, Technological Regimes, Schumpeterian Dynamics, and Spatial Boundaries*, Breschi and Malerba (1997) discuss organisations, especially firms, which co-evolve in specific sectors and which represent sources of new technologies and innovation.[46] According to their argumentation, sectoral systems have a knowledge base, technologies, inputs, and a (potential or existing) demand.[47] Malerba characterises these sectoral systems and their dynamics in terms of unique compositions of knowledge and technologies and differing set-ups of actors, networks and institutions. Such elements co-evolve over time and induce processes of change and transformation owing to evolutionary assumptions.[48]

Depending on the respective issue, sub-sectors, industries or broader sectors can be analysed. Furthermore, the dynamics and path-dependent processes within sectoral systems are consequently sector-specific. Malerba himself, however, makes the important assumption that the relationship between national institutions and sectoral systems becomes substantial. The overlap of NSI and SSI is, however, subjective, owing to the flexibility of partial analysis. Identical to NSI, sectoral systems are also country-specific, unique and primarily independent of optimality requests. Finally, the Schumpeter Mark I and II units can also alternate.[49]

3.2 Functional Boundaries and Specialisation Patterns

Despite the heterogeneous variety of research contributions to the field of agglomeration & innovation systems and its differing theoretical assumptions,[50] some works contributed to a

[44] Carlsson (1996: 220); Gregersen/Johnson (1997: 482); Carlsson/Stankiewicz (1991: 111).

[45] Carlsson/Stankiewicz (1991: 111); Sharif (2006: 756); Carlsson (2006: 58). Edquist similarly mentions functional boundaries (2001: 14).

[46] Edquist (2005: 184); Breschi/Malerba (1997); Malerba (2005: 64); Carlsson (2006: 58); Andersen et al. (2002: 185-186).

[47] Malerba (2002: 248); Malerba (2005: 64-65).

[48] Malerba (1999: 4); Malerba (2005: 66); Malerba (2002: 250).

[49] Malerba (2005: 67-69); Malerba (2002: 253). Malerba also makes the above-mentioned distinction between creative destruction caused by Schumpeter Mark I innovators, and creative accumulation originated by Schumpeter Mark II units (Malerba 2002: 253).

[50] Cooke (2001b: 23); Cooke/Memedovic (2003: 1-2).

better understanding of the transformation, hierarchy, and order within and between agglomeration appearances. In any case, innovation scholars accentuate several problems owing to the lack of an agreement on appropriate measures of the scale of RSI and clusters.[51] Similarly, Holbrook and Salazar (2003) mention that the differences between RSI and clusters may not be clear at all. According to their definitions, an RSI could also be defined as a 'cluster of clusters'.[52] In consequence, it requires us to specify what level of analysis we address with the terminus 'innovation cluster'. First, we argue that innovation clusters are entities in space which add value through the agents' geographical proximity. More precisely:

> 'A cluster is a connection of horizontal, vertical and lateral value adding activities contributed by different actors in proximity to one another which all act in relation to a specific industry. Together the actors are building a value adding web which defines the boundaries of the cluster. Direct and indirect interactions take place between these actors which may be reflected in strong, medium or weak links.' (Brown et al., 2007).

Furthermore, our working definition of innovation clusters respecting regional innovation systems draws both functional and geographical boundaries. Therefore, both Malerba's concept of sectoral innovation systems and Cooke and colleagues' definition of regional innovation systems applies. Sectoral innovation systems determine functional boundaries, whereas the regional innovation system determines the boundaries in space.[53] Malerba's concept of agents and resources in a sectoral innovation system is illustrated below.

Table 5: Sectoral Systems of Innovation

Knowledge and technologies	– a sector's specific knowledge base – technology inputs – knowledge base & technologies define the sectoral boundaries which are changing over time
Actors and networks	– heterogeneous agents (organisations and individuals) – connected through market and non-market relationships – broader interaction than in markets for know-how and licensing or firm alliances & formal networks
Institutions	– 'range from those [institutions] that bind or impose enforcements on agents to those that are created by the interaction among agents' – national (i.e. patent system) or sectoral (i.e. labour market, financial institutions)

Source: Malerba (2004: 17ff, own illustration).

> 'Firms in sectors have commonalities and at the same time are heterogeneous. … it is proposed that a sectoral system of innovation (and production) is composed of a set of agents carrying out market and non-market interactions for the creation, production and sale of sectoral products. Sectoral systems have a knowledge base, technologies, inputs

[51] Wixted (2006: 9).

[52] Holbrook/Salazar (2003: 10).

[53] Interestingly, according to Malerba (2005), system boundaries are often defined in local terms and consequently the sectoral specialisation defines the specialisation of the whole geographical unit. As a consequence, sectoral specialisation and local agglomeration can overlap in specialised clusters.

> and (potential or existing) demand.' (Malerba, 2004: 10)
>
> 'In sum, large-scale agglomeration – and its counterpart, regional economic specialization – is a worldwide and historically persistent phenomenon that is identifying greatly at the present time as a consequence of the forces unleashed by globalization. This leads us to claim that national economic development today is likely not to be less but rather more tied up with processes of geographical concentration compared with the past.'[54] (Scott/ Storper, 2003: 582)

Baptista/Swann (1998: 525) define geographical clusters as 'a strong collection of related companies located in a small geographical area'. Clusters therefore facilitate specialised labour pools, provide intermediate goods, and, most importantly, they create knowledge externalities & spillovers. Furthermore, if such spillovers are geographically bounded, clusters induce regional economic growth (Baptista/Swann, 1998: 525f). Innovation clusters/innovative clusters can also be taken for reduced NIS where system elements 'help stimulate the emergence of specific kinds of innovation in various segments of a national economy' (Bergman et al., 2001: 8).[55] We will refer to 'regional innovation systems' as follows:[56]

> 'The notion of RSI has emerged as a territorially-focused perspective of analysis derived from the broader concept of NSI: A RSI may thus be defined as the localised network of actors and institutions in the public and private sectors whose activities and interactions generate, import, modify and diffuse new technologies within and outside the region.'[57] (Iammarino, 2005: 499)

Regions as geographic termini represent large and complex phenomena which consist of different industries and more than one economic cluster.[58] Thus, finally, 'innovation clusters' stand for a fuzzy concept which includes national policy-induced networks (e.g. German High-tech Strategy), regional patterns of technological excellence (in particular innovation clusters which evolved from industrial districts), but also metropolitan areas (i.e. 'city-economies', cf. Jonas, 2006). Also note that within the literature on national systems and economic activity at the nation-state and sectoral level, major regional phenomena and

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[54] 'The RIS concept, in line with that of the learning region, is the outcome of an intellectual debate at the intersection of two bodies of work, that on the organisation and systemness of innovation on the one hand, and that of spatial agglomeration on the other hand' (De Bruijn/ Lagendijk 2005: 1155).

[55] For the relationship between clusters and NIS, see also OECD (2001b).

[56] We take 'innovation clusters' and 'innovative clusters' for synonymous terms, whereas a 'regional innovation system (RIS)' may span more than one cluster. The concept of 'RIS' exclusively indicates an economics or economic geography analysis, whereas the concept of 'innovative clusters' is also used in innovation & technology management studies.

National systems of innovation (NSI)/regional systems of innovation (RSI) and national innovation systems (NIS)/regional innovation systems (RIS) are synonymous pairs.

[57] In a more detailed form, Asheim (1998) and Asheim and Gertler (2005) distinguish between three types of RSI, similar to Cooke's contribution: 'territorially embedded regional innovation systems', 'regionally networked innovation systems' and 'regionalized national innovation systems'. Nonetheless, the explanatory capability of regional approaches suffers from the lack of a homogeneous and common operationalisation across areas, territories and regions (cf. Crescenzi/Rodríguez-Pose, 2006: 5; Cooke/Memedovic, 2003: 3; DeBrujin/Lagendijk, 2005: 1156; Moulaert/Sekia, 2003: 291).

[58] Cooke/Memedovic (2003: 3). Some authors prefer the definition of spatially concentrated sectoral systems of innovation (SSI) to RSI.

peculiarities that affect localised innovation seem to be ignored.[59] As a result, some innovation scholars engage in extending and combining special theories and approaches related to spatial and regional analyses of innovation.[60]

Chapter 4.3 emphasises the opportunity to set standards and to create industries respecting new use cases by clusters. Therefore we take clusters as an arrangement for innovation where agents cooperate and common goals are achieved. Furthermore, these arrangements seem to be history-dependent to some extent. Braczyk/Heidenreich (1998) in particular have illustrated how different types of regional innovation systems evolve from traditional strength and how regional success stories shape future specialisation patterns.[61] For suggestions on how regional technological specialisation may be measured, see Appendix A.

Additionally, Table 6 summarises research on regional specialisation patterns in the course of time. Regional specialisation and the quest of the regions' role in globalisation have, *inter alia*, been studied by sociologists and economic geographers with social sciences background. For instance, researchers who emphasise the importance of regions in globalisation are Braczyk, Giddens or Heidenreich. This sociological research tradition once included debates on the role of the nation state or, more recently, discussions on what is called 'varieties of capitalism'.

[59] This perspective can be found in Hae Seo (2006: 3); Cantwell (2005: 557); Iammarino (2005: 498); Evangelista et al. (2002: 174); or Holbrook/Salazar (2003: 2).

[60] See, for instance, Braczyk et al. (1998: 414); Cooke et al. (1997: 475); Holbrook/Salazar (2003: 2); or Carlsson (2006: 58). Furthermore, literature is extended by Evolutionary Economic Geography. This sub-approach combines insights from New Economic Geography and systems of innovation literature (Boschma/Frenken 2007: 635-649).

[61] Therefore some authors refer to a lock-in of regions or path dependencies.

