Knowledge spillovers within regional networks of innovation and the contribution made by public research

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Abstract

Although knowledge spillovers are analyzed not only on the basis of aggregate data but also with micro data, it has not yet proven possible to measure knowledge transfer directly. Nonetheless knowledge transfer in 23 German innovation networks (almost 600 participants) can be observed. Following the pattern of regional systems of innovation (RIS) a distinction has been made between certain groups (e.g. manufacturing and service companies, universities, non-university research organisations).

The first empirical part of the paper focuses on the determinants of knowledge spillovers within these innovation networks. An analysis is made, for example, of the respect to which the participants' network experience or strength of ties have a relevance regarding knowledge transfer. The questions of whether network characteristics (e.g. coherence of the network) affect knowledge transfer and whether there is a link between division of labour and knowledge transfer are also examined.

In the second part of the paper empirical results are presented that demonstrate that it is universities that are adding the most information and the most knowledge within the common process of innovation. The winners in this knowledge exchange are the manufacturing companies. Furthermore the results confirm the assumption that public research has an "antenna function" (boundary-spanning function) for the companies due to its integration into the international scientific community.

key words: innovation networks, spillovers, public research, regional innovation systems
JEL: D83, D85, L14, O32, R58

1. Introduction

Regarding the innovation process networks can be seen as being a superior mechanism of co-ordination compared to coordination by hierarchy or by markets:[1]

(1) The dynamics of technological progress, technological complexity and the rising costs of R&D result in a need to incorporate resources and capacities external to the firm, these being of much greater importance to small firms than to larger companies (Link and Rees 1990; Acs, Audretsch et al. 1994; Audretsch and Vivarelli 1994). (Becker and Dietz 2004) have found that external sources attracted by R&D-collaboration influence the probability that new products will be developed. They also found that the likelihood of realizing product innovation rises with the number of parties involved in co-operation.

(2) Where innovative division of labour by markets has to be coordinated there are special problems regarding knowledge transfer in the context of innovation activities: incomplete contracts, "thin markets" for innovative inputs and a risk of unintended knowledge abandonment (Fritsch 2001). Beyond that in the innovation process much tacit knowledge must frequently be exchanged, knowledge that is difficult to codify and which, if generated in the private sector, is often too specialized for publication. Therefore personal contacts are necessary for the acquisition of this kind of knowledge, face-to-face contact being especially helpful, at least at the beginning of a new collaboration. Furthermore, intensive face-to-face-contacts are an efficient way to accelerate the creation of trust, something that is indispensable in the exchange of sensitive information.

These conditions explain why, besides the cultural proximity or social proximity (Breschi and Lissoni 2003), the spatial proximity (Fritsch 2003) of co-operation partners is beneficial to the process of knowledge exchange. This is one part of the phenomenon whereby innovation processes have a pronounced regional dimension (Feldman 1994; Scott 1996; Fritsch 2004).

Networks involve more than bilateral or multilateral co-operation. The relevant parties collaborate on a given project and networks consist of this co-operation plus an indefinite quantity of possible relations between units not yet working together. Since it is often very difficult and costly to find suitable new partners there is a good possibility that co-operation within networks will result in access to a pool of trustworthy potential new partners. The collaborative venture, if embedded in a network context, fosters trust since opportunistic behaviour would damage one's standing within the network (reputation), as demonstrated by (Kauffeld-Monz and Daskalakis 2005)). The implication is that one does not have to develop

[1] See Powell, W. W. (1990). "Neither Market nor Hierarchy: Network Forms of Organization." Research in Organizational Behaviour **12**: 295-336.

such extensive instruments of control with regard to the relationship (governance by trust). To that extent networks are a suitable instrument for reducing transaction-cost.

With regard to the role of public research in innovation processes one can identify at least four functions: (1) generation of new knowledge; (2) accumulation of this knowledge and of knowledge originating elsewhere; (3) transmission and transfer of all knowledge accumulated. Within the discussion of mode2[2] of the innovation process a further function is increasingly attributed to public research: (4) the conversion of research results in innovation.
These functions also become effective within networks of innovation, although this has never been directly or empirically verified . This study in particular examines functions 2 and 3 in more detail. Special emphasis is placed on the hypothesis that science has an "antenna function" (Fritsch and Schwirten 1998; Revilla-Diez 2002) for local business on account of its integration into the international scientific community. Beyond that an analysis is made of which factors – independent of the groups of participants - play an important role due to the range of knowledge exchange (e.g. strength of ties, coherence of the network, mutual trust, network experience).

The paper is structured as follows: Section 2 gives a brief insight into the connections between science and the economy, as generated by empirical work. Section 3 outlines the form that analysis will take, sets up some hypotheses and introduces the database. In section 4 results are presented. Finally I draw conclusions in section 5.

2. Science-Business links

Policy measures with regard to the transfer of knowledge from science to business have enormously affected the links between the public and private spheres (Hall, Link et al. 2000; Cohen, Nelson et al. 2002; Fontana, Geuna et al. 2004). The increased relevance of science-business co-operation is based on both the multidisciplinary character of the research and a stronger dependence of technological advances on science, which is also becoming apparent in the increasing role of R&D due to the generation of new products (Grupp and Schmoch 1992; Rosenberg and Nelson 1994). Thus it is hardly surprising that knowledge flow between

[2] The increasingly networked mode of knowledge production, in which the rigid borders between disciplines, interest positions and groups of participants dissolve; see e.g. Etzkowitz, H. and L. Leydesdorff (2000). "The dynamics of innovation: from National Systems and Mode 2 to a Triple Helix of university-industry-government relations." Research Policy **29**: 109-123.; Gibbons, M., C. Limoges, et al. (1994). The new production of knowledge: The dynamics of science and research in contemporary societies. London, Sage Publications.

science and business increased threefold in the U.S. between the end of the '80s and the mid '90s (Narin, Hamilton et al. 1997).

