NETWORK FORCES INFLUENCING OUTCOMES OF INNOVATION JOURNEYS: R&D COOPERATION IN NANOTECHNOLOGY IN THE NETHERLANDS

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ABSTRACT

Within the field of Innovation in Business Networks several authors raised the need for more process research. We contribute to this body of research by analyzing the effect of different network forces over time on application and value creation performance of industry-university R&D cooperation in nanotechnology. With these two performance measures we covered the development setting and the producing/using setting of the innovation journey. We conducted a quantitative analysis of a dataset consisting of 206 projects, over a period of five years from 2000-2004. In total 412 organizations participated as a partner in these projects. The performance was measured five years after the completion of the projects. Our study showed how different network forces effected innovation outcomes over time and how they related to each other over time. Innovation forces arising from industry heterogeneity and mobilizing forces arising from complementarity had in five of eight points in time opposing effects and oscillated together in different directions for both innovation outcomes. Innovation forces arising from knowledge heterogeneity had a cubic effect on application performance and U shaped effect on value creation performance. Efficiency Forces arising from presence of large firms had a constant negative effect on both innovation outcomes. Relationship sustaining forces had a constant positive effect on both innovation outcomes. The observed paths are in line with previous research on innovation and learning in organizations, with this research providing further insight in the development of innovation journeys in networks.

Keywords: Nanotechnology, University-Industry relations, R&D cooperation, Business Development, Innovation Performance

INTRODUCTION

In business network theory, business interactions are considered as a process consisting of episodes evolving over time (Håkansson et al., 2009). Several authors maintain that to better understand business interaction more process research is needed (Ford and Hakansson, 2006, Andersson and Mattsson, 2010, Halinen et al., 2012) and this is even more so in the case of innovation in networks (Wilkinson and Young, 2012). Business network processes have been discussed theoretically (Araujo and Harrison, 2002, Hedaa and Törnroos, 2008, Hoholm and Olsen, 2012) methodologically (e.g. Dubois and Araujo, 2004, Ryan et al., 2012, Wilkinson et al., 2010) and empirically (e.g. Loohuis et al., 2010, Corsaro and Snehota, 2012) . Most of the empirical research consists of case studies describing characteristics of relationships and their development over time. The purpose of this paper is to use network theory in an analysis over time of utilization of technology developed in public-private R&D projects. Our research questions are: 1) How do network effects on innovation outcomes evolve over time? And: 2) How do these different network effects relate to each other over time?

In doing so, we offer the following contributions. First, we advance an operationalization on network effects that build on the model of business interaction of Håkansson, Ford, Gadde, Snehota and Waluszewski(2009). Secondly, we apply it to explaining outcomes of a particular network process, that of the innovation journey. Thirdly, we show that a quantitative research strategy can provide valuable insights into the dynamic nature of networks. Though this might abstract away from the bolts and nuts of business interaction, it however provides a landscape arising from business interactions which can be easily missed from shadowing their development over time in case studies. Finally, we test the business interaction model and the theoretical propositions made by Waluszewski (2011), Hoholm & Olsen (2012), Håkanson & Waluszewski (2011) and Wilkinson & Young (2005) thus discussing the process through which network effects influence innovation outcomes over time.

The paper is organized as follows. After reviewing the relevant literature, developing hypotheses and operationalizing the business interaction model, we set out results of analysis over time of an innovation network over a period of four years. The final section covers discussion, conclusion and directions for further research.