Table 6: Regional Specialisation

Regional focus	Origins
type 1: knowledge- and service-based new high-tech / high-service a)	− clusters from mature industries which evolved competence in new industries like logistics or biotechnology (e.g. California) − high-tech clusters promoted by state intervention (e.g. Singapore, Midi-Pyrénées)
type 2: industrial cluster formation paired with technological excellence significant improvements of given technology a)	− strong production clusters − traditionally very strong in old industries like steel (e.g. North Rhine-Westphalia), electronics or mechanical engineering (e.g. Baden-Württemberg)
type 3: routine manufacturing cutting costs / increasing output a)	− regions where industrialisation set in relatively recently − or regions that are strongly dependent on others' technological expertise e.g. Catalonia or Ontario.
type 4: technological decoupling and niche production customer knowledge exploitation / high-end / business models a)	− extensive specialisation in non-high-tech product characteristics, or in particular niches (e.g. Denmark) − flexible division of labour

Source: Braczyk/Heidenreich (1998, own modification/extension). a) Own conclusions from reading.

Type 1 represents clusters that maintained their strong position in mature industries, but meanwhile gained a lead position in new industries (such like California with computers and biotechnology). Type 1 also covers successful regional specialization in new industries driven by government intervention / strong government support in the background like in the case of Singapore.[62] Metropolises such like Paris, Hamburg or Brussels have evolved into international service centers;[63] their metropolitan areas can also be characterized as clusters of type one. Braczyk/Heidenreich argue that market-driven clusters like California are "primarily orientated to utilizing and further developing the possibilities of a given technology to their fullest extend" (Braczyk/Heidenreich, 1998, p. 426). Weak ties facilitate synergies between different industries, and a business environment that supports entrepreneurs & their business partners (business start-ups, freelancers, and financiers). Type 2 is characterized by "strongly locked" production clusters and industrial branches "closely interwoven through local supply and performance relationships" (Braczyk/Heidenreich, 1998, p. 419f). This type has stabilized regional competence through a high degree of interaction and holds a leading market position in old or mature industries. Type 3 regions are classified as such that occupy

[62] Braczyk/Heidenreich, 1998, p. 418 and p. 419 Figure 16.1.

[63] Heidenreich, 1997, p. 502.

a "subordinate or downstream position in terms of their economically utilized technological capabilities" (Braczyk/Heidenreich, 1998, p. 420). Like as type 2 these clusters occupy a catching-up position in new industries.[64] Type 4 is characterized by economic success, but decoupling from the "leading edge of the continuing high-tech race" (Braczyk/Heidenreich,1998, p. 422 and p. 422 Figure 16.4).

4 Opportunities from Open Innovation within Clusters: Knowledge & Standard-setting in Space

4.1 Novel Strategic Options

Previously, we particularly focused on how RIS or Innovation Clusters can be analysed in terms of spatial concentration in space.[65] This chapter conceptualises how firms and other agents can deploy special concentrated resources for new strategic options, learning processes and spillover effects: innovation clusters provide a market for inter-firm collaboration. The variety of assets and new capabilities emerging from the industrial arena encourage ambitious, collaborative projects, but also collective learning processes. We assume that new-to-the-firm knowledge in innovation clusters can either be based on bundling superior assets or on a collaborative exploration process which unfolds knowledge new to the market and thus may create novel use cases. Another benefit of spatial concentration of valuable resources may be an innovative milieu capable of stimulating dynamic business models and technological change by entrepreneurship and venture capital or consortia-driven product development processes. Positive effects concerning regional high skilled labour pools, unemployment rates or social welfare of regional innovation activities are not taken into account by this paper. Therefore, our paper also excludes any policy implications.

Particularly intensified collaboration, multilateral asset exchange and trading of intellectual property on markets for know-how are subject to open innovation processes and business models. The converse of the traditional mode of closed innovation, open innovation stands for business models and organisational design which takes know-how and ideas for goods which are traded on markets (e.g. trading patents or setting up technology spin-offs) and non-markets (partnerships ,etc.) and allows open access to innovation activities (thus facilities innovation *coram publico*), whereas closed innovation is based on proprietary intellectual property policies and strict access (Gerybadze/Slowak, 2008). 'Semi-open innovation', suggested as a term by Gerybadze, generates a new generic type of innovation where organisation design, access to intellectual property and knowledge are only open in parts and only to particular groups of firms with regard to standard-setting community

[64] Braczyk/Heidenreich, 1998, p. 421 Figure 16.3.

[65] For economic literature reviews on spatial phenomena such as industrial districts, innovative milieus, innovative clusters and regional systems of innovation (RSI) and their access to certain resources, see Christ (2007); Iammarino (2005: 498); Asheim/Gertler (2005: 294); Cooke (2001: 949); Andersen et al. (2002: 185); Powel/Grodal (2005: 74); Cooke/Memedovic (2003: 10); OECD (1997: 8).

members.[66] Empirical studies on open innovation in multinational cooperation are offered by OECD (2008).

> 'The open innovation paradigm can be understood as the antithesis of the traditional vertical integration model where internal R&D activities lead to internally developed products that are then distributed by the firm. If pressed to express its definition in a single sentence, Open Innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively. Open Innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology … The business model utilizes both external and internal ideas to create value, while defining internal mechanisms to claim some portion of that value.' (Chesbrough, 2006: 1)

Open innovation as a new paradigm claims to use various paths to the market; it is characterised by activities which span intellectual property and knowledge stocks across institutional and formal organisational boundaries.[67] We argue that regional innovation systems or innovation clusters provide a richer science, technology and innovation base than proprietary firm subsidiary networks can offer. They may embed regional markets, but their spatially concentrated resources may also be deployed in terms of open innovation. Particularly, we suggest that there are two outcomes from inter-firm cooperation within clusters respecting collaborative activities for innovation: first, collaboration leads to learning effects for each partner. It can be explained through intended knowledge flows/knowledge stock exchange, but also through unintended knowledge spillovers between the firms (see chapter 4.2). Second, firms collaborate in order to set strong standards for international markets. The common understanding about dominant use cases creates a basis for value added strategies of the firm (see chapter 4.3). Additionally, strong regional innovation systems create distinctiveness capable of attracting venture capital, highly skilled labour, born globals and multinational firms.[68] In management studies, such regional business environments (e.g. Silicon Valley) host the multinational firms' centres of global excellence.

> 'In the proprietary model of innovation, useful knowledge is scarce, hard to find, and hazardous to rely upon … In Open Innovation, useful knowledge is generally believed to be widely distributed, and of generally high quality. Even the most capable and sophisticated R&D organizations need to be well connected to these external sources of knowledge.' (Chesbrough, 2006: 9)

We conclude that innovative clusters create more strategic options for each agent involved, particularly:

- On a micro-level of analysis, standard-setting and collaborative R&D between the cluster firms implies fewer costs, i.e. in terms of coordination or uncertainty

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66 The Center for International Management and Innovation, University of Hohenheim, developed a layered organisation concept that allows for a differentiated view on semi-open innovation processes (see Gerybadze, 2008a; König, 2008; Gerybadze/Slowak, 2008). Work in progress by Slowak (2009) looks at understanding the 'open' terminus in markets for technology and what RAND terms mean for the dynamics in the sectoral innovation system of industrial automation.

67 Chesbrough (2003, 2006a, b); Gassmann/Enkel (2004); Gassmann (2006).

68 'Innovation clusters' then turn into a policy tool deployed in order to create global lead markets but also attractive locations for global R&D.

about trustworthiness. Furthermore, there are pre-competitive, but distinctive, assets in terms of value added from each firm which evolve better in a sticky, collaborative business environment than in a proprietary R&D laboratory. Such assets are about the use of fundamentally new technology, creating industry standards or coordinating rates of technological change within systemic, complex products and technology-based services.[69]

- On a meso-level of analysis, we find that learning regions occur and that there is more knowledge accessible to the population of firms and other agents concentrated in spatial space.[70] A concentration of excellent knowledge stocks and specialised labour pools in space creates externalities, but also brings new ideas to the table. The variety and loose coupling in capabilities and approved knowledge could improve absorptive capacities for integrating other industries' standards or implementing technology in a new way as regards creating new kinds of use cases. The possible variety of technology domains of an industry is exemplified in Table 7.[71]

69 For the term 'stickiness' or clusters as 'slippery' knowledge spaces, see Markusen (1996).

70 Literature has also emphasised that we can look at cities or regions in terms of learning entities (e.g. Florida, 1995; Storper, 1995; OECD, 1999b; MacLeod, 2000; OECD, 2001a; for an overview see Rutten/Boekema, 2007). There is also in-depth research on how spatial concentration relates to competitiveness within the globalized economy (i.e. OECD, 2005a, 2006, 2007).

71 On a macro-level of analysis, we find that clusters are new entities in competition for direct investments, venture capital and social commitment of multinational cooperation and SMEs. From a growth & employment perspective, the clusters are a policy tool, for instance, for creating regional competitiveness or for exploiting excellent regional labour pools. As this addresses innovation policy issues and the role of national innovation systems for regional innovation activities and competitiveness, however, we think that such analysis needs to be described in a separate paper and thus cannot be addressed by our study.

Table 7: Variety of Technology in Sectoral Innovation Systems with Respect to Industries

Industry	Contributing Technology Domains / Fields of Expertise
nanotechnology (advanced miniaturisation technical systems) [a)]	at nanometer scale: functional materials / novel phenomena & properties (e.g. physical, chemical, biological, mechanical, electrical); composites; molecular electronics & photonics; sensors
biotechnology [b)]	– red (health, medical, diagnostics) – yellow (food, nutrition science) – blue (aquaculture, coastal and marine biotech) – green (agricultural, environmental biotechnology) – white (gene-based, see also McKelvey, 1996) – brown (arid zone and desert biotechnology) – gold (bioinformatics, nanobiotechnology) – grey (classical fermentation and bioprocess technology)
production technologies: [c)] adaptive factories / process plants (intelligent products, learning production systems)	mechanical engineering; factory operation & control; industrial software & operation research for advanced algorithms; consumer market electronics, logistics technologies & IT (in particular, wireless technologies like Wireless Area Network or RFID); new / adaptive materials; semantic web technologies; sociologists & psychologists (re-integration of the human into the adaptive factory); industrial services

Source: a) Listing derived from NASA, Center for Nanotechnology (http://www.ipt.arc.nasa.gov/nanotechnology.html).
b) Listing taken from DaSilva (2004), slightly modified.
c) This listing is based on qualitative interview series in progress by the Center of International Management and Innovation, University of Hohenheim (particularly A. Slowak).

