WHEN IS AN INNOVATION NETWORK A NEXUS FOR PATH CREATION? A STUDY OF PUBLIC NANOTECHNOLOGY R&D PROJECTS IN THE NETHERLANDS

Ariane von Raesfeld
NIKOS
School of Management and Governance
University of Twente
a.m.vonraesfeldmeijer@utwente.nl

Peter Geurts
Political Science and Research Methods
School of Management and Governance
University of Twente

Mark Jansen
NIKOS
School of Management and Governance
University of Twente

ABSTRACT

In this paper we test the effect of resource heterogeneity, value chain complementarity, user interaction, and structural stability among participants in nanotechnology R&D projects on utilization and value creation performance of these projects. In the study we used business network theory on innovation journeys to develop hypotheses. 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 158 nanotechnology research projects, which started in a five year period from 2001 to 2005. 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 industry heterogeneity among participants on both utilization and value creation performance. Also we found support for an inverted U shaped effect of the interaction between stability and respectively industry heterogeneity and value chain complementarity among participants on value creation performance. The framework introduced in this study allows an evaluation of the effects of participant portfolios on Public R&D projects performance.

Keywords: Radical innovation, Nanotechnology, Path creation, Innovation journey, Resource heterogeneity, structural stability.

COMMERCIALIZING NANOTECHNOLOGY

Nanotechnology is seen as the next general purpose technology with the potential to significantly impact industrial activity (Shea, 2005, Bozeman et al., 2007, Wood et al., 2003, Nikulainen and Palmberg, 2010). 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 (Walsh, 2004, Shea, 2005). Therefore, commercial development of nanotechnologies will depend on the ability to integrate knowledge (scientific, technological, commercial, regulatory) distributed across professional groups, companies, and research organizations (Bozeman et al., 2007, Palmberg, 2008, Nikulainen and Palmberg, 2010, Robinson et al., 2007). However, we do not know yet whether, developments in nanotechnology will lead to radical innovations in the sense that they create new market infrastructures (Garcia and Calantone, 2002). Therefore, in this paper our focus is on the divers characteristics of participants in cooperative R&D projects that enable initial utilization and value creation of new technologies. Were utilization is concerned with the development of applications of new technologies and value creation with making marketable products.

So far a large body of the literature on nanotechnology focuses on macro variables such as indicators of science and technology dynamics and use data search strategies for citation indexes and patent databases (e.g. Salerno et al., 2008, Kostoff et al., 2007, Bonaccorsi and Thoma, 2007, Youtie et al., 2008, Mogoutov and Kahane, 2007, Miyazaki and Islam, 2007, Islam and Miyazaki, 2010). At the same time government policies focus on improving technological development through establishing innovation networks. 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. In this paper, we investigate Dutch Public nanotechnology R&D projects, in which actors with different institutional backgrounds cooperate to further the utilization and value creation of nanotechnology.

Several scholars have dealt with the relationship between technological development and networks of inter-organizational interactions (Powell et al., 1996, Callon, 1998, Håkansson and Lundgren, 1995). 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, technological development 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 (David, 1985, Arthur, 1986) and institutional change (North, 1990) argue 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 to much weight to stability while there are many reasons for path dependence which do not occur at the same time and place (Håkansson and Lundgren, 1997, Beyer, 2010). A second critique is that too less weight is given to agency (Araujo and Harrison, 2002, Garud et al., 2010). The interest of the scholars who criticize the path dependence view lies in exploring the possibilities of change or path creation, through the interactions of actors, activities and resources that constitute inter-organizational networks. To answer the question when an innovation network is a nexus for path creation, we continue on ideas and findings from the Industrial Network Approach that focuses on technological development in networks (Raesfeld Meijer, 1998, Håkansson and Lundgren, 1995, Håkansson and Waluszewski, 2002, Chou and Zolkiewski, 2010). Suggestions for policy makers from Håkansson et al. (2009) are used to develop hypotheses about outcomes of Public nanotechnology R&D projects. In particular we will elaborate on the causes and dimensions of change that we will call heterogeneity and structure, and which are described by Håkansson and Lundgren (1997) in their model of network structure dynamics and overlap.

