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When is a network a nexus for innovation? A study of public nanotechnology R&D projects in the Netherlands

Ariane von Raesfeld [a],*, Peter Geurts [b], Mark Jansen [a]

[a] Business Administration, School of Management and Governance, University of Twente, Enschede, The Netherlands
[b] Public Administration, School of Management and Governance, University of Twente, Enschede, The Netherlands

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ABSTRACT

Most empirical studies that test the influence of R&D collaboration on innovation performance either focus on the diversity of partners that enhances innovation or focus on social embeddedness of partners that enhances or inhibits innovation. We combine these two factors to explain innovation. By using the business interaction model (Håkansson et al., 2009) we test the effect of resource heterogeneity, value chain complementarity, user interaction, and structural stability of partnership portfolios on application and value creation performance of public nanotechnology R&D projects. We used an enriched database on utilization of technology research projects from the Dutch Technology Foundation STW. To test our hypotheses we selected from the database 206 nanotechnology research projects, which started in a five year period from 2000 to 2004. Project performance was measured five years after completion of the project. Support is found for an inverted U shaped effect of the interaction between stability of the relationship structure and technological heterogeneity, industry heterogeneity, value chain complementarity and user interaction in the R&D partnership portfolios on both application and value creation performance. The framework introduced in this study allows an evaluation of the effects of participant portfolios on Public R&D projects performance.

1. Innovation in networks

Several scholars have dealt with the relationship between innovation and networks of inter-organizational interactions (Callon, 1998; Håkansson & Lundgren, 1995; Powell, Koput, & Smith-Doerr, 1996). Because as Powell et al. (1996: 116) state: “when the knowledge base of an industry is both complex and expanding, and sources of expertise are widely dispersed, the locus of innovation will be found in networks of learning rather than in individual firms.” Yet, innovation in networks seldom presents itself straightforward, constraints in this process are frequently explained by the concept of path dependence. The classic literature on path dependence in economics (Arthur, 1986; David, 1985) and institutional change (North, 1990) argues that self-reinforcing mechanisms, such as increasing returns, technical interrelatedness and quasi-irreversibility of technology or institutions constrain change. This view of path-dependency is criticized for giving too much weight to stability while there are many reasons for path dependence which do not occur at the same time and place (Beyer, 2010; Håkansson & Lundgren, 1997). A second critique is that too less weight is given to agency (Araujo & Harrison, 2002; Garud, Kumaraswamy, & Karnøe, 2010). The interest of the scholars who criticize the path dependence view lies in exploring the possibilities of innovation or path creation, through the interactions of actors, activities and resources that constitute inter-organizational networks. To answer the question when is a network a nexus for innovation, we continue on ideas and findings from the Business Network Approach that focuses on technological development and innovation in networks (Chou & Zolkiewski, 2010; Håkansson & Lundgren, 1995; Håkansson & Waluszewski, 2002; Raesfeld Meijer, 1998; Raesfeld, Geurts, Jansen, Boshuizen, & Luttge, 2012). In particular we will test the separate and combined influence of process and structure characteristics of relationships between participants in public–private R&D projects (Håkansson & Lundgren, 1995; Håkansson et al., 2009) on application and value creation performance of these projects. The paper is structured as follows. In the next section we develop our model based on the literature on innovation in collaborative networks. We then proceed by testing the hypotheses and presenting the findings. The final section discusses the results and provides suggestions for further study.

2. Process and structure in cooperative R&D

Assuming that continuity and change are processes driven by similar dynamics, Håkansson and Waluszewski (2002) showed how path-dependence can enable technological development, when the resources that are historically built in industrial networks are confronted with new utilization possibilities. In a similar

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* Corresponding author. Tel.: +31 53 4893338; fax: +31 53 4892159.
E-mail address: a.m.vonraesfeldmeijer@utwente.nl (A. Raesfeld).