4.2 Classifying Inter- and Intra-cluster Knowledge Dynamics

For the establishment of our conceptual approach of innovation clusters and standard-setting, we analyse the regional agglomeration of firms in terms of regional ‘knowledge capabilities’ (existing knowledge stocks), which are explored by open innovation mechanisms and exploited by value added strategies. Clusters are then characterised by localised knowledge spillovers explored and exploited through the firms’ dynamic capabilities.[72]

> ‘Such dynamic capabilities, where present, stimulate knowledge transfer spiralling that is complementary upgrading ... Crucially, research (rather than big institutions) becomes a key asset in knowledge spiralling as is increasingly recognised in firm practices.’ (Cooke, 2005: 1130)

The approach is also essentially inspired by New Economic Geography Growth (NEGG) literature, which assumes regional growth differences and core-periphery outcomes owing to localised knowledge diffusion. Baldwin and colleagues (1999) and Baldwin and Martin (2004)

[72] See Cooke (2005: 1129). He argues that globalisation is evolving from mode 1 (competition between multinational corporations & multilateral trade institutions) to mode 2 (‘the quest by multinationals for exploitable knowledge in knowledgeable regions’).

assume the spatial agglomeration of innovation and thus new knowledge owing to localised knowledge stocks.[73] Christ (2009b) contributes with a detailed NEGG and geography of innovation literature overview. Our conceptualisation builds upon but extends the basic NEGG idea by adding interdependencies between localised knowledge dynamics and standard-setting.

Furthermore, cooperation for better knowledge exploration and exploitation is addressed by various concepts of science-industry-policy interaction; for instance, the 'triple helix' approach.[74]These approaches provide evidence that collaboration between various agents may create or unfold new knowledge, but also increase the efficiency of innovation processes. But they neither explain knowledge dynamics and evolution of technology nor do they sufficiently centre on open innovation mechanisms in regional innovation systems, which matter for functional boundaries of knowledge dynamics. For this reason, this conceptual approach can be considered unique apart from the fact that it sheds light on the tensions between the geography of innovation literature and economics of standardisation and technological standard-setting.

The following figures highlight the dynamics of knowledge creation and diffusion within (Figure 9) and between (Figure 10) innovation clusters; such knowledge dynamics are interlinked with standard-setting.

Figure 9: Knowledge Dynamics in Innovation Clusters

cluster i with affiliated agents j=1…n

	working for new knowledge (k_{ij}) K1	*working with approved knowledge (stock of knowledge K_{ij})* K2
knowledge diffusion: intended (flow) D1	***knowledge matching and focusing***	***knowledge deepening***
knowledge diffusion: unintended (spillover/ externality) D2	***entrepreneurial spillovers***	***inter-temporal spillovers (intra-/ inter-industry)***

Source: Own illustration.

We assume different constellations, depending on maturity, internationalisation (geography), and consortia structure of firms within and between specialised innovation clusters. We conceptualise four possible constellations (D1, D2, K1, K2) for intra-cluster knowledge

73 Baldwin /Martin (2004); Baldwin et al. (1999). See Christ (2009b) for further details on NEGG.

74 See Etzkowitz (2002), Etzkowitz/Leydesdorff (2000), Leydesdorff (2000) and Etkowitz/Leydesdorff (1997).

dynamics. Our approach differentiates between intended and unintended diffusion mechanisms, according to the existing literature. When challenging knowledge production and their externalities, researchers usually differentiate between two essential streams in literature. Essential determinants of our approach are knowledge spillovers, which are widely accepted in literature. As Castellacci (2007) has recently reasoned:

> 'The general proposition that innovation and inter-sectoral knowledge spillovers are important for the international competitiveness of manufacturing industries is a major point of agreement between new growth theories and evolutionary economics. The two approaches, however, differ substantially in terms of the conceptualization of the innovative process and the analysis of its economic impacts.' (Castellacci 2007: 6)

As a consequence, we introduce spillovers, although being aware that literature is divided into two groups. The first sub-group assumes technological progress and knowledge to be a (pure) public good (D2, unintended diffusion) and hence knowledge spillovers are perfect and not locally bounded. This would mean a broad diffusion of knowledge between and within geographical units or nation-states, which is not entirely useful for our cluster-specific conceptualisation. In contrast with the concept of perfect knowledge externalities (global spillovers), geographical and technological proximity is interlinked with localised intra- and inter-regional knowledge spillovers of tacit (implicit) knowledge.[75] Accordingly, the second pillar within the literature supports the idea of a costly transmission of knowledge across space. This group emphasises distance decay effects of knowledge diffusion that support these phenomena of spatial concentration and localised knowledge spillover.[76] We also follow this line of argumentation in our conceptual approach (D2, K1, K2). Furthermore, this stream in literature bifurcates into 'MAR externalities' (D2), which refer to intra-industry specialisation and 'Jacobian externalities' [77](D2) which specify inter-industry externalities.[78] Some authors classify them as common synonyms for 'localization externalities' and 'urbanization externalities'. We do not share this view and classify MAR and Jacobian externalities as dynamic externalities, whereas localisation and urbanisation economies represent pecuniary (and static) externalities. MAR externalities are almost entirely allocated to industrial agglomerations, and thus to intra-industry specialisation and decreasing competition. In addition, only firms in the same industry are able to internalise these externalities.[79] Conversely, Jacobian externalities represent inter-industry knowledge spillovers that originate from diversified knowledge and different local production structures. Thus, knowledge particularly spills between different industries and the existing pools of knowledge can also be applied in different industries.[80] From our point of view, these arguments and differences in spillover research are primarily interesting when we deal with the relationship between standard-setting and knowledge stock dynamics.

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75 Holbrook/Salazar (2003: 10); Iammarino (2005: 500); Audretsch/Vivarelli (1995: 256).

76 Paci/Usai (2000: 3); Malmberg/Maskell (2005: 2).

77 Jacobs (1969).

78 Döring/Schnellenbach (2004: 2).

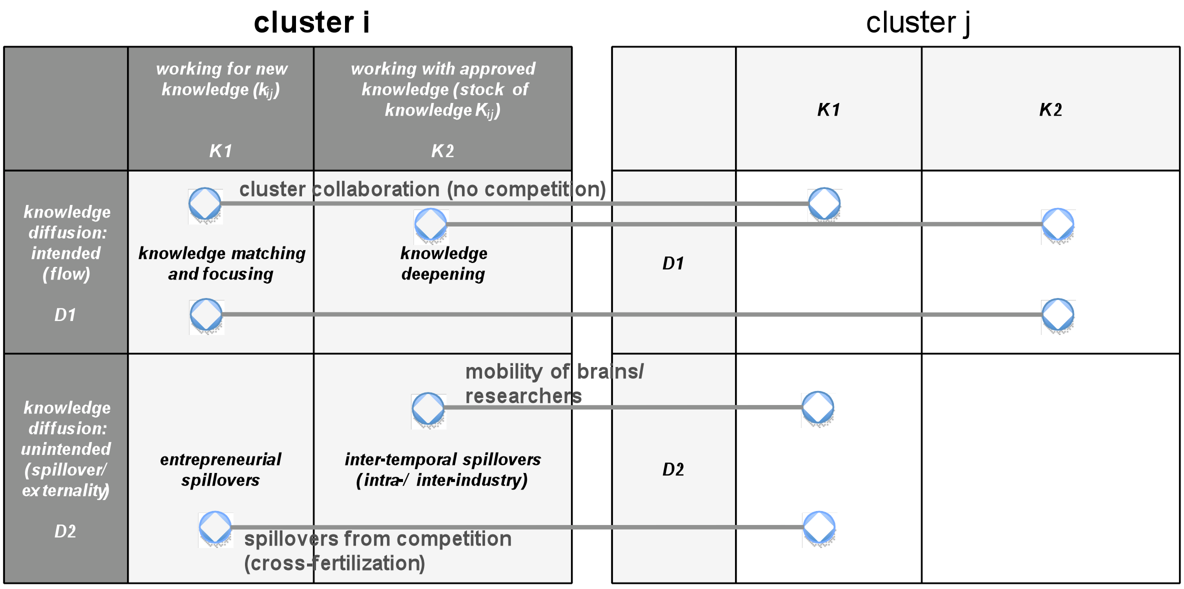
79 Paci/Usai (2000: 2); Breschi/ Lissoni (2001: 5).

80 Jacobs (1969); Glaeser et al. (1992: 1127); Audretsch/Feldman (1999: 410).

Accordingly, our conceptualisation in Figure 9 incorporates a cluster-specific knowledge production function with new knowledge (K1), approved knowledge stocks (K2), knowledge flows (D1, intended) owing to pecuniary linkages, entrepreneurial spillovers (D2, unintended) from recent R&D activities, and inter- and intra-industry externalities (D2, unintended) from already accumulated knowledge. We expect intra-cluster externalities and cluster-specific technological spillovers owing to spatial proximity. Intended knowledge diffusion happens owing to pecuniary linkages and thus is defined as flows of knowledge (collaboration). Figure 9 additionally distinguishes between two types of activities related to knowledge dynamics; firms are either working for new knowledge (k_{ij}) or working with approved knowledge stocks (K_{ij}). Consequently, the intended diffusion of knowledge differentiates between knowledge matching and focusing and knowledge deepening. We conclude that technologies differ tremendously in this regard (see additionally chapter 4.3).

Second, in line with open innovation literature, open system boundaries, and inter-cluster cooperation and competition, Figure 10 (extension of Figure 9) conceptualises knowledge dynamics between innovation clusters, which extends and opens system boundaries owing to flows and spillovers.