The results of analyses based on aggregate data confirm in principle the relevance of publicly-funded research to the economy (Jaffe 1989; Acs, Audretsch et al. 1992). Yet this kind of analysis does not provide useful information on how this scientific knowledge is channelled into the economy or who the agents and recipients of this knowledge are.

We know from studying surveys, for example, what kind of firms are co-operating with public research: they are usually large companies which operate their own R&D departments (Fritsch and Lukas 2001; Mohnen and Hoareau 2002; Laursen and Salter 2003; Busom and Fernández-Ribas 2004).[3] Moreover, they are likely to have a "Gatekeeper" who is screening the environment relevant for innovation activity (Fritsch and Lukas 2001). The *number* of R&D collaborations with public research, however, is affected by the relative size measured by R&D employment (Fontana, Geuna et al. 2004). These findings result from a certain level of "absorptive capacity" that is necessary if the value of new information is to be recognized, assimilated and applied for commercial ends (Cohen and Levinthal 1990).

From the firms' perspective, however, public research organisations are never seen as the most important sources during the innovation process, neither at the ideas stage nor at the completion phase of innovation (Cohen, Nelson et al. 2002; Fontana, Geuna et al. 2004). Nevertheless, many innovations – if they had gone ahead at all - would not have been realized without close collaboration with public science (Mansfield 1991; Beise and Stahl 1999). So it is not surprising that (Broström and Lööf 2004) point out that for Swedish firms knowledge transmission between universities and industry has a positive affect on both innovative input and innovative output (measured by the propensity to apply for a patent and the amount of innovation sales per employee).

It has been demonstrated that many achievements of public research establishments can be attributed to their immediate, spatial surroundings (Jaffe 1989; Acs, Audretsch et al. 1992; Varga 2000; Fritsch and Schwirten 2002).[4] Spatial proximity turns out to be less important for basic research than it is for applied R&D (Mansfield 1991; Mansfield 1995). Yet even the best of publicly-funded science is only of benefit to the location if it is spatially embedded in

[3] German studies found out that approximately 40% of firms have contacts to publicly-funded research establishments but only a small number of firms are cooperating in the phase of product development with external partners (Blume, L: and O. Fromm (2000); A. Eickelpasch and M. Kauffeld et al. (2001); G. Leßmann and U. Rosner (2004).

[4] That is impressively illustrated by famous case studies: Silicon Valley, Route 128, Cambridge Phenomenon.

a well developed economic environment (Varga 2000).[5] However, if we make a comparative evaluation instead of an absolute one a milder conclusion emerges (Benneworth and Charles 2004). The fact that a dominating firm in a regional innovation network is losing its central position to the local university may be regarded as a relatively extreme phenomenon, one that might be not untypical of the transformation process in the eastern part of Germany (Cantner and Graf 2004).

University partnerships especially stimulate new ideas and are instrumental in creating and bringing to the market radical innovations (Belderbos, Carree et al. 2004). But the processes universities are involved in are also directed towards completing existing R&D projects (Cohen, Nelson et al. 2002). Regional differences in the focus placed on one or the other activity depend on the socio-economic structure of a region and the quality of the regional innovation system in which public research organization is embedded (Fritsch 2004).

An interesting point of view is adopted by (Boucher, Conway et al. 2003). They analysed the degree of university involvement in their location and came to following conclusions: Universities serving a peripheral region as single-player have the highest degree of involvement in their location. However, these are the regions that suffer most of all from graduate migration to the more developed regions. Secondly, competition between universities for local institutional dominance reduces their involvement in the region. Finally, traditional universities feel more compelled to maintain their position within the international hierarchy than to cultivate their activities in their own locality.

A lot of analyses are made of the ways in which knowledge stemming from public research frequently spills over to business. The monitored channels of transfer range from publications - a very impersonal channel - and collaborative research to the migration of scientists to business e.g. via spin-offs. Publicly-funded research organizations sometimes play a major role in the location decisions of these new firms - especially in the case of scientific spin-offs, since proximity to the incubator is important for the firms' development, at least in the initial phase of development. However, this proximity usually loses its importance over time (Dahlstrand 1999).

The channels of transfer are many and varied, which explains our ignorance of the comparative importance of these channels. Furthermore, we know next to nothing about their

[5] The study demonstrated that identical amounts of university research spending can be associated with dramatically different levels of innovation output, depending on the concentration of economic activities. That tallies with what Feldman (1994) suggested in her study of the regional effects of John Hopkins University: no "critical mass" of high-tech companies, lack of service providers, lack of entrepreneurial culture and venture capital.

reciprocal effects. In this study I will concentrate on the transfer channel of R&D-co-operation within a more comprehensive context: a regional network of innovation.

3. Data and design of the analyses

3.1 Data

As a way of strengthening the innovation system and reducing what is seen as one of the weaknesses of the new, post-1990 federal states of Germany,[6] the InnoRegio-Program was launched in 2000 by the bmb+f (Federal Ministry for Education and Research)[7]. Not limited to certain technologies or industries, the bmb+f is set to provide approx. € 250 million of support to 23 networks until 2006 (selected by contest)[8]. The networks are very heterogeneous concerning their goals, and the industries and technologies involved (Biotechnology, medical technology, and owing to the respective number of participants (Eickelpasch, Kauffeld et al. 2001). Commonly it is in the networks, however, that participants from research and business collaborate with one another. One assumes that closer cooperation between them will strengthen a firm's capacity for innovation and thus give rise to stronger economic growth and employment (Kauffeld, Eickelpasch et al. 2002).
This funding initiative was observed over the last 5 years by an evaluation team (Kauffeld and Wurzel 2003). It was possible to gather extensive data on approximately 600 participants (relating to the performance of the companies, the extent to which information and knowledge were exchanged, network cohesion, strength of ties and much more). The differentiation of the surveyed groups of participants was similar to that in the RIS research, making transfer of the results to regional innovation systems possible.