INNOVATION JOURNEYS

The Minnesota Innovation Research Program (MIRP) studies were conducted to understand how changes in innovation ideas, outcomes, people, transactions and contexts develop over time (Van De Ven et al., 1989) The general conclusion of MIRP studies is that innovation cannot be reduced to a linear model of stages and phases. Van de Ven et al. (1999:184) propose that: “the innovation journey is a nonlinear cycle of divergent and convergent activities that may repeat over time and at different organizational levels if resources are obtained to renew the cycle.”. A cyclical process model is proposed that consists of a sequence of divergent and convergent phases and explains temporal dynamics in a variety of innovation processes. These divergent convergent phases reflect what March (1991) described as exploration and exploitation. Since March (1991) developed the exploration-exploitation framework and refined it together with Levinthal, the balancing of exploration and exploitation is a recurring theme in strategic management and innovation literature. Levinthal and March (1993:105) indicated that: ‘The basic problem confronting an organization is to engage in sufficient exploitation to ensure its current viability and, at the same time, to devote enough energy to exploration to ensure its future viability, Survival requires a balance ... ‘ In the strategic management literature the theme of balancing is represented by a large body of research that studies exploration and exploitation within and across organizations, and four fundamental modes of balancing can be identified: no balancing, organizational balancing, temporal balancing and domain balancing (Lavie et al., 2010).

From a network point of view one can wonder whether in the innovation journey the sequential balancing as proposed by Van de Ven et al (1999) will take place. As divergent and convergent forces often run together (Hakansson and Waluszewski, 2002) and can have opposing effects on innovation (Waluszewski, 2011, Hoholm and Olsen, 2012). In the next section we further specify network forces and their effect on innovation by making use of the business interaction model (Håkansson et al., 2009).

NETWORK FORCES

In the model of business interactions organizations are described as interacting with each other, leading to multifaceted interdependencies over time and space (Håkansson et al., 2009, Ford et al., 2010). This business interaction model specifies three structural or space related aspects (Resource Heterogeneity, Actor Jointness and Activity Interdependency) and in parallel three processes or time related aspects (Paths of Resources, Co-evolution of Actors and Specialization of Activities). Both Time and Space aspects lead in a recursive way to connected relationships that are described as activity patterns, resource constellations and actor webs. For the purpose of this study we consider the structural and processual aspects of interaction as network effects in an innovation network influencing innovation outcomes such as application developed and value created.

Particularly in the case of technological development and innovation where often public and private organizations cooperate, Håkansson & 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 the 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, activities and actors.

In order to understand the forces that influence the outcomes of innovation journeys Waluszewski (2011) proposes to analyze resources, activities and actors in combination with the developing, producing and using setting, thus representing nine different “interface logics”. Waluszewski (2011:140) argues that innovation forces can be understood by the way resources are developed and combined. Efficiency forces can be understood from the activities performed and linked within and across organizations. The more efficient alignment of activities in established production systems the more difficult it is to change them.

In relation to the view on innovation journeys as suggested by Van de Ven et al (1999) we learn from the reasoning above that innovation forces are particular divergent behaviours and efficiency forces are particular convergent behavior. Moreover, sequential balancing as proposed by Van de Ven et al (1999) does not take place(Hoholm and Olsen, 2012:353). Instead, innovation and efficiency forces run together and can have opposing effects on innovation. Therefore, we propose.

Hypothesis 1: E*fficiency and innovation forces in networks occur at the same time and have opposing effects on innovation outcomes in the network*.

Via mobilizing forces, efficiency and innovation forces can be balanced (Waluszewski, 2011). Balancing these two different forces can be understood in a way that actors are related and how relationships develop within and across organizations. According to Waluszewski (2011:152) this process can be managed by balancing across settings, this is done by influencing the composition of partners in the R&D projects; choices can be made about the involvement of partners from the development, producing and using setting. This is what Lavie et al (2010) would call a balancing between domains. In our previous research the positive effect of a balanced partner composition is confirmed (Raesfeld et al., 2012a, Raesfeld et al., 2012b). So far however, we did not analyze the interactions between the structural variables, which might have revealed a less significant outcome. Contrary to this balance argument, Håkansson and Waluszewski (2011:178) hold that when bringing together different interfaces, the effects will differ over time, as interactions and interdependencies in the network make outcomes nonlinear and unpredictable. However, in this paper we investigate if some prediction is possible. There are different types of prediction of analyses over time, depending on whether a system is random, chaotic or periodic (Van de Ven, 1999:188). Systems can differ in terms of a prediction of path or a prediction of pattern. Path is a trajectory over time and pattern is a temporal shape which one can observe when looking at the route of measurements over time. Random systems are not predictable in path and pattern; chaotic systems are predictable in pattern but not in path and periodic systems are predictable in path and pattern. We expect a network to be a chaotic system. Consequently we suggest the following hypothesis:

Hypothesis 2: *Over time, efficiency, innovation and mobilizing forces in networks are predictable in pattern but not in path*.