Figure 10: Knowledge Dynamics between Innovation Clusters



Source: Own illustration; extension of Figure 9.

We conceptualise several types: inter-cluster collaboration, mobility of brains, and cross-fertilisation. The figure also highlights unintended and intended knowledge diffusion mechanisms. The functional boundaries of knowledge diffusion again depend, however, on the technology. Thus, we assume cluster-specific knowledge production functions and their interdependence as follows:

(1) $$Pat_{i,t} = \alpha_1 RD_{i,t} + \alpha_2 K_{i,t-n} + W_{ij}\beta_1 RD_{j,t} + W_{ij}\beta_2 K_{j,t-n}$$

Cluster-specific innovative output (technological knowledge) $Pat_{i,t}$ depends on the clusters' own R&D activities $RD_{i,t}$, and knowledge externalities of clusters' existing stock of approved knowledge $K_{i,t(-n)}$ (with or without time lag). Additionally, $Pat_{i,t}$ is influenced by technological and/ or spatial neighbouring cluster j via $RD_{j,t}$ and $K_{j,t}$ owing to technological and/or spatial proximity, which is captured by a proximity matrix W_{ij}. Note that such a production function can also be defined at the firm level.[81] Additionally, $RD_{j,t}$ could be replaced by W_{ij} µ $Pat_{j,t}$ (W_{ij} µ $K_{j,t}$) which would represent a spatial autoregressive model/ spatial cross-regressive model with spatial dependence of innovative output (or input).

Within the next chapter, the tension and interdependencies between knowledge dynamics and standard-setting will be conjointly researched. We conclude that the conceptualisation of knowledge spillovers, dynamic externalities and knowledge flows within and between clusters could give important insights into the relationship and potential dependencies between spatial proximity, knowledge diffusion and standard-setting.[82]

4.3 Collaborative Standard-setting

West (2007) distinguishes four phases of technology diffusion: specification of a technology, implementation, complement phase, and use phase. The first two phases, namely specification and implementation, establish a standard. Implementations and complements enhance and exploit a standard. The specification phase defines the core of a new technology whereas its implementation makes the technology available to the market. Hence, these two phases create the core concept of a new standard. Complementors then create added value respecting complements which build on this standard. Co-operation in the R&D process focuses on standard-setting, whereas market competition is based on complements and advanced functionality in line with the previously established core concept.

The terms behind Figure 11 are to be read as follows (cf. West, 2007: 95ff). 'Implementation' means to create a specification from a technology; its implementation generates products, but it also determines pricing and use policies; and finally, users adopt the implemented specification respecting use the products created if the create utility, i.e. in terms of interoperability. 'Complement providers' search for standards which open up large markets for them. Note that this model implicitly assumes some kind of network effects / markets where different goods interfere via standards.

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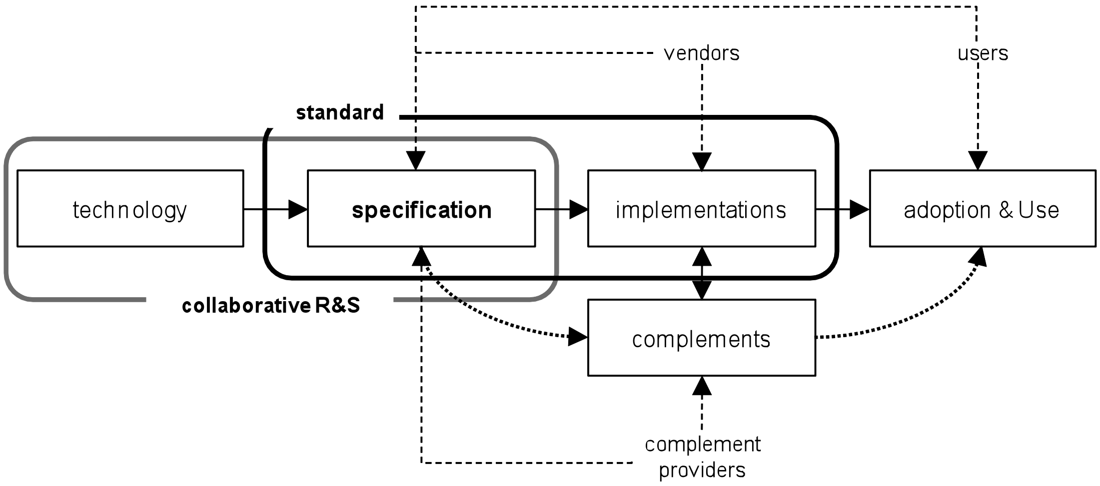
[81] There exists an increasing research community on KPF and knowledge spillovers. Because of our alternative focus, we do not discuss different knowledge production functions. See Christ (2009b) for further details and literature survey on this issue.

[82] Audretsch/Vivarelli (1996: 250-256); Breschi/ Lissoni (2001: 1); Cooke/Memedovic (2003: 7); and Scott/Storper (2003: 183). For a detailed differentiation between rent spillover (traded innovative goods via market transaction) and pure knowledge spillovers (knowledge spills without transaction) see Los/Verspagen (2007) and Audretsch (1998).

Figure 11: The Linear Standard-setting Process



Source: West (2007: 95, Figure 3.2), modified.

Standards at the same time drive innovation and restrain it. On the one hand, standards encourage the use of new product/specify important aspects of interaction in socio-technical systems, and they also describe usage and implementation of a new technology. On the other hand, they make particular socio-technical alternatives irrelevant (as those are not embedded in the specification/considered by the standard's selection) – standards thus devalue particular knowledge stocks and intellectual property. There are three key arguments which illustrate the economic value of standards. First, standards promote quality and embed know-how.[83] Second, firms establish standards in order to create value from technology and industrial knowledge. Firms invest in technologies, which are incompatible or different in their approach to competitors' portfolios. They gain strategic advantages if they can force their competitors to adopt. There is a particularly rich tradition in the analysis of 'standard wars'[84] and 'markets with network effects' which is continuing in case studies on video, office file and game formats. Third, standards serve as a framework for subsequent innovation and value capturing from technology. Authors who illustrate this point focus on the tension between intellectual property and specification versus implementation phases. The discussion in particular refers to terms such as intellectual property and standard-setting bodies[85] and the various 'meanings of open [standards]'.[86] Note that the reading of Simcoe (2006) illustrates that there is a trade-off between openness which accelerates a standard's diffusion (value creation) and the appropriation of innovation rents (value capturing) which mean to 'close' to some degree certain parts of a standard. Standard-setters produce

[83] In particular: Blind (2004); Fraunhofer ISI (2007); and DTI (2005). Blind/Jungmittag (2008) give statistical evidence that both national patents and standard stocks serve as an important knowledge pool for economic growth. For analysis of formal standardisation processes, see DeLacey et al. (2006), Blind (2006), Chiao et al. (2005); and Eickhoff/Hartlieb (2002).

[84] Important contributions for instance are Katz/Shapiro (1994, 1986, 1985); Farrell/Saloner (1986, 1985); Shapiro/Varian (1999b). For a recent summary see Shapiro/Varian (1999a).

[85] Among others Staniszewski (2007); Updegrove (2007b); Blind/Thumm (2004); Lemley (2002); or Blind et al. (2002). In the American literature intellectual property & antitrust also is an important research theme. For an overview on this topic see American Bar Association (2007).

[86] For this discussion see Krechmer (2006; 1998); Updegrove (2005a,b; 1995); and West (2004).

standardisation between different possible alternatives by agreements, either on technical documents[87] or in general[88]. Finally, Swann's (2000) definition of standards turns standards-setting success into a competitive edge: standards are employed to solve problems of incompatibility, quality, variety and information. The technology diffusion process is typically modelled by an s-shaped curve (Geroski, 2000). It can either be taken for a linear process, characterised by path-dependent & evolutionary processes of selection, mental & technical lock-ins and mutation;[89] or a non-linear process, but representing a function of time.[90] In either case, firms need to participate within some kind of organisational frames which support their technologies by industry standards and stabilise their market segments.

In terms of knowledge we define the core concept respecting the common set of technology standards of a cluster as established from firm-specific knowledge stocks[91] k_i, representing particular individual firms' knowledge stocks, that in turn represent the cluster-specific knowledge K_i), which the standard-setting partners agree on at the start of a new technology diffusion process. Other competing firm-level knowledge stocks k_m need to be made compatible with firm-specific k_is over time or they are abandoned. Standard-setting is characterised by a choice between different technology alternatives; thus, specification and implementation phases match and focus the portfolio of relevant knowledge stocks. Particular knowledge, however, is deepened in terms of value added by each firm in the market-place. More precisely, the adoption & use phase widens the portfolio of relevant knowledge stocks – firms modify the standards through 'value added' features and technologies at the market-place. Whereas the standard is a common good between the cluster members respecting a club good, market offers embed the standard in a way that allows the sale of something unique again. This transformation of the standard into a proprietary market offer, for instance, an industry solution, can be understood as 'creating value added' for a strong standard with regard to 'collaborating on the standard, but competing on implementation' (this idea is taken from Simcoe, 2006). That being so, the standard-setting process needs to be set in an industry context: value propositions either contribute to common knowledge stocks or create new knowledge and new implementations within an industry. Competing on implementation means that each firm contributes to the common stock of knowledge by collaborative standard-setting and de iure standardisation, but it also creates proprietary knowledge and services beyond this stock. This proprietary domain is the basis for 'value added' strategies at the market.

Our models of standard-setting as provided in the following Figures 12 and 13 extend the linear process by a nonlinear front end of pre-competitive activities related to complementary

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87 Updegrove, 2006; Geradin, 2006; Blind, 2004.

88 Borowicz, 2001; Swann, 2000.

89 Carrillo-Hermosilla/Unruh (2006), Arthur (1990), Arthur (1989), and David (1985). These are just examples taken from a rich, but still non-mainstream, research school.