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way though focusing more on agency and less on substance, Garud et al. (2010) put forward a path creation perspective suggesting instead of lock-in, the provisional stabilization of networks, in which initial conditions are socially constructed, self-reinforcing mechanisms for change and stability, are strategically cultivated, and where contingencies emerge and serve as embedded contexts for ongoing action. For this study the question then is: what are these contingencies emerging and what is their influence on inter-organizational innovation? Araujo and Harrison (2002) and Garud et al. (2010) suggest that at certain points in time and space a collection of independent factors as well as stabilized network structures probably will affect the choices and outcomes that will arise. This is not the same for every actor due to differences of embeddedness in the network and not completely determined as there is room for strategic choice. Håkansson et al. (2009: 236) are explicit about what embedddedness is, they consider a network as consisting of the tangible and intangible investments that connect relationships between more than two businesses and these connections, not the relationships in themselves, provide opportunities to multiply the effect of investments. Connections are made of resource ties, activity links and actor bonds. This implies that networks evolve over time through linking new resources to existing resource combinations and relating new activities to existing activity patterns. Therefore, in order to improve this process it is important to be conscious about both the time and space aspects of the business network (Waluszewski, 2011a). Continuing on this line of reasoning we hereafter, address factors affecting the innovation outcomes of inter-organizational R&D projects.

In the business network approach organizations are portrayed as closely interacting with each other, which leads to multifaceted interdependencies over time and space. In the descriptive model of business interaction (Ford, Hakansson, Snehota, & Waluszewski, 2010; Håkansson et al., 2009), inter-organizational relationships are specified over time and space. This business interaction model indicates three structural or space related mechanisms (resource heterogeneity, actor jointness and activity interdependency) and in parallel three processes or time related mechanisms (paths of resources, co-evolution of actors and specialization of activities) that influence outcomes of interaction between organizations. Particularly in the case of technological development and innovation where often public and private organizations cooperate, Håkansson and Waluszewski (2007) stress to be conscious about the different coexisting economic logics of development, use and supply. Therefore, Håkansson et al. (2009) distinguish three settings of innovation development: 1) idea development, 2) production infrastructure development, and 3) user environment development. Each setting is involved in the embedding of different types of resources and activities. Hereafter, to explain technological development in public–private R&D projects, we derive hypotheses from the business interaction model in different settings of the business landscape. We investigate two particular outcomes of cooperative R&D: 1) application development which is closely related to the idea development setting and 2) value creation which is more related to the using and producing settings.

The domain of idea development involves the combination of resources to build up functionality; it is about creating new solutions. The search for functionality is often found into combining and recombining a large number of tangible and intangible resources (Håkansson et al., 2009). When a research project provides linkages between universities, research institutes and the private sector, the resources of collaborative partners can be assessed through these linkages (Gnyawali & Madhavan, 2001). Baum, Calabrese, and Silverman (2000) argue that it is not so much the number of linkages, but rather the diversity of the partner portfolio that influences performance, as combinations of partner resources create value and application opportunities. Therefore our first hypothesis is:

Hypothesis 1. Heterogeneity of resources in inter-organizational R&D projects has a positive influence on application and value creation performance of these projects.

The domain of the production infrastructure is important in innovation as new solutions have to be embedded in an efficient production system. From an innovation point of view the production system has to be co-developed with the new solution, it is concerned with searching for complementarity in the value chain (Håkansson et al., 2009). Collaboration provides access to complementary assets that support both application development and value creation (Arora & Gambardella, 1990; Bonaccorsi & Thoma 2007; Hagendoorn, 1993; Teece, 1986). Consequently, the following hypothesis is proposed:

Hypothesis 2. Value chain complementarity between partners in inter-organizational R&D projects has a positive influence on application and value creation performance of these projects.

In innovation studies there is abundant attention for user/technology alignment, as indicated by Abernathy and Utterback's (1978) life cycle theory, Burgelman's (1983) market technology linking and von Hippel (1986) lead-user approach. Use of a new solution is a central aspect that has to be developed together with the new idea and its production structure (Håkansson et al., 2009). Requirements for use of a new solution will develop in the interaction between developers and users. This leads to the following hypothesis.

Hypothesis 3. User participation in inter-organizational R&D projects has a positive influence on application and value creation performance of these projects.

Still, interdependencies in existing relationships can enable as well as constrain innovation (Ford et al., 2010; Håkansson & Ford, 2002). In earlier work Håkansson and Lundgren (1997) already discussed the embedding of resource ties, activity links and actor bonds to explain change in industrial networks. In this same writing, in addition to the issue of embedding, they used structural strengths as a force that has a decreasing effect on innovation and change. This process or time dimension indicates the degree of stability of activity patterns, actor webs and resource constellations. Therefore, we propose.

Hypothesis 4. Stability in relationship structures of the inter-organizational R&D projects has a negative influence on application and value creation of these projects.