As a result, the question arises if it is possible to manage innovation and change in networks at all? Wilkinson and Young (2005) and Bairstow and Young (2012) maintain that the causes of network evolution are largely beyond the control of individual organizations within that network but are built up from the actions and interactions between the organizations involved in the network. These networks of organizations have greater intrinsic variety and therefore greater ability to cope with uncertainty and complexity. For that reason it makes sense for individual organizations to participate in, co-create with and sustain networks of relationships. Within IMP research this is commonly accepted and proven in empirical research and reflected in the discussion on mobilizing forces. In previous research on R&D partnerships we found a positive influence of established relationships on innovation performance ((Raesfeld et al., 2012b)). We expect that over time established relationships have a predictable positive effect on innovation outcomes. This leads to the following hypothesis.

Hypothesis 3: *Over time, relationships sustaining forces are predictable in both path and pattern and have a positive effect on innovation outcomes in the network.*

So far, we did not make a distinction between innovation outcomes, but as indicated by (Håkansson and Waluszewski, 2007), the use, production and development have different economic logics. We therefore expect the different network forces to have dissimilar effects on outcomes of the development, the producing or the using setting. This leads to the following hypothesis.

Hypothesis 4: *Over time the effects of network forces follow a different path and pattern in the development, producing and using setting.*

Following the above line of argumentation in the next section we set out our operationalization to analyze inter-organizational R&D projects as events that emerge over time into a larger innovation network. We do so to investigate the four network forces on application development and value creation outcomes in the network.

METHODS

Research design

Our intent to contribute to process research in business network studies and analyze the role of network effects on innovation outcomes over time lead us to conduct a research approach that comes close to a 'Quantification strategy' (Langley, 1999) or 'weak process research' (Tsoukas and Chia, 2002). We started with a database on industry – university R&D cooperation projects. We considered he projects as events that emerged into a larger network and we focused on change in characteristics of the projects Over time and their influence on innovation outcomes. We try to explain change in term of causal relationships between independent and dependent variables in the analysis over time. Our research also follows a process method in the sense that we try to find an overall pattern over time (Van de Ven and Poole, 2005:1384).

Research setting

The research setting is a nanotechnology R&D network in the Netherlands. 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). Commercial development of nanotechnologies are expected to depend on the ability to integrate development, producing and using settings distributed across professional groups, companies, and research organizations (Bozeman et al., 2007, Palmberg, 2008). The investigated nanotechnology network is build from R&D projects, in which a diversity of actors participate such as companies, governmental parties, research institutes, hospitals/medical institutions, universities/schools and special interest groups.

Data

In this research we used 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 we used 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 211 nanotechnology projects, which started in a period from 2000 until 2004. We excluded 5 projects because they had no other participants involved and therefore variables about partnership characteristics in the projects 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. Finally, we collected information for each company participating on size and the industry classes they belong to.

Dependent Variables

We made a distinction between two types of innovation outcomes with application performance representing outcomes related to the development setting and value creation performance representing outcomes related to the producing and using setting. 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.

Independent variables

Innovation forces in a network are defined as the heterogeneity of resources embedded in the R&D projects over time. We used two different operationalizations of innovation forces: Knowledge heterogeneity[1] and Industry heterogeneity. The heterogeneity measures for knowledge and industry heterogeneity and the one for balanced 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.

Knowledge 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 and can provide different use contexts. For this measure the Dutch version of the sic coding was used, which consists of 21 different industry classes.

Efficiency forces in a network are defined as the established activity interdependencies of the actors in the R&D projects over time. We used large firm interaction as a proxy of efficiency forces. Previous research in which we controlled for firm size showed that having large firms in a research project has a negative effect on the innovation outcomes(Raesfeld et al., 2012b). Large firm interaction is measured as a dummy variable large firm participating in the project; large firms are those who have more than 500 employees.