90 For literature on technology diffusion see Gerybadze (2004: 128-133); Damsgaard/Henriksen (2004); Rogers (2003); Geroski (2000); Barrell et al. (1999).

91 Such 'knowledge stocks' include technology assets such as secrets and patents, know-how necessary for implementation, but also competencies regarding the management of nonlinear and collaborative innovation processes.

goods, industry context, creation or modification of a use case and organisational frames. It seems to us that maturity of the use case and complexity of technologies included in a standard (technology – specification – use case) and also the inner logics of organisational frames determine bargaining power in the specification process; the logics also shape intellectual property policies and time-to-standard. Note that there should be more sophisticated frames and that the use case should be more elaborated in non-high-technology industries. This is because the agents of the sectoral innovation system have experience and are familiar with well-established institutions of their activity fields. Conversely, high-technologies may be created for new use cases and demand novel complementary assets. If inventor firms are rather young or new to the sectoral innovation system, organisational frames for collaborative standard-setting are immature or they do not exist.

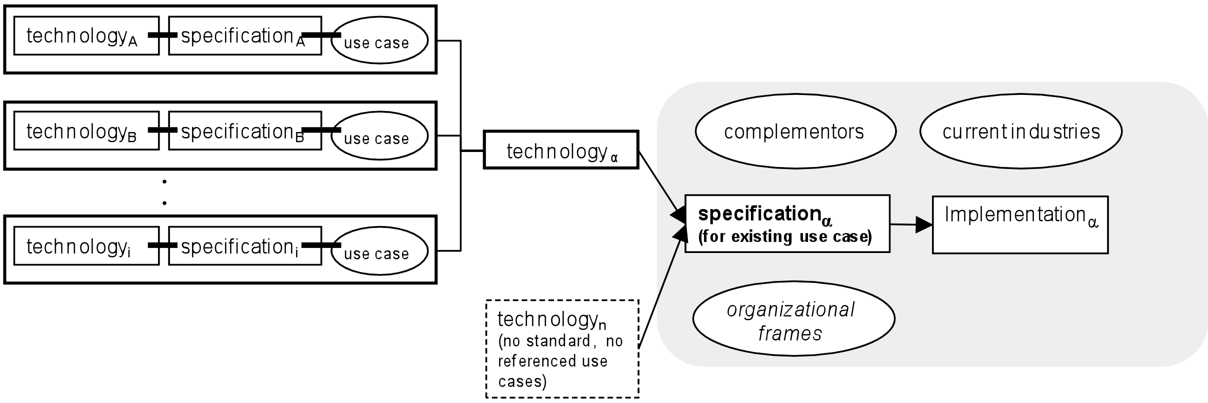
Particularly, an analysis of the standard-setting process in clusters should take into account the creation of a use case or even a lead market and organisational frames which coordinate standardisation interests among the population's agents. Note that organisational frames can be industry consortia, working groups of industry associations or de iure bodies. Also note that any specification of technology implicitly refers to a use case; the case ascribes artefacts or industrial processes to a technology (e.g. web browser to XML, or high-throughput experimentation to pharmaceutical and drug development or coatings industry). Therefore, our models distinguish between standard-setting in high- versus low-tech industries.

Our standard-setting model for low-tech industries, illustrated in Figure 12, is as follows. There are a well-defined sectoral innovation system, well-defined products & service markets and a well-established use case. Nonetheless, this arrangement is challenged by new technologies from overlapping fields and also from consumer high-technology. Thus the model must account for the capability of integrating other industries' specified technologies or standards (technology includes specification and original use case). These standards need to be coupled with the own industry's stock of technologies and knowledge. Furthermore, they need to be transformed into the use case of the own industry (e.g. consumer WiFi operates in a different context from industrial WiFi). Standards are usually created for current, traditional industries. In the light of the empirical case of industrial automation, Slowak (2008) has described how standard-setting in medium/low-tech industries takes place in standard-setting communities where firms collaborate on standards, but compete on implementations in the market. More precisely, it needs to be explained how firms can both collaborate and compete at the same time. There are dynamic capabilities which somewhat moderate a trade-off between collaboration (collaborative R&D, collaborative standard-setting, collaboration on market offers or sourcing) and proprietary activities (value added strategies), but also between the dimensions of value creation and value capture.

> '[…] members of a standard-setting community solve the trade-off between exploitation and exploration (from a process view) respecting value created and value captured (from a knowledge dynamics view) through switching from competition to collaboration on standards. This switch is moderated and maintained by dynamic standard-setting

> capabilities … standard-setting communities can be understood as innovation ecosystems or 'semi-open' clubs which specify and promote particular technologies in the context of particular use cases. They are arrangements where firms practice their standard-setting capabilities.' (Slowak, 2008)
>
> 'Collaborative standard-setting can be thought of as alignment against challenges from the market field. Standard-setting communities provide an institutional frame for replication of success by new, innovative but backward-compatible standard vintages.' (Slowak, 2008)[92]

Figure 12: Standard-setting in Medium/low-tech Clusters: Evolution from Industrial Districts



Source: Own illustration. Note that in this case technologies are well-known and innovation thus means to advance given technology. We assume that the use case is well established and that the new standard or new standard vintage refers to previous standards.

Given the number of technologies to be integrated into a standard and the various contexts (related industries, use cases, well-established organisational frames for standard-setting), innovation clusters in traditional and non-high-technology industries could serve as a place where systemic standards for systemic products[93] are created and where RIS and NIS are linked in order to ensure accurate representation of home-based MNEs in international de iure bodies such as the International Electrotechnical Commission for mechanical engineering. It seems that the variety of knowledge within a spatially concentrated innovation ecosystem is a very fruitful basis for synchronisation processes between knowledge stocks from various fields. From our perspective, the agents align firm and cluster strategies both striving for excellence. 'Openness' between the cluster partners within the standard-formation phase respecting technology specification allows for access on a broad variety of assets and capabilities which leverage the individual resources of each firm and – in doing so – promotes technology and knowledge spillovers from collaboration. There may also be positive externalities in terms of an emerging unique industrial atmosphere in the cluster.

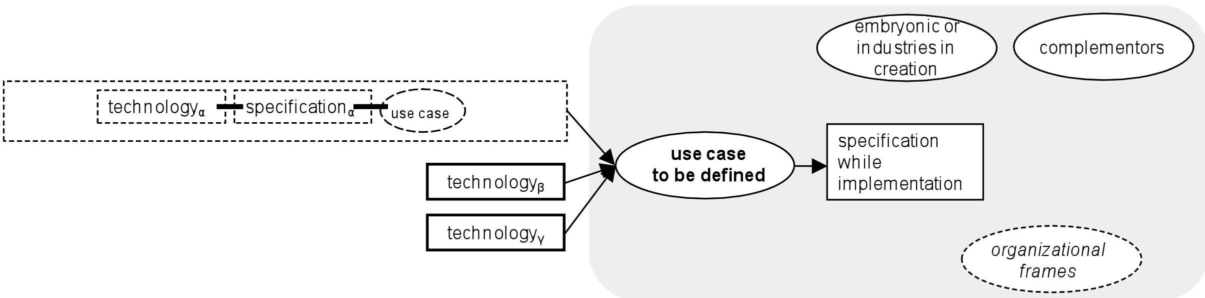
[92] A 'replication of success' implies that history does matter. Thus it could be fruitful to consider concepts such as path dependencies or technological lock-in. In the course of time, standards build on previous vintages which they defend or extend.

[93] Systemic products are either characterised by modularisation or by their hybrid mix from goods and services/by product-service bundles. (For a review on modularity in product architectures cf. Sanchez, 2008.) Quality standards guarantee a minimum product and service quality which reduces the search and transaction costs of a customer. They are the basis for most service industries (Swann, 2000a: section 1; additionally see Blind/Jungmittag, 2008). Furthermore, quality standards allow companies to develop new market segments of existing markets (Blind/Jungmittag, 2008).

Standard-setting in low-tech industries could be taken for sophisticated routines linked to the proven industry-specific innovation chain. Innovation clusters provide spatially concentrated resources in geographically bounded space; they are thus arrangements for collaboration, inter alia standard-setting, evolved over time.

Our standard-setting model for high-tech industries, illustrated in Figure 13, is as follows. The sectoral innovation system is not yet stabilised and dominant use cases lack a proper definition. Industries are still in an embryonic stage or they still need to be created. Technical high-tech standards are usually created for new fields or in a new product & service context. Thus, specification evolves while implementation matures. Standard-setting activity in high-tech respecting basically new knowledge and new technological know-how differs significantly from standard-setting in the low-technology case. It does not represent a replication process of success. Rather, standard-setting then is a challenge characterised by uncertainty, by yet unstructured industries or contexts, or sometimes determined by turbulences and changes in the emerging sectoral innovation system. As for innovation, standard-setting for embryonic technologies can be taken for a dynamic, nonlinear process where hierarchies, use cases and meaning have to be established from scratch. Note that there is no value creation without a market, but no market for new technology without a transparent use case, which implies the emergence or existence of standards.

Figure 13: Standard-setting in High-tech Clusters: Creation from Scratch



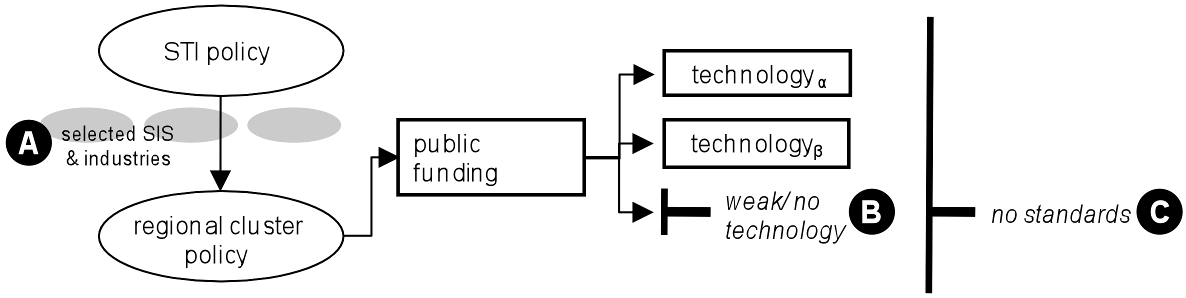
Source: Own illustration. Note that in this case technologies are basically new and innovation also needs to create or stabilise the innovation ecosystem. Particularly, the use case is to be defined and organisational frames are insufficient for technology diffusion. The targeted industry is in an embryonic stage and complementors are just discovering the technology for their purposes.