The response rate of more than 80% and the uniform and common reference system used by the participants who responded – the respective innovation network – can be seen as enhancing the value of the data.

Included variables: (insert table 1 here)

[6] e.g. innovation efficiency, DIW, IfW, et al. (2003). "Zweiter Fortschrittsbericht wirtschaftswissenschaftlicher Institute über die wirtschaftliche Entwicklung in Ostdeutschland." DIW-Wochenbericht(47/03).
[7] For more details see: www.unternehmen-region.de
[8] For an economic evaluation of this promotion philosophy see Eickelpasch, A. and M. Fritsch (2005). "Stimulating the Division of Innovative Labour by Competition for R&D Subsidies - A new Approach in German Innovation Policy." Research Policy **34**.

3.2 Design of the Analyses

In the first part of empirical section factors that influence the variety of knowledge received are analysed by regression. From former studies we know of the (lock-in) risk of strong ties (Granovetter 1973; Grabher 1993) but I will assume that strong ties are a positive factor in the first phase of an innovation network: Ties have to be strong because a considerable amount of knowledge has to be exchanged. Furthermore, close contacts are helpful for generating the level of trust that is indispensable if knowledge is to be given away that is sensitive to the organization, especially to firms. Leaving aside the co-operative ventures (joint projects involving 2 to 10 partners) I argue that the cohesion or lack of cohesion in a network is a crucial factor in assessing knowledge exchange.

Besides the characteristics relating to ties I will analyse the influence of the R&D collaborative experience in general.[9] I also examine the effects of innovation network experience due to the absorption of knowledge within a process of innovation that is embedded in a more extensive context.[10] I assume that it is more efficient to have some experience of handling such networks (for the most part tacit knowledge) on account of the range of knowledge one can extract.

⇒ Hypothesis 1: Experience gathered in collaborations or innovation networks is positively connected to the amount of knowledge attracted within the network

⇒ Hypothesis 2: Strong ties have a positive effect on knowledge exchange

⇒ Hypothesis 3: Network coherence has a positive influence on knowledge exchange

In the second part I will analyse the relevance of publicly-funded research to the process of knowledge exchange. From the givers' perspective I intend to show the extent to which universities and non-university research organizations contribute to knowledge exchange. Moreover, the "antenna function" of public research is being examined empirically for the first time.[11] In addition the statement regarding "absorptive capacity" is examined for its application to the companies.

⇒ Hypothesis 4: It is in the innovation process that public research is adding most knowledge

⇒ Hypothesis 5: Public research has an "antenna function" for the private sector due to the role it plays in the international scientific community

[9] measured by frequency of co-operation in basic research, product development and process development on a scale of 5 (not at all/../../../often).

[10] Queried directly

[11] measured by frequency of R&D co-operation and the specification of spatial classification (intra-regional or supra-regional)

⇒ Hypothesis 6: The benefit experienced by companies in terms of increased knowledge is the largest benefit, when compared to those experienced by the other groups, and it corresponds to their absorptive capacity.

Finally a set of further hypotheses are tested separately:
Empirical analyses do not usually distinguish between knowledge and information. If a theoretical distinction is made, then it can be demonstrated that the transfer of tacit knowledge requires personal contacts and/or more intensive face-to-face contacts (Noteboom 2001). However, this paper argues that intensive contacts are crucial not only to the transfer of tacit knowledge but also to the screening and transfer of useful information. In order for information to be really useful to the recipient, the information provider must know exactly what the needs of the recipient are. The usefulness of the received information thus depends on the intensity of the contact between information transmitters and receivers. There will not necessarily be an increase in the amount of information exchanged but it will be more purposeful.

⇒ Hypothesis 7: Intensive contacts are crucial not only for the transfer of tacit knowledge but also for the transfer of information

⇒ Hypothesis 8: Increasing division of labour within the process of innovation involves an increase in knowledge exchange.

One can assume that the complementary character of partners' respective banks of knowledge diminishes over time. If lock-ins (associated with the evaporation of cognitive distance) are to prevented it is important to integrate new partners into the innovation network (Kauffeld-Monz and Daskalakis 2005).

⇒ Hypothesis 9: The influx of new partners has a positive effect on the appropriation of knowledge.

4. Results

Network experience, strength of ties and network coherence

Only 30% of participants have experience of innovation networks even though about 60% collaborate in R&D. Thus, in spite of a high affinity for collaboration in the new, post-1990 federal states of Germany, involvement in more comprehensive processes of innovation is a new thing for most partners. It can therefore be said that programs that foster those multi-measure/multi-agent innovation activities and allow accession to complex and sophisticated networks generally make sense.

(insert table 2 here; see appendix)

Model 1 points out that participants' network experiences have no significant effect on companies but is a help to scientific partners due to the volume and diversity of new, incoming knowledge. It is particularly the experience had collaborating on process development that affects the amount of knowledge received from network partners. However collaborative experience in basic research tends to decrease the volume of knowledge received from partners.