So far, we discussed the linear influence of the heterogeneity, interdependency and connectivity between collaboration partners and of the stability of relationship structure on innovation performance. However, structural characteristics of relationships in combination with stability of the network are expected to have a nonlinear effect on innovation. Håkansson and Waluszewski (2002) showed, in their study of the development of the new 'green' catalogue paper, that path dependence can in fact stimulate innovation. Thus, varying combinations of stability and structural aspects such as heterogeneity, connectivity and interdependence can lead to varying possibilities for application and value creation of new technologies. The work of Håkansson and Lundgren (1997) suggests that a balance between heterogeneity and stability is optimal for innovation performance. This implies that the interaction effect of network stability and respectively resource heterogeneity, value chain complementarity and user participation is a inverted U shaped function for application and value creation (see Fig. 1). A comparable line of reasoning is given by Nooteboom et al. (2007). This argumentation leads to the following hypotheses:

Hypothesis 5. The simultaneous increase of network stability and respectively partner heterogeneity, value chain complementarity and user participation in the project has an inverted U shaped effect on application and value creation of these projects.

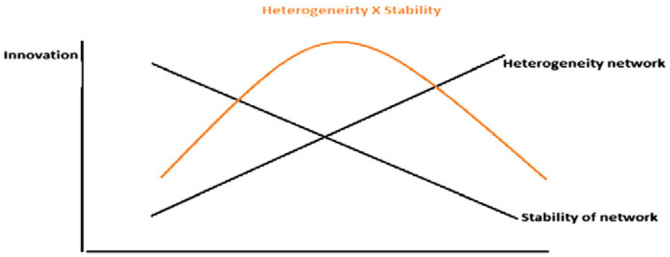

Fig. 1. Interaction effect between network heterogeneity and network stability.

The interaction effect between relationship characteristics and network stability is graphically represented in Fig. 1. The hypotheses are graphically represented in the research model in Fig. 2.

3. Methods

3.1. Setting and data

Nanotechnology is seen as the next general purpose technology with the potential to significantly impact industrial activity (Bozeman, Laredo, & Mangematin, 2007; Nikulainen & Palmberg, 2010; Shea, 2005; Wood, Jones, & Geldart, 2003). Academics and policy makers expect that utilization and value creation of nanotechnologies will cut across established knowledge, technological, and organizational boundaries and might disrupt traditional industries (Shea, 2005; Walsh, 2004). Therefore, commercial development of nanotechnologies will depend on the ability to integrate development, producing and using settings distributed across professional groups, companies, and research organizations (Bozeman et al., 2007; Nikulainen & Palmberg, 2010; Palmberg, 2008; Robinson, Rip, & Mangematin, 2007.

Most industrialized countries develop collaborative structures where universities and firms work together in transferring knowledge for commercial or societal purposes. However, there are surprisingly few studies on the interaction between different actors in the process of nanotechnology development, with the exception of Nikulainen and Palmberg (2010) who investigated the relationship between, motives of researchers, university industry interactions, and nanotechnology transfer challenges and outcomes when commercializing scientific knowledge. Their findings show that the most important modes of industry university interactions in the field of nanotechnology take place in Public R&D programs and at conferences. This is in line with earlier findings of D'Este and Patel (2007) who showed that technology transfer between universities and firms mainly takes place in consultancy, contract research, joint research and training and much less via patenting and spin-off activities.

We tested the hypotheses using a dataset on utilization of all technology research projects funded by the Dutch Technology Foundation STW. STW funds utilization oriented technology research at Dutch universities and selected institutions. Through the Dutch Organization for Scientific Research (NWO), STW receives its funding from the Dutch Ministry of Economic Affairs and the Dutch Ministry of Education, Culture and Science. The participants in the project consist of the researchers and potential users of the results who are not directly part of the research group. The 'users' provide input, as well as financial or other contributions to the project. All potential users of knowledge — knowledge institutions, large, medium-sized and small businesses, as well as those involved in R&D — are eligible for participation in a R&D project. They are given the opportunity to work alongside the researchers and be the first to learn of the results. The STW dataset describes 798 Public R&D projects over a period from 1992 to 2009 and cover per project the researchers and research institutes involved, the participants in the project, commitment of the users, and the resulting products and revenues.