The paper is structured as follows. In the next section we develop our model based on the literature on path creation. We then proceed by testing the hypotheses and presenting the findings. The final section discusses the results and provides suggestions for further study.

PATHS AND HETEROGENEITY IN COOPERATIVE R&D

Path Creation in Networks

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 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 stabilizations of networks, in which initial conditions are socially constructed, self-reinforcing mechanisms for change and stability are strategically cultivated, and 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. According to Håkansson et al (2009: 250): "policy measures can support network development if they relate to the pre-existing and evolving processes within a business network". Therefore, in order to improve this process policymakers but also firms have to be conscious about both the stability and the heterogeneity of the business network. Continuing on this line of reasoning we hereafter, address factors affecting the outcomes of inter-organizational R&D projects.

Innovation, resource heterogeneity and network stability

In the innovation literature resource heterogeneity is seen as a crucial condition for technological development (Nelson and Winter, 1982) and inter-organizational cooperation is seen as a means for organizations to combine heterogeneous resources in new ways (Raesfeld Meijer, 1998, Boschma, 2005, Håkansson and Waluszewski, 2002, Håkansson and Lundgren, 1995, Nooteboom, 1992). In the book on 'Business in Networks' (Håkansson et al., 2009) three areas of innovation development are distinguished. In these three areas are: 1) idea development, 2) production infrastructure development, and 3) user environment development. Each area is involved in embedding of different types of resources. 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. Possibilities for resource combinations are in fact endless, which is good for creating new ideas but problematic from an economic point view. Miotti and Sachwald (2003) state, that when the aim of partners is to reduce costs and risks they pool similar resources to the cooperation, while if they want to develop technology they pool dissimilar resources. This argumentation leads to the following hypothesis:

Hypothesis 1: Heterogeneity of resources in inter-organizational R&D projects has a positive influence on utilization 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. Consequently, the following hypothesis is proposed:

Hypothesis 2: Value chain complementarity between partners in inter-organizational R&D projects has a positive influence on utilization 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 Hippels' (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. Use can 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 utilization and value creation performance of these projects.

Still, interdependencies in existing relationships can enable as well as constrain innovation (Håkansson and 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 structural 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 utilization and value creation of these projects.

However, in combination with heterogeneity of resources the effect of stability is not linear, while heterogeneity and instability increase the number of possible new combinations that can be made, too much of them creates a coordination problem (Håkansson and Lundgren, 1997). Seen from another angel, 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 heterogeneity can lead to varying possibilities for utilization and value creation of new technologies. The work of Håkansson and Lundgren (1997) suggests that a balance between resource heterogeneity and stability is optimal for innovation performance. This implies that the combined effect of stability and respectively resource heterogeneity, value chain complementarity and user participation is a quadratic inverted U shaped function for utilization and value creation. This argumentation leads to the following hypotheses:

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

METHODS

Setting and data

We tested the hypotheses using a dataset on utilization of 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 1992-2009 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.

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 (Bozeman et al., 2007, Balogh, 2010). 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 207 projects.

Secondly, we listed all the participating organizations (476) 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 207 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.

Dependent variables

We used measures for utilization 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 *Utilization performance* as the degree to which the project leads to a tangible product such as software, patent, prototype or process description. For utilization performance we used the product generation scale from the STW database, which comes closest to our definition of utilization 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.

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 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 476 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 consist 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 presence of a user in the project. Assuming that hospital/medical institutions can be considered as users of the innovation, we measured presence of a hospital./ medical institution by a dummy variable set to one if a participant is a hospital/medical institution.

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.

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 et al. (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.