Mobilizing forces are the activities directed to balancing innovation and efficiency forces in the R&D projects and used balanced complementarity[2] as a proxy. Assuming that organizations active in different transformational activities have different roles in the innovation journey, we construct a measure of balanced 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.

Relationship sustaining forces are defined as those activities directed towards working repeatedly together with similar partners and we used network stability as a proxy. Network

[1] In previous research (Raesfeld et al, 2012a; Raesfeld et al, 2012b) we labeled this variable as technological heterogeneity, but as it is calculated on the basis of patents owned by the participants we think that knowledge heterogeneity is a better term.

[2] In previous research (Raesfeld et al, 2012a; Raesfeld et al, 2012b) .we used the same measure labeled as value chain complementarity however in a different causal structure, therefore we labeled the measure differently in this paper.

stability is a count of the number of participants in a project that had been participating before in the network. The participants in the year 2000 were used as base year. Finally we controlled for small firm presence, proportion of firms in the project and commitment.

Analysis

In the analyses it was 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. For the years 2001-2004 we calculated means and standard deviations and conducted an analysis of variance to see if there were significant differences between the years. Next in order to picture the path and patterns of the influence of the forces on application development and value creation, we estimated these effects for the years 2001-2004 and plotted it in two graphs one for application performance and one for value creation performance.

RESULTS

Table 1 describes the means and standard deviations of the variables over the years 2001-2004. The analysis of variance indicated that only for the variable network stability the difference between the means over the years was significant $F(4,202) = 2,13$, $p < 0,5$, The year 2004 shows a significant higher mean of network stability. Table 2 summarizes the estimates and standard errors of the effects on application performance in the years 2001-2004, and these are depicted in figure1. Table 3 summarizes the estimates and standard errors of the effects on value creation performance in the years 2001-2004 and depicted in figure 2. It is 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.

Table 1: Means and standard deviations of the parameters

	2000		**2001**		**2002**		**2003**		**2004**	
	mean	Std. Deviation	mean	Std. Deviation	mean	Std. Deviation	mean	Std. Deviation	mean	Std. Deviation
Innovation Forces										
Knowledge Heterogenity	0.07	0.06	0.07	0.06	0.08	0.06	0.07	0.06	0.05	0.03
Industry Heterogenity	0.06	0.08	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.05
Efficiency Forces										
Presence of Large Firms	0.82	0.39	0.91	0.29	0.83	0.38	0.83	0.38	0.89	0.31
Mobilizing forces										
Balanced Complementarity	0.07	0.07	0.07	0.04	0.07	0.07	0.08	0.06	0.07	0.04
Relationship Sustaining Forces										
Network Stability			3.27	1.77	2.91	1.69	3.31	1.62	4.61	2.01

Effects of network forces on application performance

Table 2 and figure 1 show that by 2004 the effects of innovation and efficiency forces are negative, and those for mobilizing and relationship sustaining forces are positive. Figure 1 reveals an almost constant effect of Efficiency (measured by Presence of large firms) and Relationship sustaining forces (measured by network stability) on application performance. A degreasing effect of Industry heterogeneity and oscillating effects in the same direction of Knowledge heterogeneity and Balanced complementarity is shown in figure 1.

Table 2 Effects of network forces on application performance

	2001	**2002**	**2003**	**2004**
n	33	35	52	38
Innovation Forces				
Knowledge Heterogenity	-4.71 (9.31)	10.94 (10.55)	-7.37 (7.33)	-1.77 (15.34)
Industry Heterogenity	21.07** (9.39)	6.15 (6.22)	-1.32 (5.18)	-3.80 (9.60)
Efficiency Forces				
Presence of Large Firms	-1.60 (2.75)	-.12 (1.59)	.74 (.93)	-3.47*** (1.44)
Mobilizing forces				
Balanced Complementarity	-25.79* (16.81)	16.78** (9.92)	.49 (10.83)	9.24 (15.73)
Relationship Sustaining Forces				
Network Stability	.33 (.28)	.50* (.34)	-.37** (.22)	.09 (.23)