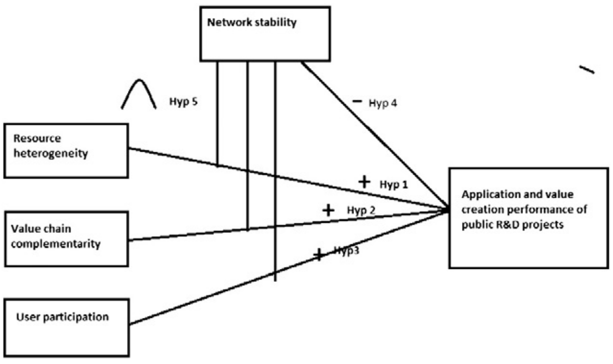

Fig. 2. Research model.

An expert in the field of nanotechnology selected the nanotechnology projects based on National Nanotechnology Initiative's definition: 'Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nm, were unique phenomena enable novel application' see (Balogh, 2010; Bozeman et al., 2007). This resulted in 158 nanotechnology projects, which started in a period from 2000 until 2004. We excluded 5 projects because they had no other participants involved and therefore complementarity and technology variables could not be generated, so we continued with 206 projects.

Secondly, we listed all the participating organizations (412) from the projects and classified them in six types: firms; governmental parties; research institutes; hospitals; universities; and special interest groups.

Thirdly, we checked the names of participating organizations for duplicates and misspellings and consolidated firm names up to the holding level. We collected patent information for all participants in the 206 research projects using data from the European Patent Office (EPO). For each participant, patent applications from 1995 to 2002 were collected at the consolidated firm level. In this way, information on 99.730 patents was gathered.

3.2. Dependent variables

We used measures for application performance and value creation performance five years after the completion of the projects, because these performances are likely to lag R&D activity. We define *Application performance* as the degree to which the project leads to a tangible product such as software, patent, prototype or process description. For application performance we used the product generation scale from the STW database, which comes closest to our definition of application performance and distinguishes: 1) project prematurely ended; 2) no tangible product; 3) a temporary design or principle is developed, verification still needed; 4) a product is developed, such as software, a prototype, a process description or a patent. We took 1 and 2 together into one level because in both cases there is no product at all.

Value creation performance is defined as the degree to which the project generated revenues. For value creation performance we used the revenue generation scale from the STW database, ranging from 1) project failed 2) no revenues 3) occasionally parts of knowledge are sold but no revenues from exploitation 4) continuous stream of revenues from knowledge exploitation. Again, we merged 1 and 2 because at both levels, no revenues were there. Also, we combined levels 3 and 4 because of a small number of observations at level 4.

3.3. Independent variables

The heterogeneity measures for technological and industry heterogeneity and the one for value chain complementarity are calculated with the Hirschman–Herfindahl index as used by Baum et al. (2000) and computes heterogeneity as one minus the sum of the squared proportions of different resource types divided by the project's total number of resource types. High index outcomes indicate an equal distribution of the different types.

Resource heterogeneity is defined as the diversity of resources embedded in the R&D projects. We used two different operationalizations for resource heterogeneity: Technological heterogeneity and Industry heterogeneity.

Technological heterogeneity is defined as the degree to which there is a complete coverage of the eight main European patent classes. We calculated the diversity in a project based on the four digit EPO patent numbers. The eight main classes are: A) Human necessities, B) Performing Operations/ Transporting; C) Chemistry; Metallurgy; D) Textiles/Paper; E) Fixed constructions; F) Mechanical engineering/Lighting/Heating/ Weapons/Blasting; G) Physics; H) Electricity. Among the 412 participants the highest numbers of patents are in Human necessities in order of number followed by Chemistry/Metallurgy; Electricity and Physics. Correlation analysis of the eight classes showed strong correlation between Human necessities and Chemistry/Metallurgy and between Physics and Electricity, implying that in nanotechnology R&D these fields are combined.

Industry heterogeneity is defined as the distribution of the industry classes to which the participants in the research projects belong. For this measure the Dutch version of the sic coding was used, which consists of 21 different industry classes.

Value chain complementarity is defined as the diversity of value chain roles per project. Assuming that organizations active in the same line of transformational activities have similar roles, we construct a measure of the value chain complementarity of a project that captures the diversity of the project's participant types. The participant types that were identified in the sample were: 1) companies, 2) governmental parties, 3) research institutes, 4) (academic) hospitals/medical institutions, 5) universities/schools and 6) special interest groups.

User participation is defined as the proportion of firms participating in the project. Assuming that research institutes, academic hospital./ medical institution, and universities are especially involved in the idea development and firms in the using and producing setting users of the innovation, we measured the proportion of firms as the number of firms participating divided by the total number of participants in the project.