Analysis

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

Table 1

Correlation Matrix

		N	mean	st dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Utilization Performance after 5 years	158	2,025	0,722	1													
2	Value creationl Performance after 5 years	158	1,241	0,429	,453	1												
3	Dummy Firm Small	158	0,570	0,497	,190	,011	1											
4	Dummy Firm Large	158	0,861	0,347	-,037	-,159	-,128	1										
5	Commitment	158	1,943	0,660	,350	,364	,061	,076	1									
6	Technological Heterogenity	158	0,070	0,053	-,049	-,004	-,016	-,376	-,008	1								
7	Industry Heterogenity	158	0,063	0,064	,067	,085	,123	-,124	,040	,347	1							
8	Value Chain Complementarity	158	0,073	0,054	-,001	,026	-,214	-,199	-,176	,141	,140	1						
9	User Interaction	158	0,177	0,383	,145	,088	,035	-,340	,015	,125	,136	,309	1					
10	Stability	158	3,525	1,857	,057	-,032	,046	,223	-,001	-,505	-,138	-,107	,083	1				
11	Technological Heterogenity * Stability	158	0,197	0,135	-,025	-,110	-,005	-,176	-,062	,507	,286	,093	,194	,295	1			
12	Industry Heterogenity * Stability	158	0,207	0,225	,016	-,044	,096	,080	,027	,038	,733	,055	,180	,367	,450	1		
13	Value Chain Complementarity * Stability	158	0,247	0,181	-,020	-,085	-,252	-,033	-,192	-,228	,015	,646	,281	,529	,286	,282	1	
14	User Interaction * Stability	158	,684	1,701	,152	,061	,064	-,172	,052	-,032	,082	,143	,869	,297	,214	,279	,342	1

RESULTS

Resource heterogeneity, value chain complementarity, user participation and structural stability

Table 1 presents descriptive statistics and the correlations for all variables. Table 2 and 3 summarize the analyses for testing hypotheses 1-5. In model 4 in Table 2 and model 8 in table 3 we present the results of the regression with respectively the dependent variables utilization and value creation performance.

Table 2

Determinants of: Utilization performanceof Nanotechnology R&D projects

	1			2			3			4		
	B	s.e.	p	B	s.e.	p	B	s.e.	p	B	s.e.	p
[invention performance = 1]	,974 *	,625	,119	1,496 *	,955	,117	1,352 **	,785	,085	1,950 **	1,047	,063
[Invention performance = 2]	3,364 ***	,684	,000	3,947 ***	1,005	,000	3,789 ***	,842	,000	4,444 ***	1,105	,000
Control variables												
Dummy Firm Small	,678 **	,316	,032	,721 **	,333	,030	,759 **	,337	,024	,649 **	,353	,066
Dummy Firm Large	-,331	,449	,460	-,108	,521	,836	-,145	,473	,759	,019	,553	,973
Commitment	1,079 ***	,248	,000	1,123 ***	,255	,000	1,112 ***	,257	,000	1,118 ***	,260	,000
Explanatory variables												
Technological Heterogenity				-2,788	3,778	,461				-5,006	6,089	,411
Industry Heterogenity				1,204	2,694	,655				9,317 **	5,173	,072
Value Chain Complementarity				2,080	3,196	,515				4,920	5,855	,401
User Interaction				,726 *	,464	,118				,468	1,034	,651
Stability				,024	,099	,811				,175	,182	,336
Technological Heterogenity * Stability							-,270	1,337	,840	1,008	2,156	,640
Industry Heterogenity * Stability							-,476	,843	,572	-2,841 **	1,568	,070
Value Chain Complementarity * Stability							,690	1,016	,497	-1,226	2,122	,564
User Interaction * Stability							,152 *	,103	,141	,095	,232	,682
Nagelkerke Pseudo R²	,172			,204			,195			,226		
Chi-Square	25,912 ***		,000	31,170 ***		,000	29,740 ***		,000	34,927 ***		,000