In model 2 one can see confirmation of hypothesis 2: strong ties can be seen as being an important factor in knowledge exchange at the initial stages of a collaboration. Yet a small difference can be observed if we consider the results for the firms taken by themselves (Sample B). The intensity of contacts plays a minor role in the firms' absorption of knowledge but they need a higher level of trust if they are to exchange a similar amount of knowledge.

Results in the respective third columns indicate the influence of the network's characteristics. Shared visions and norms as well as a real identification with the network are factors that contribute to a more rapid circulation of knowledge within innovation networks. These findings give an impression of the importance of the networks' coherence.

The final column verifies the assumption that the absorptive capacity of firms increases with the size of the firm.

The "antenna function" of public research and its contribution to knowledge exchange

At first glance one can see in Graph 1 (appendix) that universities give most information and knowledge to their network partners. On average, however, other scientific groups (non-university research organizations, An-Institutes, private research companies) do not add as much as the firms. Especially the service firms can be seen as important medium for knowledge spillovers due to its “antenna function” on basic research.[12] If we take a look at the balance of information and knowledge (disparities between giving and receiving) it becomes clear that manufacturing firms make up the group that benefits most from exchange. Moreover different attraction levels are discernible when “absorptive capacity” is considered:

(insert Graphs 1 and 2 here)

The findings relating to the „antenna function“ (table 3) of public science are somewhat surprising. Firstly, regarding only the existence of partnerships at supra-national level, it is not of importance due to the amount of knowledge given to network partners. With respect to the frequency of supra-regional collaborations in R&D, however, it is shown that for the universities the antenna becomes effective, although this does not apply in the case of non-university research organizations! Moreover I have discovered that a further group is enormously important to any consideration of the “antenna function”: the private research companies.[13]

(insert Table 3 and Graph 3 here)

Contact intensity and information exchange

The data allows for a distinction to be made between knowledge and information. Following a further hypothesis referred to in Section 3 I found strong evidence for a positive correlation between information exchange and intensity of contacts. Thus it can be said that information exchange requires intensive contact just as the exchange of tacit knowledge does.

(insert Graph 4 here)

Division of labour, new partnerships and knowledge exchange

Finally the assumption holds that increasing division of labour leads to a rise in knowledge exchange (Graph 5). An increase in the amount of technical support given to network partners results in real specialisation. If the effect had is considerable then partners’ support for each other is almost as extensive as the support they receive from their own organisation. Further findings support the hypothesis that new partners are needed to appropriate new knowledge (Graph 6).

[12] That, however, turns out to be not significant, probably by reason of the cases’ small number.

5. Conclusions

For 70% of the networks' members acting within regional innovation networks is a new experience although approximately 60% of members have R&D partners who are not part of the firm and/or organization. Thus, in spite of a high affinity for collaboration in the newer German federal states, involvement in more comprehensive processes of innovation is a new experience for most of the partners. The results generated in this analysis indicate a higher level of knowledge absorption for groups with network experience. It generally makes sense, therefore, to organise support programmes that foster those multi-measure/multi-agent innovation activities and allow accession to complex and sophisticated networks.

For the exchange both of knowledge and of information strong ties are useful at least in the developmental phase of networks and collaborations. Indications are, however, that the weakness of strong ties (Granovetter 1973; Grabher 1993) reveals itself at a later stage in the network process; during the consolidation phase the level of trust is much more likely to be the crucial factor in the survival of a given collaboration than is the amount of knowledge received from partners over a period of years. These findings highlight the general trade-off between short-term benefits of a reduction in transaction cost (since strong ties and trust even developed) and the long-term chance to absorb more external knowledge within new partnerships. Knowledge exchange is improved not only by the strength of ties in particular but also by improvements in networks' coherence. This effect is even more pronounced for the firms than it is for the remaining participants.

If a distinction has been made between certain groups, following the pattern of regional systems of innovation, it is above all universities that give most knowledge to their network partners. Also the service firms have shown themselves to be the partners with whom collaboration involves an amount of knowledge exchange above average. Thus, my results partly correspond to findings, that knowledge intensive service providers can be seen as important medium for knowledge spillovers (Leydesdorff and Fritsch 2005): (1) Compared to other groups of participants they add more knowledge and information to the process of innovation. (2) If operating more frequently on basic research at an inter-regional level, they transfer more knowledge to the network partners ("antenna function"). This "antenna function" also becomes apparent to the universities, An-Institutes, and private research

[13] These are a feature of the research landscape in Germany's new federal states.

companies but surprisingly not to the non-university research organizations at a significant level. It may be, therefore, that non-university research organizations do not consider their contribution correctly or they are not so much involved as the other scientific participants.

Fortunately most of all knowledge arrives to the manufacturing companies, regarding the absolute as well as the relative return. According to (Cohen and Levinthal 1990) the absorptive capacity of larger firms - measured by knowledge appropriation - is significantly higher than knowledge absorption in small firms.

In principle the findings can be regarded as being transferable from regional innovation networks to regional innovation systems. This applies in particular to the behaviour-conditioned results. With regard to the effectiveness of the "antenna function" of science, however, it may rather be that findings are transferable to those regions with similar socio-economic characteristics, the reason being that this antenna function conceivably becomes effective where firms engage less frequent in supra-regional collaborations.

Although division of innovative labour was increasing and resulting in a high degree of spillovers actually we do not know whether it has occurred sufficiently to bring economic benefits. Moreover, if reference to Vargas' findings (2000) we can not be sure if sufficient complementary regional inputs and assets are available for successful market realization. By way of recapitulation, however, one may say that, in principle, regional innovation networks function according to ideal-typical conceptions.