Given the uncertainty and embryonic stage of the use case, innovation clusters in new technical fields respecting high-technology could serve as a place where new players get together, but also where the economic interests of the emerging sectoral innovation system are aligned and articulated to policymakers (e.g. legal concerns about gene research and cloning in biotechnology). Innovation clusters in high-tech create a context which means to define the sectoral innovation system, industry context and generic logics of implementation with regard to promising use cases.

(2) $$S_{i,t} = \beta_1 S_{i,t-1} + \beta_2 \Delta Tech_{i,t}(RD_{i,t-1} + ... + RD_{i,t-n}, dc) + \sum_{j=1}^{N} \beta_j (dc, IPR)$$

$S_{i,t}$ represents a cluster's standard i created at period t, whereas $\Delta Tech_{i,t}$ accounts for the technological progress relevant to $S_{i,t}$ and created within the cluster at period t. Additionally, dc shall be the dynamic capability as 'ability to' deploy all resources accessible by the cluster. Furthermore, RD_i stands for research & development activities which are relevant to s_i and accessible to cluster members. $\sum \beta_j(dc, IPR)$ represents standards created outside the cluster which are integrated in or referenced to the cluster's standard s_i. Note that the ability to integrate such external standards depends on both dynamic capability (dc) and intellectual property rights given against integration or use by the cluster (IPR). Thus we denote it as *f* (dc, IPR).

Figure 14: Policy-induced Innovation Clusters



Source: Own illustration.

STI policy has not been subject to our analysis for two reasons: first, policymakers could create artificial purposes which are often not necessarily in line with the industry's innovation agenda; and second, we argue that technology and standard-setting dynamics are better understood by leading firms than by regional governments or public funding departments. Nonetheless, if policymakers truly collaborate with leading firms our assumptions may not hold. More precisely, there could be a inefficient selection of sectoral innovation systems by STI policy (see mark A in Figure 14); secondly, cluster initiatives may not strive for ambitious project, they could also rather just seek funding for recent in-house development projects (mark B); and third, initiatives such as the German High-technology Initiative often focus on R&D in global trends such as biotechnology which are not necessarily in line with the standard-setting opportunities of a national innovation system (mark C). For, instance Germany is strong in mechanical engineering but the German High-technology Initiative is biased in favour of American strength such as biotechnology or information technologies.

Note that standard-setting processes differ depending on inter-firm/standard-setting organisation structures and institutions within the sectoral innovation system (see 'organisational frames' in Figures 12 and 13). In recent years, there has been much research conducted on the characteristics of de jure bodies, standardisation working groups in industry associations or on high-technology consortia. However, within the scope of this paper we cannot address 'organisational structure' as an issue.

4.4 The Synthesis of Standard-setting and Knowledge Creation

Standard-setting and knowledge creation activities interfere in space owing to standard-setting deploying knowledge stocks, and knowledge can only be used in a standardised form which allows for mental representation of knowledge, its transfer between teams and firms, and compatibility despite variety. More precisely, technical standards and business standards are inputs in 'working with approved knowledge' (see Figure 9 in chapter 4.2). Behavioural/business standards allow for fair behaviour against partners working for new knowledge; owing to uncertain and unknown outcomes of high-tech research and standardisation firms may not be able to fully negotiate ownership and access to future technology formally in advance. Velocity markets need flexible policies which are to be interpreted in terms of technology and industry dynamics. Note that fixed formal and static policies do not sanction hidden agendas, opportunistic behaviour as conceptualised by principal agent theory or bad faith bargaining in the course of time. Also note that standards are basically 'documents' from specification processes and therefore apply to many fields of economic activity, not only the development and diffusion of technology. In any case, extensive documentation of standards underpins the potentialities of technology-specific knowledge spill-over. Thus, knowledge dynamics and technological specification/alignment are interrelated. Know-how and knowledge represented in technology are crucial inputs of the standard-setting respecting the specification process. Technical standards must bring some functionality or technological advancement to the table in order to replace given standards and to defend their own implementation in the course of time.

5 Implications and Further Research

Our paper offers a complementary view on clusters from a geography of innovation, systems of innovation theory, and economics of standards perspective. We introduced a non-HT case (mechanical engineering) and HT case (biotechnology) for conceptualising technology-specific knowledge dynamics and standard-setting. Chapter 2 highlights a high concentration of patents in both technology fields. For this purpose, we calculated GINI coefficients, RPA values and Herfindahl indices by using EPO patent applications. RIS may be both sectoral innovation systems and settings of spatially concentrated economic activity where firms and other agents, in particular their knowledge stock, co-evolve over time. The explicit implementation of knowledge externalities and flows related to cluster-specific knowledge accumulation and finally the effect on standard-setting is essential.

Mechanical engineering is increasingly modernised by the integration of high-tech knowledge stocks and new technology designs (integrated stocks are both open standards, e.g. Internet technologies and patented technology, e.g. nanotechnology). Innovation is consequently often incremental and patents represent both input and output of knowledge creation. We primarily approach knowledge and patents as an output, which fosters knowledge diffusion by localised and cluster-specific knowledge production functions. Biotechnology in contrast represents a relative new and emerging technology field; processes of innovation are mainly driven by defining the use case and sectoral innovation system for new high-tech methods (e.g. gene analysis and visual representation). Thus, patents are merely outputs or strategic tools to slow competitors in innovation; knowledge stocks are of a new kind.

Clusters may create strong and enduring standards which accelerate the process of technology diffusion, but also promote full exploration and exploitation of resources within a region. They may also stabilise lead markets at their location or create new market fields for new technologies from new standards and use cases. More precisely, we find that knowledge creation and standard-setting are cross-fertilising each other: Whereas the spatial concentration of assets and high-skilled labour provides new opportunities to the firm, each firm's knowledge stocks need to be contextualised. The context in terms of a use case for technology and 'knowledge biography' makes technologies (as represented in knowledge stocks) available for collaboration, but also clarifies relevance and ownership, in particular intellectual property concerns. Owing to this approach we propose a conceptualisation which contains both areas with inter- and intra-cluster focus. This concept paper additionally concludes that spatial and technological proximity benefit standard-setting in high-tech and low-tech industries in very different ways. More precisely, the versatile tension between knowledge stocks, their evolution, and technical specification & implementation requires the conceptualisation and analysis of nonlinear processes of standard-setting. Particularly, the use case of technologies is essential. Related to this approach, clusters strongly support the establishment of technology use cases in embryonic high-tech industries. Low-tech industries in contrast rather depend on approved knowledge stocks, whose dynamics provide better and fast accessible knowledge inputs within low-tech clusters. In this context, knowledge spillovers play a crucial role in technology diffusion and finally standard-setting.

Table 8 summarises additional lack of research related to our conceptual approach. We distinguish between two essential topics, which are highly dependent and interrelated. Technology competence needs further research in terms of patent and employment analyses. From this perspective, specialisation and localised accumulation of knowledge are of primary interest. Second, standard-setting competence has to be challenged intensively; such competence in innovation clusters particularly concerns the alignment of different partners' but also agglomerated industries' knowledge stocks in order to deepen the common STI base (matching of knowledge stocks). Therefore, the emergence of dominant patent classes and patent trees would be interesting to measure. Standard-setting activities in general could be quantified with respect to time until a momentum for a newly-specified technology has been reached, or also with respect to global high-norm activities.

Table 8: Agenda for Further Quantitative Research on Standard-setting & Knowledge Dynamics in Innovation Clusters

Research Issue		Method	Suggested Data Base
technology competence	specialisation and level of highly-skilled labour	employment statistics, educational systems	EUROSTAT (NUTS1/2), ILO, OECD
	technological specialisation & technology complexity	patent count, inter-industry patent citations	EUROSTAT (NUTS1/2), PATSTAT, OECD
	competence accumulation (cumulativeness of knowledge stocks)	intra-industry patent citations (industries to be separated by SIC/IPC-USPTO concordances)	national databases incl. EPO (EPO, USPO, JPO), PATSTAT
standard-setting competence	momentum	time to and count of triad patents	OECD Triadic patent database, OECD MSTI (data need to be linked to national databases incl. EPO)
	capability of matching knowledge stocks	deepening of cluster-specific knowledge stocks k_{ij} over time (dominance and depth of patent trees)	national databases incl. EPO (EPO, USPO, JPO)
	global influence on formal standards (high-norm activities)	norm counting (for NIS)	PERINORM

Source: Own illustration.