N=158 * p<0,20; **p<0,10; *** p<0,02; one-sided test Link function: Logit

Table 3

Binary Logistic regression

Determinants of Value creation Performance of Nanaotechnology R&D projects

	5			6			7			8		
	B	s.e.	p	B	s.e.	p	B	s.e.	p	B	s.e.	p
Constant	-3,264 ***	,881	,000	-2,833 **	1,295	,029	-2,535 ***	1,061	,017	-3,777 ***	1,472	,010
Control variables												
Dummy Firm Small	-,121	,419	,772	-,171	,449	,704	-,130	,444	,770	-,568	,494	,250
Dummy Firm Large	-1,391 ***	,551	,012	-1,521 **	,668	,023	-1,529 ***	,597	,010	-1,734 **	,780	,026
Commitment	1,596 ***	,357	,000	1,583 ***	,360	,000	1,561 ***	,366	,000	1,585 ***	,382	,000
Explanatory variables												
Technological Heterogenity				-5,639	5,276	,285				-3,917	7,827	,617
Industry Heterogenity				2,312	3,679	,530				14,483 **	7,823	,064
Value Chain Complementarity				1,436	4,221	,734				15,073 **	8,161	,065
User Interaction				,173	,589	,769				-,571	1,422	,688
Stability				-,041	,133	,754				,540 **	,237	,023
Technological Heterogenity * Stability							-2,649 *	2,092	,206	-2,068	3,127	,508
Industry Heterogenity * Stability							-,103	1,114	,926	-3,751 *	2,350	,110
Value Chain Complementarity * Stability							-,412	1,383	,766	-6,170 **	3,040	,042
User Interaction * Stability							,107	,130	,409	,255	,299	,392
Nagelkerke Pseudo R²	,246			,260			,270			,339		
Chi-Square	28,382 ***		,000	30,097 ***		,000	31,390 ***		,000	40,519 ***		,000

N=158 * p<0,20; **p<0,10; *** p<0,02; one-sided test

The control variables have the expected effect on performance. Commitment has a positive significant effect on both utilization and value creation performance. Participation of small firms has a positive effect on the dependent variable utilization performance. Large firm participation has a negative effect on the dependent variable value creation performance, but is not significant for utilization 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 and 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 utilization 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, but confirmed for industry heterogeneity.

In Hypothesis 2 we argue that value chain complementarity between the participants in the R&D projects enhance utilization 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 relationship between user participation and utilization performance and value creation performance of the projects as postulated in Hypothesis 3 has to be rejected. The results depict the expected sign for utilization though not significant and in case of value creation performance the sign is not as expected and not significant.

In Hypothesis 4 we predicted a negative effect of stability on the two dependent variables. Results show a sign opposite from expected, not significant for utilization performance and significant for value creation performance. Therefore, hypothesis 4 has to be rejected.

In Hypothesis 5 we predicted an inverted U shaped relationship of the combined effect of stability and respectively resource heterogeneity, value chain complementarity and user participation. In the case of the interaction effect between industry heterogeneity and stability on utilization and value creation performance hypothesis 5 is supported. And in the case of the interaction effect between value chain compatibility and stability on value creation performance hypothesis 5 is supported.

CONCLUSION, FOLLOW UP RESEARCH

In this paper we first analyzed the effect of resource heterogeneity in the development, production and use domains of the innovation journey of Public nanotechnology research project. We investigated the influence of the different types of heterogeneity on the project's utilization and value creation performance. Secondly, we investigated the combined impact of structural stability with respectively resource heterogeneity, value chain compatibility and user participation on the two dependent variables.

Prior research on technological development in networks provides evidence from case studies and research on alliances provide evidence on dyadic relationships. In order to test business network theory, we used a project portfolio approach. Assuming that heterogeneous resources are needed to develop technological applications, we found that especially industry heterogeneity had a positive impact on both utilization and value creation performance. The impact of technological heterogeneity was less clear.

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 the value creation performance of the project.

In relation to building up a use function for the innovation, we found a positive influence of user participation on utilization performance and a negative on value creation performance though both not significant.

Support is found for an inverted U shaped effect of the interaction between stability of the relationship structure and industry heterogeneity on both utilization and value creation performance. Also we found support for an inverted U shaped effect of the interaction between stability and respectively industry heterogeneity and value chain complementarity on value creation performance.