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Appendix:

Table 1: list of variables

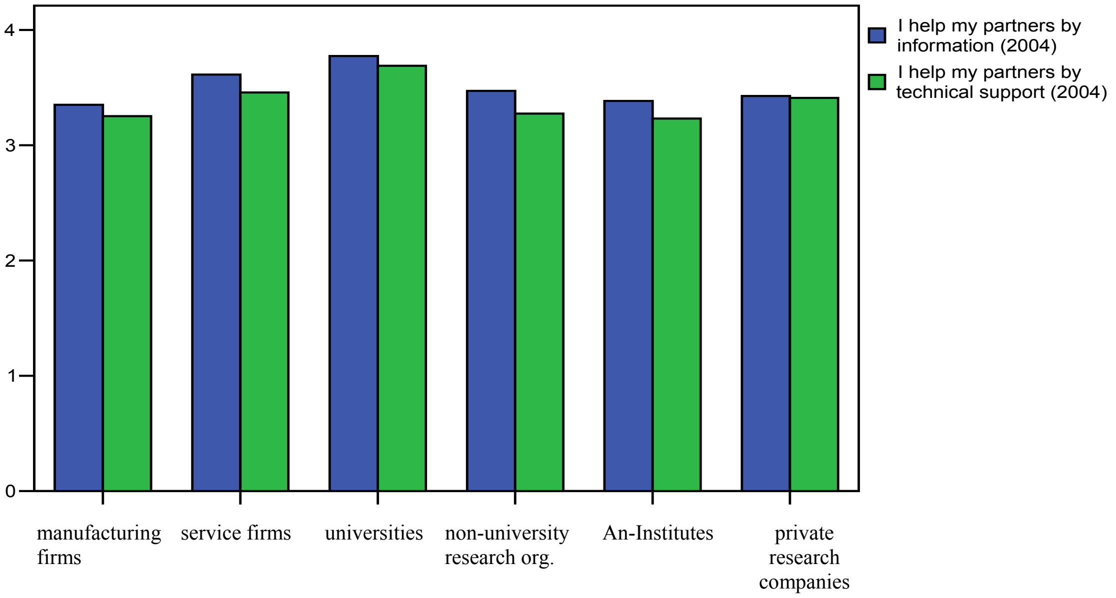
variable	description	measurement
regression analysis (table 2)		
KNOW	received knowledge	1 = very few 3 = moderately 5 = very much
NW-EXP	network experience (direct queried)	1 = yes; 2 = no
CO_EXPBR	co-operation experience in basic research	1 = not at all 3 = at times 5 = frequently
CO_EXPPDD	co-operation experience in product development	
CO_EXPPCD	co-operation experience in process development	
COUPLE_PROJ	coupled project	1 = yes ; 2 = no
DEP-PRO	project dependence of other partners	1 = not at all 3 = partly 5 = completely
CON_INT	the partners' intensity of contact	1 = not at all 3 = partly 5 = completely
TRUST	fairness and trust between the partners	
COM_NORMS	common norms and values	
COM_VISION	common vision	
IDENT	identity with the network	
FIRM_SIZE	size of the firms by size range	1 = up to 10 employees 3 = 5 = 500 und above
Universities' contribution and "antenna function" analysis		
Received information/ knowledge	Information/technical support received from network partners	1 = very few 2 = few 3 = partly 4 = much 5 = very much
Given information/technical support	I was helping partners by information/technical support	
Co-operation activity on product development	How often do you co-operate on product development? Specification: Partner from outside the region among them?	1 = not at all 3 = sometimes 5 = often
Further analyses		
Division of labour benefits	Advantage of specialization (due to the co-operation activity within the network)	1 = does not apply 2 = applies partly 5 = applies fully
New partner benefits	I found new partners for R&D (due to the co-operation activity within the network)	

Table 2: Regression summary: level of technical support received from partners

	Sample A (all)				Sample B (firms only)			
model	1	2	3	4	1	2	3	4
constant	3,464*** (12,8)	0,384 (1,235)	1,415*** (6,679)	0,193 (0,459)	3,389*** (9,479)	0,447 (1,093)	1,199*** (4,202)	-0,242 (-4,15)
NW_EXP	-0,238** (-0,94)			-0,088 (-0,858)	-0,164 (-1,148)			0,036 (0,247)
CO_EXPBR	-0,87** (-2,416)			-0,061* (-1,760)	-0,080* (-1,737)			-0,064 -1,409)
CO_EXPPDD	0,085** (0,035)			0,013 (0,336)	-0,010 (-0,191)			0,014 (0,250)
CO_EXPPCD	0,138*** (3,442)			0,101*** (2,590)	0,214*** (4,048)			0,148*** (2,834)
COUPLE_PROJ		0,323*** (2,758)		0,274** (1,829)		0,368** (2,208)		0,283 (1,531)
DEP-PRO		0,092** (2,543)		0,065* (1,698)		0,095** (2,025)		0,048 (0,931)
CON_INT		0,258*** (4,708)		0,213*** (3,464)		0,102 (1,451)		-0,013 (-0.162)
TRUST		0,315*** (5,541)		0,191*** (2,864)		0,438*** (5,856)		0,235** (2,492)
COM_NORMS			0,249*** (4,847)	0,107* 1,829)			0,273*** (4,011)	0,131 (1,409)
COM_VISION			0,122** (1,962)	0,081 (1,268)			0,151** (1,988)	0,115 (1,455)
IDENT			0,209*** (3,272)	0,090 (1,327)			0,222*** (2,758)	0,157* (0,1930)
FIRM_SIZE								0,179*** (3,073)
num. of observ.	544	549	537	483	325	323	314	255
R^2	0,06	0,17	0,16	0,23	0,05	0,18	0,18	0,27