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Appendix A: Indices of Regional Technological Specialisation (selected examples)

Indicator	Index	References
Revealed Technological Advantage (RTA) *Revealed Patent Advantage (RPA)*	$RTA = \frac{p_{ij} \Big/ \sum_{i=1}^{N} p_{ij}}{\sum_{j}^{N} p_{ij} \Big/ \sum_{i=1}^{N} p_{ij}}$ $RPA = 100 \ln RTA = 100\,(RTA^2 - 1) / (RTA^2 + 1)$ $-100 \leq RPA \leq 100$	OECD (1994); Wessa (2008)
Herfindahl index (HHI)	$HHI = \sum_{i=1}^{N} p_i^2 = \sum_{i=1}^{N} \frac{x_i^2}{X^2}$ $\quad \frac{1}{n} \leq HHI \leq 1$	OECD (1994); Wessa (2008)
GINI coefficient	$G = \left(\frac{2}{n^2 \overline{x}}\right) \sum_{i=1}^{N} \left(\left(i - \frac{n+1}{2}\right) \frac{x_i}{1}\right) \quad 0 \leq G \leq 1$	OECD (1994); Wessa (2008)
geographic concentration of patents (absolute)	$\sum_{i=1}^{N} \lvert p_i - a_i \rvert$ where p_i is the patents' share of region i, a_i is the area of region i as a percentage of the country area, N stands for the number of regions and | | indicates the absolute value. The index lies between 0 (no concentration) and 1 (maximum concentration).	OECD (2005c, p. 194)
bibliometric indicators	$\frac{\text{share (\%) of publications of region X in field Y}}{\text{share (\%) of world publications in field Y}}$	UIS (2005)
geographic concentration of highly skilled population	$\sum_{i=1}^{N} \lvert hs_i - a_i \rvert$ where hs_i is the share of population with tertiary education of region i, a_i is the area of region i as a percentage of the country area, N stands for the number of regions and | | indicates the absolute value. The index lies between 0 (no concentration) and 1 (maximum concentration).	OECD (2005c, p. 194)

Source: Own illustration. For methodology concerning data and interpretation within science and technology studies see the Frascati, the Oslo and the Canberra Manual (OECD, 1994, 1995, 2002, 2005b; Wessa, 2008).

Appendix B: NUTS Classification (NUTS0, NUTS1, NUTS2)

AT	**ÖSTERREICH / AUSTRIA**
AT1	OSTÖSTERREICH
AT11	Burgenland (A)
AT12	Niederösterreich
AT13	Wien
AT2	SÜDÖSTERREICH
AT21	Kärnten
AT22	Steiermark
AT3	WESTÖSTERREICH
AT31	Oberösterreich
AT32	Salzburg
AT33	Tirol
AT34	Vorarlberg
BE	**BELGIQUE-BELGIË / BELGE**
BE1	RÉGION DE BRUXELLES-CAPITALE / B
BE10	Région de Bruxelles-Capitale / Brussels H
BE2	VLAAMS GEWEST
BE21	Prov. Antwerpen
BE22	Prov. Limburg (B)
BE23	Prov. Oost-Vlaanderen
BE24	Prov. Vlaams-Brabant
BE25	Prov. West-Vlaanderen
BE3	RÉGION WALLONNE
BE31	Prov. Brabant Wallon
BE32	Prov. Hainaut
BE33	Prov. Liège
BE34	Prov. Luxembourg (B)
BE35	Prov. Namur
BG	**BULGARIA**
BG3	SEVERNA I IZTOCHNA BULGARIA
BG31	Severozapaden
BG32	Severen tsentralen
BG33	Severoiztochen
BG34	Yugoiztochen
BG4	YUGOZAPADNA I YUZHNA TSENTRALN
BG41	Yugozapaden
BG42	Yuzhen tsentralen
CY	**KYPROS - KIBRIS / CYPRUS**
CY0	KYPROS / KIBRIS
CY00	Kypros / Kibris
CZ	**CESKA REP. / CZECH REP.**
CZ0	CESKA REPUBLIKA
CZ01	Praha
CZ02	Stredni Cechy
CZ03	Jihozapad
CZ04	Severozapad
CZ05	Severovychod
CZ06	Jihovychod
CZ07	Stredni Morava
CZ08	Moravskoslezsko
DE	**DEUTSCHLAND / GERMANY**
DE1	BADEN-WÜRTTEMBERG
DE11	Stuttgart
DE12	Karlsruhe
DE13	Freiburg
DE14	Tübingen
DE2	BAYERN
DE21	Oberbayern
DE22	Niederbayern
DE23	Oberpfalz
DE24	Oberfranken
DE25	Mittelfranken
DE26	Unterfranken
DE27	Schwaben
DE3	BERLIN
DE30	Berlin
DE4	BRANDENBURG
DE41	Brandenburg - Nordost
DE42	Brandenburg - Südwest
DE5	BREMEN
DE50	Bremen
DE6	HAMBURG
DE60	Hamburg
DE7	HESSEN
DE71	Darmstadt
DE72	Gießen
DE73	Kassel
DE8	MECKLENBURG-VORPOMMERN
DE80	Mecklenburg-Vorpommern
DE9	NIEDERSACHSEN
DE91	Braunschweig
DE92	Hannover
DE93	Lüneburg
DE94	Weser-Ems
DEA	NORDRHEIN-WESTFALEN
DEA1	Düsseldorf
DEA2	Köln
DEA3	Münster
DEA4	Detmold
DEA5	Arnsberg
DEB	RHEINLAND-PFALZ
DEB1	Koblenz
DEB2	Trier
DEB3	Rheinhessen-Pfalz
DEC	SAARLAND
DEC0	Saarland
DED	SACHSEN
DED1	Chemnitz
DED2	Dresden
DED3	Leipzig
DEE	SACHSEN-ANHALT
DEE0	Sachsen-Anhalt
DEF	SCHLESWIG-HOLSTEIN
DEF0	Schleswig-Holstein
DEG	THÜRINGEN
DEG0	Thüringen
DK	**DANMARK / DENMARK**
DK0	DANMARK
DK01	Hovedstaden
DK02	Sjælland
DK03	Syddanmark
DK04	Midtjylland
DK05	Nordjylland
EE	**EESTI / ESTONIA**
EE0	EESTI
EE00	Eesti
ES	**ESPAÑA / SPAIN**
ES1	NOROESTE
ES11	Galicia
ES12	Principado de Asturias
ES13	Cantabria
ES2	NORESTE
ES21	País Vasco
ES22	Comunidad Foral de Navarra
ES23	La Rioja
ES24	Aragón
ES3	COMUNIDAD DE MADRID
ES30	Comunidad de Madrid
ES4	CENTRO (E)
ES41	Castilla y León
ES42	Castilla-La Mancha
ES43	Extremadura
ES5	ESTE
ES51	Cataluña
ES52	Comunidad Valenciana
ES53	Illes Balears
ES6	SUR
ES61	Andalucía
ES62	Región de Murcia
ES63	Ciudad Autónoma de Ceuta
ES64	Ciudad Autónoma de Melilla
ES7	CANARIAS
ES70	Canarias
FI	**SUOMI / FINLAND**
FI1	MANNER-SUOMI
FI13	Itä-Suomi
FI18	Etelä-Suomi
FI19	Länsi-Suomi
FI1A	Pohjois-Suomi
FI2	ÅLAND
FI20	Åland
FR	**FRANCE**
FR1	ÎLE DE FRANCE
FR10	Île de France
FR2	BASSIN PARISIEN
FR21	Champagne-Ardenne
FR22	Picardie
FR23	Haute-Normandie
FR24	Centre
FR25	Basse-Normandie
FR26	Bourgogne
FR3	NORD - PAS-DE-CALAIS
FR30	Nord - Pas-de-Calais
FR4	EST
FR41	Lorraine
FR42	Alsace
FR43	Franche-Comté
FR5	OUEST
FR51	Pays de la Loire
FR52	Bretagne
FR53	Poitou-Charentes
FR6	SUD-OUEST
FR61	Aquitaine
FR62	Midi-Pyrénées
FR63	Limousin
FR7	CENTRE-EST
FR71	Rhône-Alpes
FR72	Auvergne
FR8	MÉDITERRANÉE
FR81	Languedoc-Roussillon
FR82	Provence-Alpes-Côte d'Azur
FR83	Corse
FR9	DÉPARTEMENTS D'OUTRE-MER
FR91	Guadeloupe
FR92	Martinique
FR93	Guyane
FR94	Réunion
GR	**ELLADA/ GREECE**
GR1	VOREIA ELLADA
GR11	Anatoliki Makedonia, Thraki
GR12	Kentriki Makedonia
GR13	Dytiki Makedonia
GR14	Thessalia
GR2	KENTRIKI ELLADA
GR21	Ipeiros
GR22	Ionia Nisia
GR23	Dytiki Ellada
GR24	Sterea Ellada
GR25	Peloponnisos
GR3	ATTIKI
GR30	Attiki
GR4	NISIA AIGAIOU, KRITI
GR41	Voreio Aigaio
GR42	Notio Aigaio
GR43	Kriti
HU	**MAGYARORSZAG / HUNGARY**
HU1	KOZEP-MAGYARORSZAG
HU10	Kozep-Magyarorszag
HU2	DUNANTUL
HU21	Kozep-Dunantul
HU22	Nyugat-Dunantul
HU23	Del-Dunantul
HU3	ALFOLD ES ESZAK
HU31	Eszak-Magyarorszag
HU32	Eszak-Alfold
HU33	Del-Alfold
IE	**IRELAND**
IE0	IRELAND
IE01	Border, Midland and Western
IE02	Southern and Eastern
IT	**ITALIA / ITALY**
ITC	NORD-OVEST
ITC1	Piemonte
ITC2	Valle d'Aosta/Vallée d'Aoste
ITC3	Liguria
ITC4	Lombardia
ITD	NORD-EST
ITD1	Provincia Autonoma Bolzano/Bozen
ITD2	Provincia Autonoma Trento
ITD3	Veneto
ITD4	Friuli-Venezia Giulia
ITD5	Emilia-Romagna
ITE	CENTRO (I)
ITE1	Toscana
ITE2	Umbria
ITE3	Marche
ITE4	Lazio
ITF	SUD
ITF1	Abruzzo
ITF2	Molise
ITF3	Campania
ITF4	Puglia
ITF5	Basilicata
ITF6	Calabria
ITG	ISOLE
ITG1	Sicilia
ITG2	Sardegna
LT	**LIETUVA / LITHUANIA**
LT0	LIETUVA
LT00	Lietuva
LU	**LUXEMBOURG (GRAND-DUCHÉ)**
LU0	LUXEMBOURG (GRAND-DUCHÉ)
LU00	Luxembourg (Grand-Duché)
LV	**LATVIJA / LATVIA**
LV0	LATVIJA
LV00	Latvija
MT	**MALTA**
MT0	MALTA
MT00	Malta
NL	**NEDERLAND / NETHERLANDS**
NL1	NOORD-NEDERLAND
NL11	Groningen
NL12	Friesland (NL)
NL13	Drenthe
NL2	OOST-NEDERLAND
NL21	Overijssel
NL22	Gelderland
NL23	Flevoland
NL3	WEST-NEDERLAND
NL31	Utrecht
NL32	Noord-Holland
NL33	Zuid-Holland
NL34	Zeeland
NL4	ZUID-NEDERLAND
NL41	Noord-Brabant
NL42	Limburg (NL)
PL	**POLSKA/ POLAND**
PL1	REGION CENTRALNY
PL11	Lodzkie
PL12	Mazowieckie
PL2	REGION POLUDNIOWY
PL21	Malopolskie
PL22	Slaskie
PL3	REGION WSCHODNI
PL31	Lubelskie
PL32	Podkarpackie
PL33	Swietokrzyskie
PL34	Podlaskie
PL4	REGION POLNOCNO-ZACHODNI
PL41	Wielkopolskie
PL42	Zachodniopomorskie
PL43	Lubuskie
PL5	REGION POLUDNIOWO-ZACHODNI
PL51	Dolnoslaskie
PL52	Opolskie
PL6	REGION POLNOCNY
PL61	Kujawsko-Pomorskie
PL62	Warminsko-Mazurskie
PL63	Pomorskie
PT	**PORTUGAL**
PT1	CONTINENTE
PT11	Norte
PT15	Algarve
PT16	Centro (P)
PT17	Lisboa
PT18	Alentejo
PT2	Região Autónoma dos AÇORES
PT20	Região Autónoma dos Açores
PT3	Região Autónoma da MADEIRA
PT30	Região Autónoma da Madeira
RO	**ROMANIA**
RO1	Macroregiunea unu
RO11	Nord-Vest
RO12	Centru
RO2	Macroregiunea doi
RO21	Nord-Est
RO22	Sud-Est
RO3	Macroregiunea trei
RO31	Sud - Muntenia
RO32	Bucuresti - Ilfov
RO4	Macroregiunea patru
RO41	Sud-Vest Oltenia
RO42	Vest
SE	**SVERIGE / SWEDEN**
SE1	Östra Sverige
SE11	Stockholm
SE12	Östra Mellansverige
SE2	Södra Sverige
SE21	Småland med öarna
SE22	Sydsverige
SE23	Västsverige
SE3	Norra Sverige
SE31	Norra Mellansverige
SE32	Mellersta Norrland
SE33	Övre Norrland
SI	**SLOVENIJA / SLOVENIA**
SI0	SLOVENIJA
SI01	Vzhodna Slovenija
SI02	Zahodna Slovenija
SK	**SLOVENSKA REP. / SLOVAKIA**
SK0	SLOVENSKA REPUBLIKA
SK01	Bratislavsky kraj
SK02	Zapadne Slovensko
SK03	Stredne Slovensko
SK04	Vychodne Slovensko
UK	**UNITED KINGDOM**
UKC	NORTH EAST (ENGLAND)
UKC1	Tees Valley and Durham
UKC2	Northumberland and Tyne and Wear
UKD	NORTH WEST (ENGLAND)
UKD1	Cumbria
UKD2	Cheshire
UKD3	Greater Manchester
UKD4	Lancashire
UKD5	Merseyside
UKE	YORKSHIRE AND THE HUMBER
UKE1	East Yorkshire and Northern Lincolnshire
UKE2	North Yorkshire
UKE3	South Yorkshire
UKE4	West Yorkshire
UKF	EAST MIDLANDS (ENGLAND)
UKF1	Derbyshire and Nottinghamshire
UKF2	Leicestershire, Rutland, Northamptons.
UKF3	Lincolnshire
UKG	WEST MIDLANDS (ENGLAND)
UKG1	Herefordshire, Worcestershire, Warwick.
UKG2	Shropshire and Staffordshire
UKG3	West Midlands
UKH	EAST OF ENGLAND
UKH1	East Anglia
UKH2	Bedfordshire and Hertfordshire
UKH3	Essex
UKI	LONDON
UKI1	Inner London
UKI2	Outer London
UKJ	SOUTH EAST (ENGLAND)
UKJ1	Berkshire, Buckinghamshire and Oxfor.
UKJ2	Surrey, East and West Sussex
UKJ3	Hampshire and Isle of Wight
UKJ4	Kent
UKK	SOUTH WEST (ENGLAND)
UKK1	Gloucestershire, Wiltshire, Bristol
UKK2	Dorset and Somerset
UKK3	Cornwall and Isles of Scilly
UKK4	Devon
UKL	WALES
UKL1	West Wales and The Valleys
UKL2	East Wales
UKM	SCOTLAND
UKM2	Eastern Scotland
UKM3	South Western Scotland
UKM5	North Eastern Scotland
UKM6	Highlands and Islands
UKN	NORTHERN IRELAND
UKN0	Northern Ireland