These initial 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. However before strong conclusions can be drawn, we have to deal with some method issues, we have to further develop our stability measure as it still has a high standard deviation and the user interaction measure as it is only measures the interaction with one assumed user.

.

ACKNOWLEDGEMENTS

We would like to thank the Dutch Technology Foundation (STW) for providing us the opportunity to analyze a part of their dataset on utilization projects. Also, we like to thank the anonymous reviewer for the useful comments..

REFERENCES

ABERNATHY, W. J. & UTTERBACK, J. M. 1978. Patterns of Industrial Innovation. *Technology Review,* 80**,** 40-47.

AHUJA, G. & LAMPERT, C. M. 2001. Entrepreneurship in the large corporation: A longitudinal study of how established firms create breakthrough inventions. *Strategic Management Journal,* 22**,** 521-543.

ARAUJO, L. & HARRISON, D. 2002. Path dependence, agency and technological evolution. *Technology Analysis & Strategic Management,* 14**,** 5-19.

ARTHUR, W. B. 1986. *Industry location patterns and the importance of history,* Stanford, Calif., Center for Economic Policy Research, Stanford University.

BALOGH, L. P. 2010. Why do we have so many definitions for nanoscience and nanotechnology? *Nanomedicine: Nanotechnology, Biology and Medicine,* 6**,** 397-398.

BAUM, J. A. C., CALABRESE, T. & SILVERMAN, B. S. 2000. Don't Go It Alone: Alliance Network Composition and Startups' Performance in Canadian Biotechnology. *Strategic management journal,* 21**,** 267-294.

BEYER, J. 2010. The Same or Not the Same: On the Variety of Mechanisms of Path Dependence. *International journal of social sciences,* 5**,** 1.

BONACCORSI, A. & THOMA, G. 2007. Institutional complementarity and inventive performance in nano science and technology. *Research policy,* 36**,** 813-831.

BOSCHMA, R. A. 2005. Proximity and innovation: A critical assessment. *Regional Studies,* 39**,** 61-74.

BOZEMAN, B., LAREDO, P. & MANGEMATIN, V. 2007. Understanding the emergence and deployment of "nano" S&T. *Research policy,* 36**,** 807-812.

BURGELMAN, R. A. 1983. A Process Model of Internal Corporate Venturing in the Diversified Major Firm. *Administrative Science Quarterly,* 28**,** 223-244.

CALLON, M. 1998. *Techno-economic Networks and Irreversibility,* N.Y, Routledge.

CHOU, H. H. & ZOLKIEWSKI, J. 2010. The arrival of technological changes at the business net: a learning process. *Journal of Business & Industrial Marketing,* 25**,** 443-453.

D'ESTE, P. & PATEL, P. 2007. University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry? *Research Policy,* 36**,** 1295-1313.

DAVID, P. A. 1985. Clio and the Economics of Qwerty. *American Economic Review,* 75**,** 332-337.

GARCIA, R. & CALANTONE, R. 2002. A critical look at technological innovation typology and innovativeness terminology: a literature review. *Journal of Product Innovation Management,* 19**,** 110-132.

GARUD, R., KUMARASWAMY, A. & KARNØE, P. 2010. Path Dependence or Path Creation? *Journal of Management Studies,* 47**,** 760-774.

HÅKANSSON, H. & FORD, D. 2002. How should companies interact in business networks? *Journal of Business Research,* 55**,** 133-139.

HÅKANSSON, H., FORD, D., GADDE, L. E., SNEHOTA, I. & WALUSZEWSKI, A. 2009. *Business in Networks,* Chichester, John Wiley & Sons Ltd.

HÅKANSSON, H. & LUNDGREN, A. 1995. Industrial Networks and Technological Innovation *In:* MÖLLER, K. & WILSON, D. (eds.) *Business Marketing: An Interaction and Network Perspective.* Boston: Kluwer Academic Publishers.