p<0.20; **p<0.10; *** p<0.02; one-sided test

Figure 1: Effect of network forces on application performance over time

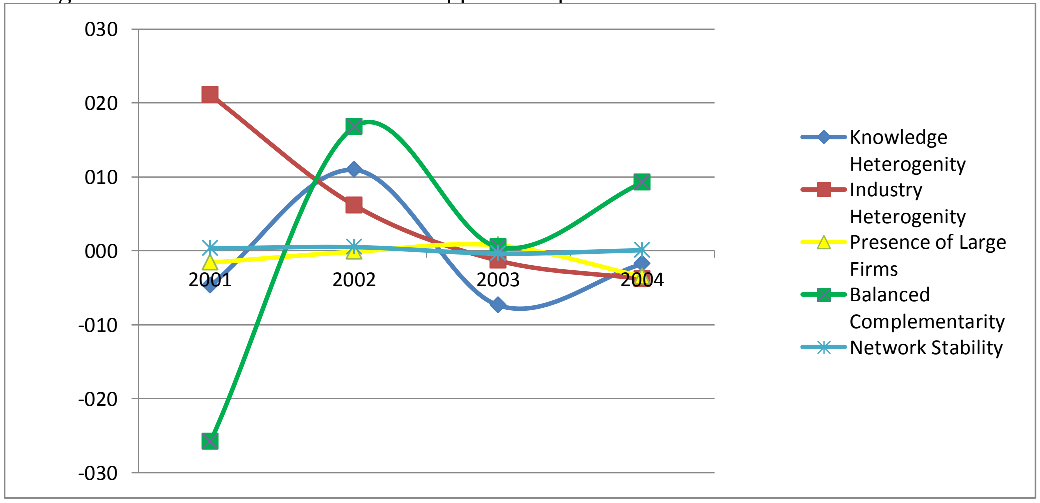


Table 2, indicates that not at all points in time Innovation Forces and Efficiency Forces have an opposite effect on application development. However, figure 1 shows an opposite trend effect between the two. So when looking at the trend effects of innovation and efficiency forces on application performance, hypothesis 1 : E*fficiency and innovation forces in networks occur at the same time and have opposing effects on innovation outcomes in the network*. can be confirmed.

Figure 1, shows a predictable path and pattern for efficiency forces measured by Presence of Large Firms, and innovation forces measured by Industry Heterogeneity and Relationship sustaining forces measured by Network Stability. In figure 1 we see that Knowledge Heterogeneity and Industry Heterogeneity the two measures for innovation forces do not have the same pattern. Over time the effect on application performance of Knowledge Heterogeneity oscillates and might be a cubic shaped effect, while Industry heterogeneity follows a decreasing path. Mobilizing forces measured by Balanced Complementarity shows no predictable path but a predictable pattern which might and up in cubic or quartic shaped effects. So for the effect of Knowledge heterogeneity and balanced complementarity on application development Hypothesis 2: *Over time, efficiency, innovation and mobilizing forces in networks are predictable in pattern but not in path.* can be confirmed for application performance. But Hypothesis 3 is not confirmed for the effect of Industry Heterogeneity, Presence of large firms, and Network on application performance.

A look at figure 1 and table 2 shows that Relationship Sustaining forces as measured with network stability is predictable in path and pattern.. It shows a low almost constant positive effect on application performance, with a negative dip in 2003. Therefore Hypothesis 3: *Over time, relationships sustaining forces are predictable in both path and pattern and have a positive effect on innovation outcomes in the network* is partly confirmed for application performance.