Source: Own illustration based on EUROSTAT.

Appendix C: Classification of Mechanical Engineering in IPC

F	**Section F - Mechanical engineering; lighting; heating; weapons; blasting**
F01	Machines or engines in general; engine plants in general; steam engines
F02	Combustion engines; hot-gas or combustion-product engine plants
F03	Machines or engines for liquids; wind, spring, weight, or miscellaneous motors; producing mechanical power or a reactive propulsive thrust, not otherwise provided for
F04	Positive-displacement machines for liquids; pumps for liquids or elastic fluids
F15	Fluid-pressure actuators; hydraulics or pneumatics in general
F16	Engineering elements or units; general measures for producing and maintaining effective functioning of machines or installations; thermal insulation in general
F17	Storing or distributing gases or liquids
F23	Combustion apparatus; combustion processes
F25	Refrigeration or cooling; combined heating and refrigeration systems; heat pump systems; manufacture or storage of ice; liquefaction or solidification of gases
F26	Drying
F27	Furnaces; kilns; ovens; retorts
F28	Heat exchange in general

Source: Own illustration based on EUROSTAT (selected IPC of F classes only).

Appendix D: Classification of Biotechnology in IPC

IPC codes	Definition of Biotechnology
A01H 1/00	Processes for modifying genotypes
A01H 4/00	Plant reproduction by tissue culture techniques
A61K 38/00	Medicinal preparations containing peptides
A61K 39/00	Medicinal preparations containing antigens or antibodies
A61K 48/00	Medicinal preparations containing genetic material which is inserted into cells of the living body to treat genetic diseases; Gene therapy
C02F 3/34	Biological treatment of water, waste water, or sewage: characterised by the microorganisms used
C07G 11/00	Compounds of unknown constitution: antibiotics
C07G 13/00	Compounds of unknown constitution: vitamins
C07G 15/00	Compounds of unknown constitution: hormones
C07K 4/00	Peptides having up to 20 amino acids in an undefined or only partially defined sequence; Derivatives thereof
C07K 14/00	Peptides having more than 20 amino acids; Gastrins; Somatostatins; Melanotropins; Derivatives thereof
C07K 16/00	Immunoglobulins, e.g. monoclonal or polyclonal antibodies
C07K 17/00	Carrier-bound or immobilised peptides; Preparation thereof
C07K 19/00	Hybrid peptides
C12M	Apparatus for enzymology or microbiology
C12N	Micro-organisms or enzymes; compositions thereof propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media
C12P	Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition or to separate optical isomers from a racemic mixture
C12Q	Measuring or testing processes involving enzymes or micro-organisms; compositions or test papers therefor; processes of preparing such compositions; condition-responsive control in microbiological or enzymological processes
C12S	Processes using enzymes or micro-organisms to liberate, separate or purify a pre-existing compound or composition processes using enzymes or micro-organisms to treat textiles or to clean solid surfaces of materials
G01N 27/327	Investigating or analysing materials by the use of electric, electro-chemical, or magnetic means: biochemical electrodes
G01N 33/53*	Investigating or analysing materials by specific methods not covered by the preceding groups: immunoassay; biospecific binding assay; materials therefore
G01N 33/54*	Investigating or analysing materials by specific methods not covered by the preceding groups: double or second antibody: with steric inhibition or signal modification: with an insoluble carrier for immobilising immunochemicals: the carrier being organic: synthetic resin: as water suspendable particles: with antigen or antibody attached to the carrier via a bridging agent: Carbohydrates: with antigen or antibody entrapped within the carrier
G01N 33/55*	Investigating or analysing materials by specific methods not covered by the preceding groups: the carrier being inorganic: Glass or silica: Metal or metal coated: the carrier being a biological cell or cell fragment: Red blood cell: Fixed or stabilised red blood cell: using kinetic measurement: using diffusion or migration of antigen or antibody: through a gel
G01N 33/57*	Investigating or analysing materials by specific methods not covered by the preceding groups: for venereal disease: for enzymes or isoenzymes: for cancer: for hepatitis: involving monoclonal antibodies: involving limulus lysate
G01N 33/68	Investigating or analysing materials by specific methods not covered by the preceding groups: involving proteins, peptides or amino acids
G01N 33/74	Investigating or analysing materials by specific methods not covered by the preceding groups: involving hormones
G01N 33/76	Investigating or analysing materials by specific methods not covered by the preceding groups: human chorionic gonadotropin
G01N 33/78	Investigating or analysing materials by specific methods not covered by the preceding groups: thyroid gland hormones
G01N 33/88	Investigating or analysing materials by specific methods not covered by the preceding groups: involving prostaglandins
G01N 33/92	Investigating or analysing materials by specific methods not covered by the preceding groups: involving lipids, e.g. cholesterol

* Those IPC codes also include subgroups up to one digit (0 or 1 digit). For example, in addition to the code G01N 33/53, the codes G01N 33/531, GO1N 33/532, etc. are included.

Source: Own illustration; data: OECD & EUROSTAT (http://www.biotechnologie.de/).

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