* indicates significance at 10% level ** indicates significance at 5% level *** indicates significance at 1% level
t-value between brackets

Graph 1: Received as well as contributed information and knowledge, by groups (means)



Graph 2: Balance of information and knowledge, by groups (means)

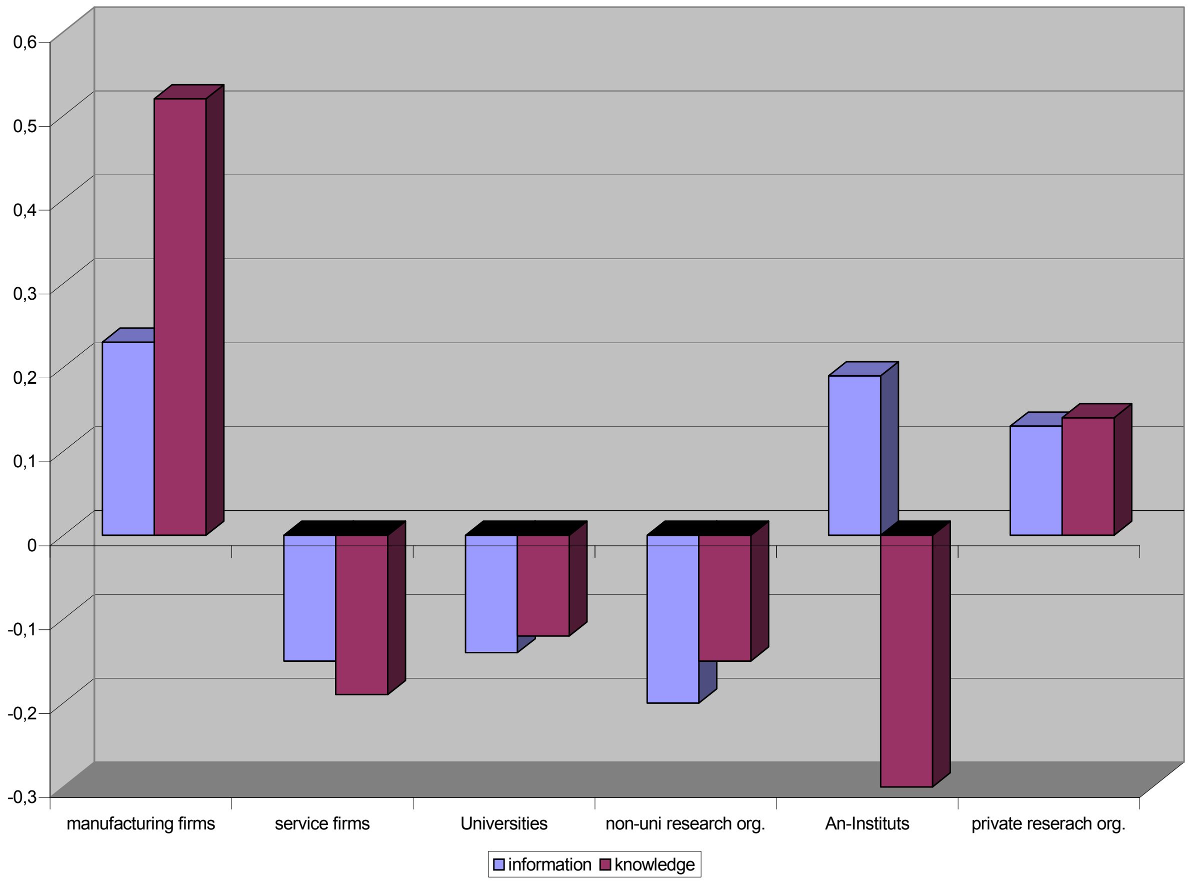
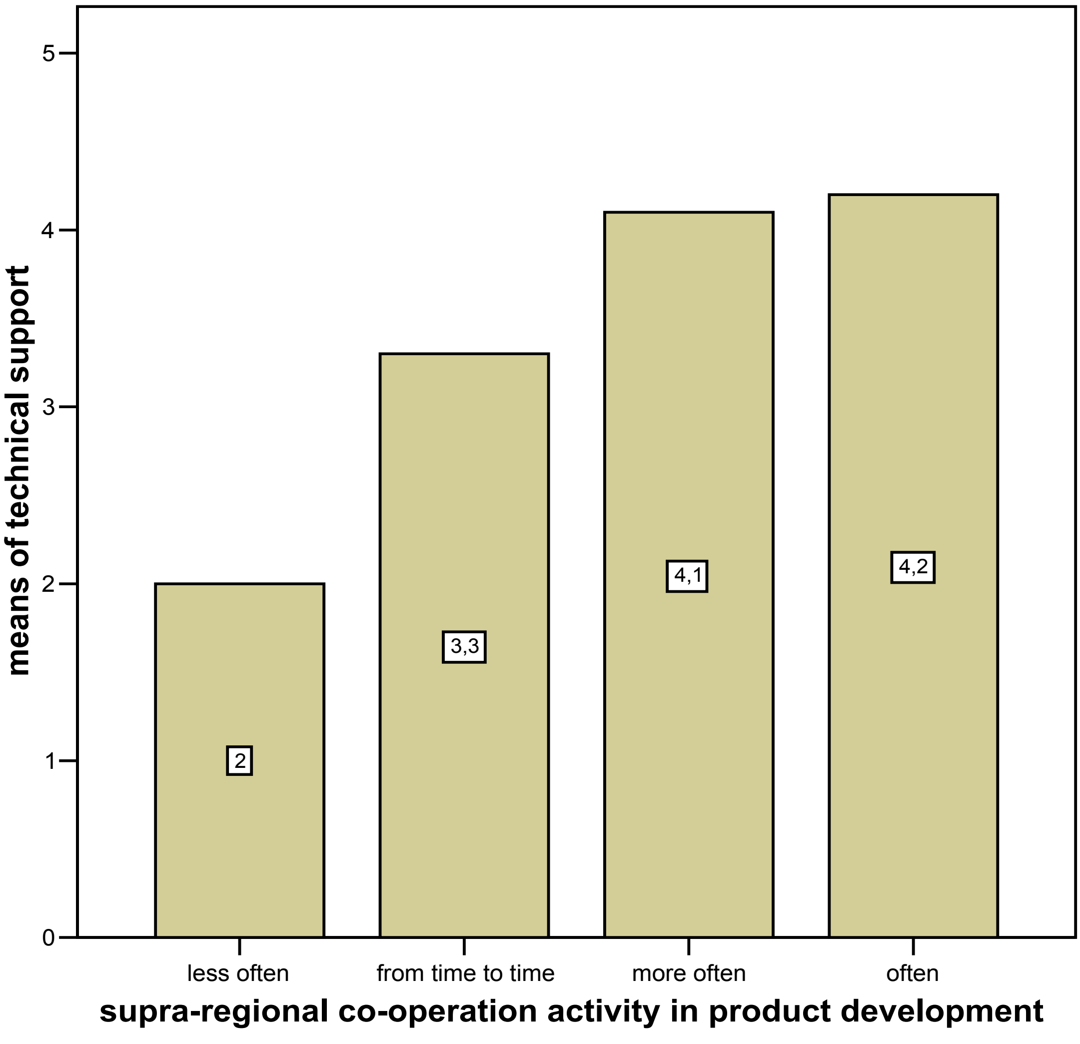