Effects of network forces on value creation performance

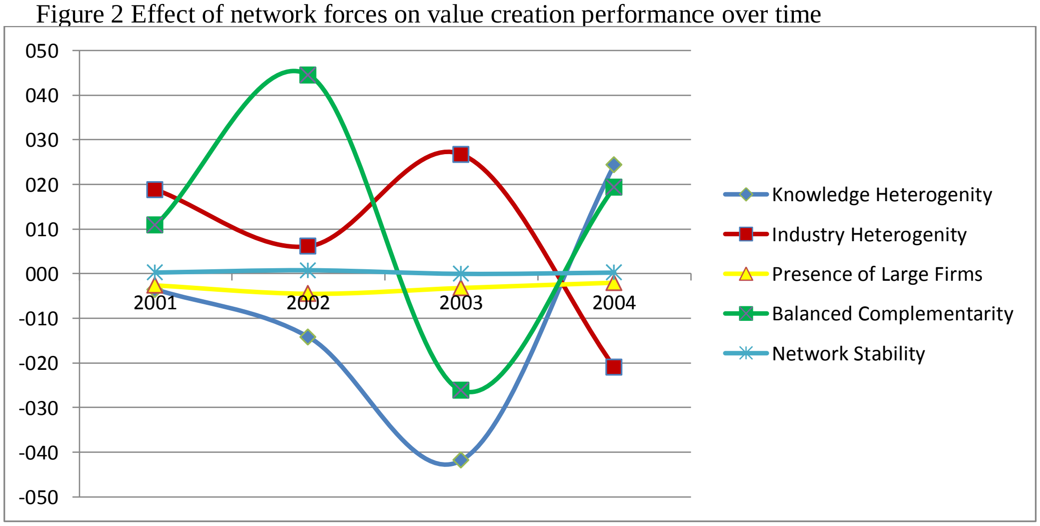
Figure 2 reveals an almost constant effect of Efficiency Forces measured by Presence of Large Firms and of Relationship Sustaining Forces measured by Network Stability on value creation performance. The yearly effects of Knowledge Heterogeneity on value creation are negative up till 2004 and follow a U shaped curve. The effects of Industry Heterogeneity and Balanced complementarity oscillate in opposite directions.

Table 3: Effects of network forces on value chain performance

	2001	**2002**	**2003**	**2004**
n	33	35	52	38
Innovation Forces				
Knowledge Heterogenity	-3.54 (11.45)	-14.20 (24.40)	-41.83** (23.79)	24.39 (24.78)
Industry Heterogenity	18.83* (12.73)	6.13 (14.16)	26.73* (16.75)	-20.97 (18.96)
Efficiency Forces				
Presence of Large Firms	-2.64 (2.27)	-4.52* (3.10)	-3.21* (2.13)	-2.03 (1.86)
Mobilizing forces				
Balanced Complementarity	10.87 (26.08)	44.55** (19.24)	-26.18 (26.02)	19.31 (25.37)
Relationship Sustaining Forces				
Network Stability	.24 (.40)	.76* (.50)	-.05 (.36)	.23 (.35)

p<0.20; **p<0.10; *** p<0.02; one-sided test

Figure 2 Effect of network forces on value creation performance over time



The two measures of innovation forces have opposite effects over the whole period of which Knowledge heterogeneity is negative up till 2004 and the effect of Industry Heterogeneity has the reverse effects. Efficiency forces are constantly negative. Therefore Hypothesis 1: E*fficiency and innovation forces in networks occur at the same time and have opposing effects on innovation outcomes in the network,* can only be confirmed up till 2003 for the industry heterogeneity in combination with presence of large firms.

Figure 2 shows that Efficiency forces (Presence of large firms) and Innovation forces, Knowledge heterogeneity) follow a predictable path. While Innovation forces (Industry heterogeneity) and Mobilizing forces (balanced complementarity) follow a pattern in opposite directions. Therefore, Hypothesis 2: *Over time, efficiency, innovation and mobilizing forces in networks are predictable in pattern but not in path*, is partly confirmed.

A look at figure 2 and table 3 shows that Relationship Sustaining forces as measured with network stability is predictable in both path and pattern. Only for 2003 there is a slight negative dip. Therefore Hypothesis 3: *Over time, relationships sustaining forces are predictable in both path and pattern a have positive effect on innovation outcomes in the network* is partly confirmed for value creation performance. Table 4 summarizes the assessments of the hypothesis for the two dependent variables.