HÅKANSSON, H. & LUNDGREN, A. 1997. Paths in Time and Space - Path Dependence in Industrial Networks. *In:* MAGNUSSON, L. & OTTOSSON, J. (eds.) *Evolutionary Economics and Path Dependence.* Cheltenham: Edward Elgar.
HÅKANSSON, H. & WALUSZEWSKI, A. 2002. Path dependence: restricting or facilitating technical development? *Journal of Business Research,* 55**,** 561-570.
ISLAM, N. & MIYAZAKI, K. 2010. An empirical analysis of nanotechnology research domains. *Technovation,* 30**,** 229-237.
KOSTOFF, R. N., KOYTCHEFF, R. G. & LAU, C. G. Y. 2007. Global nanotechnology research literature overview. *Technological Forecasting and Social Change,* 74**,** 1733-1747.
MIOTTI, L. & SACHWALD, F. 2003. Co-operative R&D: why and with whom?: An integrated framework of analysis. *Research policy,* 32**,** 1481-1499.
MIYAZAKI, K. & ISLAM, N. 2007. Nanotechnology systems of innovation--An analysis of industry and academia research activities. *Technovation,* 27**,** 661-675.
MOGOUTOV, A. & KAHANE, B. 2007. Data search strategy for science and technology emergence: A scalable and evolutionary query for nanotechnology tracking. *Research policy,* 36**,** 893-903.
MORA-VALENTIN, E. M., MONTORO-SANCHEZ, A. & GUERRAS-MARTIN, L. A. 2004. Determining factors in the success of R&D cooperative agreements between firms and research organizations. *Research Policy,* 33**,** 17-40.
NELSON, R. R. & WINTER, S. G. 1982. The Schumpeterian Tradeoff Revisited. *American Economic Review,* 72**,** 114-132.
NIKULAINEN, T. & PALMBERG, C. 2010. Transferring science-based technologies to industry--Does nanotechnology make a difference? *Technovation,* 30**,** 3.
NOOTEBOOM, B. 1992. Towards a dynamic theory of transactions. *Journal of Evolutionary Economics,* 2**,** 281.
NORTH, D. C. 1990. *Institutions, institutional change, and economic performance,* New York, Cambridge University Press.
PALMBERG, C. 2008. The transfer and commercialisation of nanotechnology: a comparative analysis of university and company researchers. *The Journal of Technology Transfer,* 33**,** 631-652.
POWELL, W. W., KOPUT, K. W. & SMITH-DOERR, L. 1996. Interorganizational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology. *Administrative science quarterly,* 41**,** 116-145.
RAESFELD MEIJER, A. R. 1998. MISSING THE BUS: A SOCIO-COGNITIVE PERSPECTIVE ON TECHNOLOGICAL NETWORKS. *International journal of innovation management,* 2**,** 161.
ROBINSON, D. K. R., RIP, A. & MANGEMATIN, V. 2007. Technological agglomeration and the emergence of clusters and networks in nanotechnology. *Research policy,* 36**,** 871-879.
SALERNO, M., LANDONI, P. & VERGANTI, R. 2008. Designing foresight studies for Nanoscience and Nanotechnology (NST) future developments. *Technological Forecasting and Social Change,* 75**,** 1202-1223.
SHEA, C. M. 2005. Future management research directions in nanotechnology: A case study. *Journal of Engineering and Technology Management,* 22**,** 185-200.
VON HIPPEL, E. 1986. Lead Users: A Source of Novel Product Concepts. *Management Science,* 32**,** 791-805.
WALSH, S. T. 2004. Roadmapping a disruptive technology: A case study: The emerging microsystems and top-down nanosystems industry. *Technological Forecasting and Social Change,* 71**,** 161-185.

WOOD, S., JONES, R. A. L. & GELDART, A. 2003. *The social and economic challenges of nanotechnology,* Swindon, Economic and Social Research Council.
YOUTIE, J., IACOPETTA, M. & GRAHAM, S. 2008. Assessing the nature of nanotechnology: can we uncover an emerging general purpose technology? *The Journal of Technology Transfer,* 33**,** 315-329.