Table 3: importance of the "antenna function", by groups (correlation coefficients)

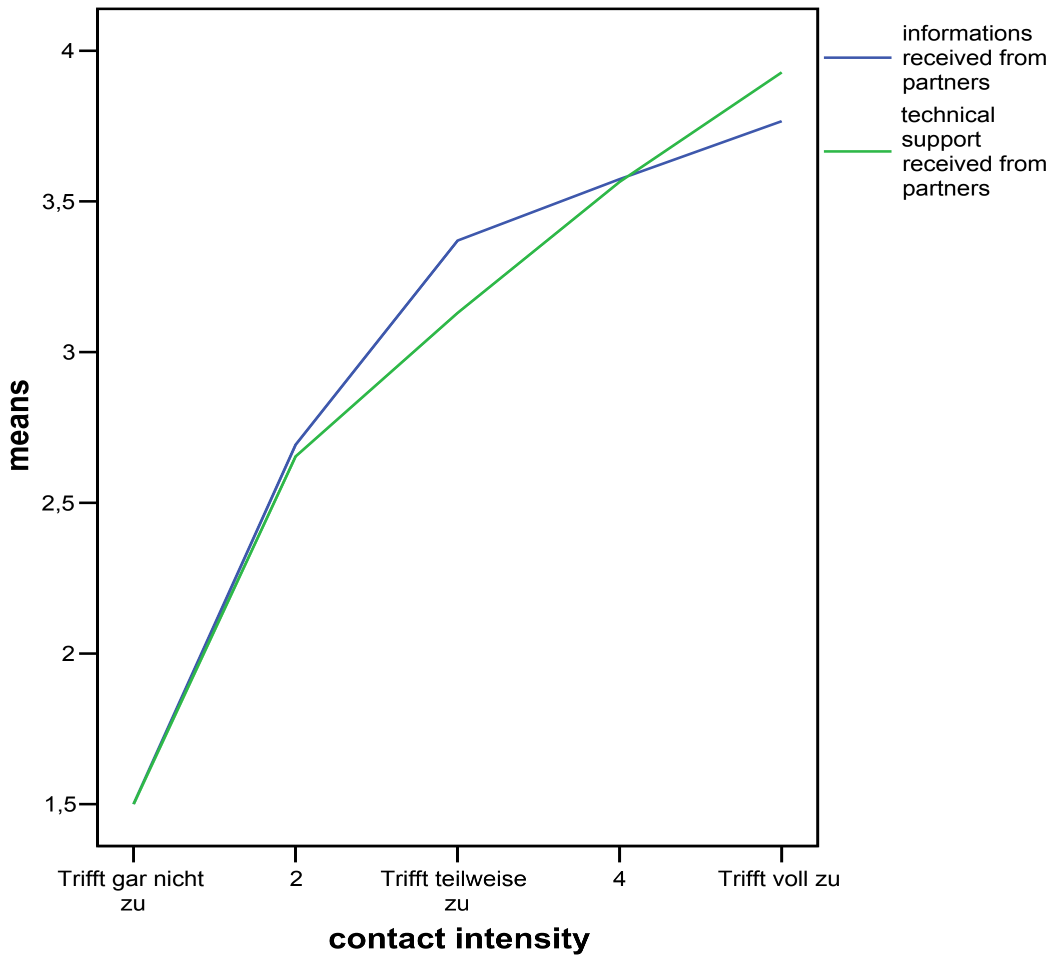
	dependent variable: technical support given to partners					
	basic research		product development		process development	
	1	2	1	2	1	2
manufacturing firms	-	0,70 (47)	-	0,105 (72)	-	0,112 (63)
service firms	-	0,262 (29)	-	-0,061 (37)	-	0,009 (37)
universities	-	0,057 (64)	-	0,468*** (47)	-	0,310 (39)
non-university research org.	-	0,165 (28)	-	0,264 (19)	-	0,227 (20)
An-Institutions	-	0,0 (10)	-	0,542* (11)	-	0,624 (8)
private research (e. V.)	-	-0,007(40)	-	0,465*** (37)	-	0,490*** (34)