3.4. Network stability

Network stability is defined as the degree of establishment of relationship structures. Its measurement is a count of the number of participants in a project that had been participating before in the STW network. The participants in the year 2000 were used as base year.

3.5. Control variables

An additional characteristic that may have an effect on the performance of nanotechnology research project is the size of participating firms. We control for variation of *firm size* by including two dummy variable for small and large firms, set to one if a participant is a small firm/ large firm (default is medium sized firm). For this measure the firms in the project were classified in small, medium or large firms on employee size, small firms 1–49 employees, medium firms as 50–499 employees and large firms are those who have over 500 employees.

Commitment of participants in the project is defined as the degree to which participants actively contribute to the project. We control for commitment as Mora-Valentin, Montoro-Sanchez, and Guerras-Martin (2004) found a positive effect of commitment on cooperation success. Thus one could argue that without commitment, resource combination is difficult. For *Commitment of participants in the project* we applied the scale from the STW database, which goes from, 1) commitment failed no relevant results for user; 2) users participated in user committee; 3) users participate actively and provide some tangible support such as money or materials; 4) users participate substantially, by providing extensive support and/or by making cooperation contracts.

3.6. Analysis

In the analyses it is appropriate to use an ordered logit to estimate the effect of the independent variables of the ordinal categories on the continuum from less to more application. To estimate the effect of the independent variables on the two categories for value creation performance, we used a binary logistic regression.

4. Results

4.1. Resource heterogeneity, value chain complementarity, user participation and network stability

Table 1 presents descriptive statistics and the correlations for all variables. Tables 2 and 3 summarize the analyses for testing Hypotheses 1–5. In model 3 in Table 2 and model 6 in Table 3 we present the results of the regression with respectively the dependent variables application and value creation performance. Important to notice that we investigated the whole population and not a sample, therefore we have no errors related to sample variability and the standard errors (and statistical significance) are to be considered as expression of error from omitted variables and measurement.

Tables 2 and 3 clearly show that adding the combined effect of process and structure has a positive effect on the explained variance of the model, implying that the two should be considered together. The control variables have the expected effect on performance. Commitment has a positive significant effect on both application and value creation performance. Participation of small firms has a positive effect on the dependent variable application performance. Large firm participation has a negative effect on the dependent variable value creation performance, but is not significant for application performance. This complies in the first place with previous research that showed that new disruptive innovations are likely to come from small firms rather than from large firms (Ahuja & Lampert, 2001). Secondly, it is in line with studies on technology development in networks showing that innovation is not always positively received by actors in the existing network.

In Hypothesis 1 we pose that resource heterogeneity has a positive effect on application and value creation performance of the nanotechnology R&D projects. For technological heterogeneity the direction of the effect is opposite to the expectation and not significant. However, the results depict a positive significant relationship between industry heterogeneity and the two dependent variables. Therefore, in the case of technological heterogeneity, Hypothesis 1 is disconfirmed for technological heterogeneity, but confirmed for industry heterogeneity.

In Hypothesis 2 we argue that value chain complementarity of the participants in the R&D projects enhance application and value creation performance of these projects. The results depict a positive effect of value chain complementarity on both dependent variables, but only significant for value creation performance, thereby providing support for the Hypothesis 2 in the case of value creation performance.

The positive effect of user participation and application performance and value creation performance of the projects as postulated in Hypothesis 3 is confirmed. The results depict the expected sign and are almost significant for both dependent variables.

In Hypothesis 4 we predicted a negative effect of stability on the two dependent variables. Results show a sign opposite from expected, almost significant for application development and value creation performance. Although, for both dependent variables the effect is much lower than that for the other main effect. Still, Hypothesis 4 has to be rejected.

Overall, the effect of value chain complementarity followed by industry heterogeneity has the strongest effect on the dependent variables. For application development the effect of technological heterogeneity is stronger than the effect of user interaction. In the case of value creation performance it is the other way around, the

Table 1
Range, means, standard deviation and correlations of the variables ($N=158$).