1 = supra-regional co-operations (yes/no); 2 = in case of 1= yes: frequency of co-operation; (N)
indicates significance at 10% level ** indicates significance at 5% level *** indicates significance at 1% level

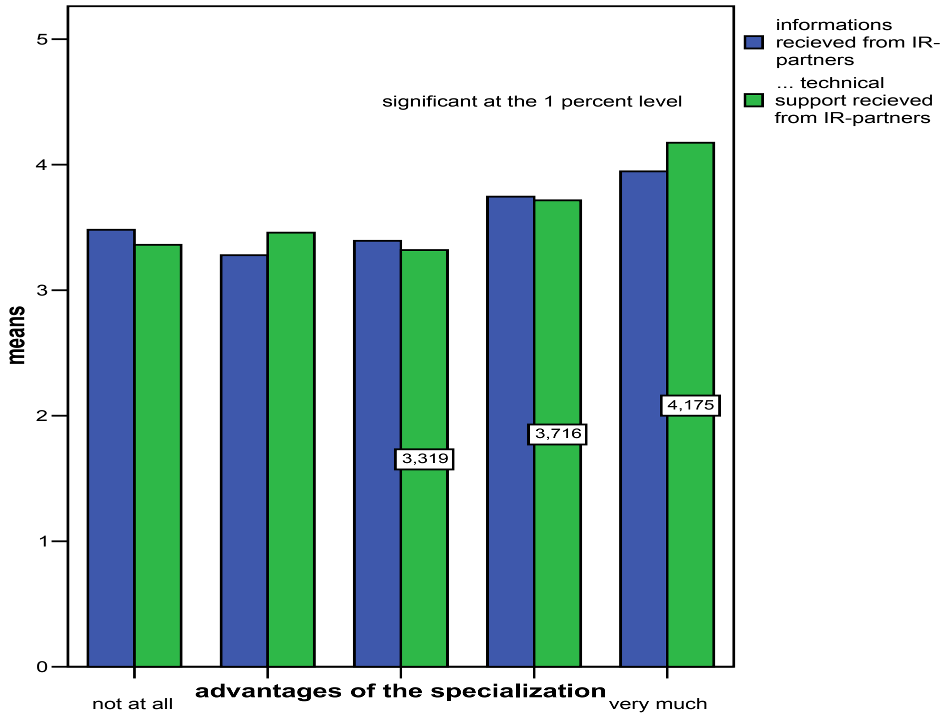
Graph 3: universities' technical support by frequency of supra-regional co-operation (product development)



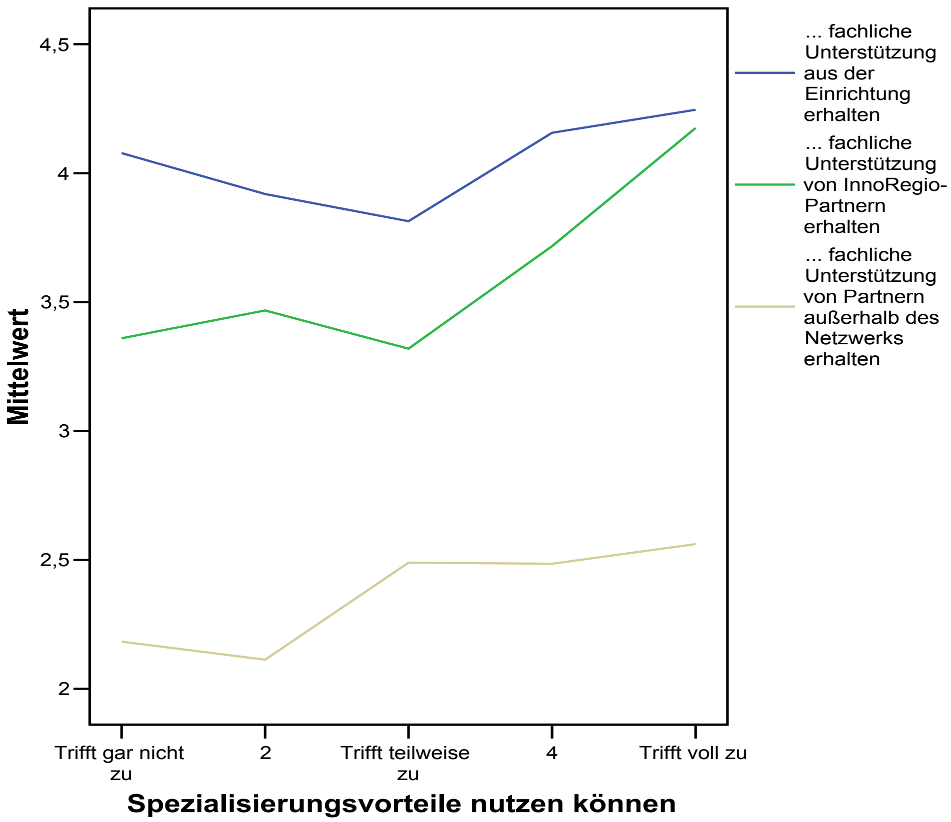
Graph 4: Information exchange by intensity of contacts



Graph 5a: knowledge transfer arising from possible specialization benefits



Graph 5b: knowledge transfer arising from possible specialization benefits



Graph 6: knowledge transfer by degree of new co-operation partners