	Mean	St dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Application performance after 5 years	2.025	0.722	1													
Value creation performance after 5 years	1.241	0.429	.453	1												
Dummy firm small	0.570	0.497	.190	.011	1											
Dummy firm large	0.861	0.347	−.037	−.159	−.128	1										
Commitment	1.943	0.660	.350	.364	.061	.076	1									
Technological heterogeneity	0.070	0.053	−.049	−.004	−.016	−.376	−.008	1								
Industry heterogeneity	0.063	0.064	.067	.085	.123	−.124	.040	.347	1							
Value chain complementarity	0.073	0.054	−.001	.026	−.214	−.199	−.176	.141	.140	1						
User Interaction	0.684	0.236	.047	.058	.194	.281	.168	−.099	−.054	−.727	1					
Network Stability	3525	1857	.057	−.032	.046	.223	−.001	−.505	−.138	−.107	−.112	1				
Technological heterogeneity × stability	0.148	0.198	.140	.117	.271	−.215	.066	.599	.268	−.040	.018	−.444	1			
Industry heterogeneity × stability	0.144	0.207	.167	.178	.326	−.204	.157	.241	.670	−.045	−.038	−.236	.628	1		
Value chain complementarity × stability	0.130	0.134	.180	.132	.281	−.148	.008	189	.219	.383	−.404	−.262	.531	.561	1	
User Interaction × stability	2.363	1.478	.075	.015	.176	.309	.077	−.471	−.157	−.420	.380	.845	−.387	−.238	−.384	1

effect of user interaction is stronger than the effect of technological heterogeneity.

In Hypothesis 5 we predicted an inverted U shaped relationship of the combined effect of network stability and respectively resource heterogeneity, value chain complementarity and user participation. In the case of the interaction effect between industry heterogeneity, value chain complementarity and user interaction and network stability on application and value creation performance Hypothesis 5 is supported. Models 3 and 6 show a positive significant main effect and a negative squared effect of the interaction effect on both application development and value creation performance.

5. Conclusion, contributions and further research

In this paper we investigated the separate and combined influence of different structural aspects of the R&D partnership portfolios and the process aspect of network stability on the R&D project's application and value creation performance. There is a large body of research on the impact of a diversity of partnership on innovation (e.g. Becker & Dietz, 2004; Nelson & Winter, 1982; Nieto & Santamaria, 2007; Nooteboom, van Haverbeke, Duysters, Gilsing, & van Oord, 2007). There is a comparable large body of research on the impact of relational structure on innovation (e.g. Ahuja, 2000; Gulati, 1995a; Powell et al., 1996). Less research combines both explaining factors (e.g. Gilsing, Nooteboom, Haverbeke, Duysters, & Van Oord, 2008; Petruzelli, 2011) and those who do focus on dyadic relationships, with the exception of Håkansson and Lundgren (1997) who provide evidence from case studies on technological development in networks of organizations. Our contributions lie in investigating the combined effect of R&D partnership portfolio heterogeneity, interdependence, and connectivity together with network stability on innovation performance. In doing so we applied the business interaction model (Håkansson et al., 2009) to an analysis of time and space in business networks. Also we further test prior research of Håkansson and Lundgren (1997) on technological development in networks that provides evidence from case studies. The explained variance of our model improved with the addition of the combined effect of structural and processual aspects of R&D partnership portfolios, indicating that these two should be considered together.

Assuming that heterogeneous resources are needed to develop technological applications, we found that especially industry heterogeneity had a positive impact on both application and value creation performance. The impact of technological heterogeneity was negative and not significant. This different effects of industry and technological heterogeneity seem to match the argument of Håkansson and Waluszewski, 2011:185: “The existence of variety as well as the capacity to take advantage of it in a specific resource is directly related to the total set of resources it belongs to …”. Participating firms with different industry backgrounds provide different resource constellations in which applications can be developed and value can be created (Harrison & Waluszewski, 2008). In the case of technological heterogeneity which is measured by the patent portfolios of the participants there is not yet an activated resource constellation to which the application and value creation can be related.

Considering the resource combinations needed to build up production facilities for the innovation, we found as expected a positive influence of value chain complementarity of partners on application

Table 2
Determinants of application performance public nanotechnology R&D projects.

	1			2			3		
	B	s.e.	*p*	*B*	s.e.	*p*	*B*	s.e.	*p*
[application performance = 1]	.974*	.625	.119	2513**	1358	.064	4167**	2291	.069
[application performance = 2]	3364***	.684	.000	4948***	1406	.000	6631***	2329	.004
Dummy firm small	.678**	.316	.032	.695**	.334	.037	.705**	.352	.045
Dummy firm large	−.331	.449	.460	−.551	.517	.287	−.427	.534	.424
Commitment	1079***	.248	.000	1124***	.255	.000	1117***	.259	.000
Technological heterogeneity				−2016	3809	.597	−3966	6354	.533
Industry heterogeneity				1467	2692	.586	8544*	5349	.110
Value chain complementarity				6948*	4483	.121	10.855*	7692	.158
User interaction				1231	1069	.250	2692	2333	.248
Network stability				.101	.103	.327	.726	.615	.238
Technological heterogeneity × stability							−2527*	1607	.116
Industry heterogeneity × stability							−1896	2895	.513
Value chain complementarity × stability							−.606	.658	.357
User interaction × stability							.975	2228	.662
Nagelkerke pseudo R^2	.172			.196			.214		
Chi-square	25.912***		.000	29.859***		.000	32.876***		.001

$N=158$ $^{*}p<0.20$; $^{**}p<0.10$; $^{***}p<0.02$; one-sided test Link function: Logit.

Table 3
Determinants of value creation performance of public nanotechnology R&D projects.

	4			5			6		
	B	s.e.	p	B	s.e.	p	B	s.e.	p
Constant	−3264***	.881	.000	−6763**	2391	.005	−8568**	4176	.040
Dummy firm small	−.121	.419	.772	−.345	.463	.457	−.513	.495	.299
Dummy firm large	−1391***	.551	.012	−2108**	.708	.003	−2088**	.761	.006
Commitment	1596***	.357	.000	1682***	.377	.000	1617***	.386	.000
Technological heterogeneity				−4566	5521	.408	−1494	8677	.863
Industry heterogeneity				2164	3802	.569	12.508*	8309	.132
Value chain complementarity				13.856**	7183	.054	24.402**	13.298	.067
User interaction				4015**	1973	.042	5147	4216	.222
Network stability				.116	.145	.425	1263	.999	.206
Technological heterogeneity × stability							−3190	2535	.208
Industry heterogeneity × stability							−5828	4555	.201
Value chain complementarity × stability							−.788	1065	.459
User interaction × stability							−2498	3375	.459
Nagelkerke pseudo R^2	.246			.299			.346		
Chi-squared	28.382***		.000	35.162***		.000	41.550***		.000

$N = 158$ $^{*}p<0.20$; $^{**}p<0.10$; $^{***}p<0.02$; one-sided test.

development and value creation performance of the project. In fact this effect was the strongest compared to the other main effect such as the industry heterogeneity. This implies that in the network the efficiency forces are stronger than innovation forces (Waluszewski, 2011b).

In relation to building up a use function for the innovation, we found a positive influence of user participation on application and value creation. However in the case of application development the effect of technological heterogeneity was higher, while for value creation the effect of user interaction was higher. This suggests that over the innovation journey the importance of networks change. Recently the process aspects of business networks and innovation get more attention (Halinen, Medlin, & Tornroos, 2012; Hoholm & Olsen, 2012). This study used a variance approach (Poole et al., 2000) to analyze innovation in networks. As each R&D project can be considered as an event in an innovation journey further research is needed that investigates the network effects on innovation over time.

Contrary to our hypothesis a positive effect of network stability on the performance is found. As indicated by Håkansson and Ford (2002) and Ford et al. (2010), established relationships can both hinder and enable outcomes of interaction. In alliance research Gulati (1995b) showed that in an uncertain environment repeated collaboration initially creates knowledge benefits, but over time these benefits dry up. In our case of R&D cooperation in nanotechnology it can be assumed that there is still enough uncertainty towards the direction of the technology to make established relationships worthwhile. For R&D partnerships in information technology Frankort, Hagedoorn, and Letterie (2012) found an inverted U shaped effect of the share of novel partners on the inflow of technological knowledge. Further research can be done to investigate the inverted U shaped main effect of established relationships in R&D partnerships in nanotechnology.

Our findings indicate that in projects, in which applications and innovations from a radical technology are developed, best can have participants that operate in different industries, and have different value chain roles but at the same time take part in an established network. Therefore, we investigated the combined effects of different partner portfolio characteristics and network stability. Support is found for an inverted U shaped effect of the interaction between stability of the relationship structure and industry heterogeneity, value chain compatibility and user interaction on both application and value creation performance. These results suggest that a balanced portfolio should optimally combine benefits of long term relationships with resource heterogeneity, activity complementarity and actor connectivity. We aim to further investigate these network effects in order to gain insight into and help practitioners with coping with innovative and efficiency forces of networks (Waluszewski, 2011b).

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