Comparison of the effects on the two innovation outcomes shows different patterns. Only network stability has a similar effect for both application and value creation performance all the other network forces showed different effects over time on the innovation outcomes representing the development setting and the producer/user setting. Therefore, Hypothesis 4: *Over time the effects of network forces follow a different path and pattern in the development, producing and using setting* is confirmed for all network forces except for the Relationship Sustaining Force

Table 4: Summary of the assessment of the hypotheses

Hypotheses	**Effect on application performance**	**Effect on value creation performance**
H1 : *Efficiency and innovation forces in networks occur at the same time and have opposing effects on innovation outcomes in the network*	Confirmed	Partially confirmed
H2: *Over time, efficiency, innovation and mobilizing forces in networks are predictable in pattern but not in path.*	Partially confirmed	Partially confirmed
H3: *Over time, relationships sustaining forces are predictable in both path and pattern and have a positive effect on innovation outcomes in the network.*	Partially confirmed	Partially confirmed
Hypothesis 4: *Over time the effects of network forces follow a different path and pattern in the development, producing and using setting.*	Partially confirmed	

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CONCLUSION, DISCUSSION AND FURTHER RESEARCH

Within the field of Innovation in Business Networks several authors raised the need for more process research. We contribute to this body of research by analyzing the effect of different network forces over time on application and value creation performance of industry-university R&D cooperation. To do so we conducted a quantitative analysis of a dataset consisting of 206 projects in which in total 412 organizations participated. Our study showed how different network forces effected innovation outcomes over time and how they related to each other over time. For both application and value creation performance, Relationship Sustainable Forces had a constant positive effect and Efficiency Forces had an almost constant negative effect. The Mobilizing Forces (measured by Balanced Complementarity) and the Innovation Forces (measured by Industry Heterogeneity) were oscillated together in different directions for both innovation outcomes and in five of the eight points in time had opposing effects. The two variables by which we measured Innovation Forces had completely different effects, suggesting that they have their innovative force on different settings, Knowledge Heterogeneity on the development setting and Industry Heterogeneity on the using/producing setting.

Compared to a cross section analysis, the analysis of network forces over time conducted in this study provides further insight into the developments taking place in innovation journeys. Hereafter, we try to explain the effects of network forces in view of the innovation journey that took place in the nanotechnology network under study. The overall patterns in figure 1, suggests that for application development first design requirements from different contexts are specified, after which the use of a variety of knowledge becomes important. From the pattern in figure 1, one can assume that in 2001 variety of business contexts was necessary to start the innovation journey, at that moment a variety of knowledge is difficult to match with the problems articulated by firms from different industries and at the same time established firms try to keep the status quo and hindered the development. It is not yet clear how the new solutions will be integrated in new ways and therefore the effect of a balanced partner complementarity is negative. Around 2002 probably opportunities for new dominant designs arise, showing a decreasing effect of Industry Heterogeneity and thus a diminishing variety of practice combined with an increasing positive effect of Balanced Complementarity and Knowledge Heterogeneity. Around 2003 the pattern suggests that dominant designs get established which goes together with an increasing importance of Mobilizing Forces, negative effects of Innovation Forces and negative effects of Efficiency Forces coming from established firms.

The pattern in figure 2 suggest that for value to be created in the producing and using setting, Knowledge Heterogeneity and Presence of Large Firms have a negative effect, at this stage new dominant designs provably have to be further developed and new knowledge and established firms inhibit this process. The effects of Industry Heterogeneity and Balances Complementarity are positive, however between 2001 and 2002 the effect of Industry Heterogeneity decreases and that of balanced complementarity increases, this indicates that integration for value creation is necessary. Between 2002 and 2003 the effect of Industry Heterogeneity increases, while the effect of Balanced Complementarity decreases, this indicates that a search for novel use contexts sets in. Overall, over the years we see an oscillation of the effects of Industry Heterogeneity and Balanced Complementarity on Value Creation. In 2004 Industry Heterogeneity had a negative effect on value creation probably new using context did not provide further generalization of the technology, but the effect of Balanced Complementarity provided opportunities for further knowledge integration and the effect of Knowledge Heterogeneity becomes positive.

The observed paths are in line with previous research on innovation and learning in organizations (Nooteboom, 1999) and allows for more research on the level of networks. Also, these paths indicate interacting effects between network forces that go beyond the choices made by project managers, participants and policy makers. Therefore, we suggest a further multi-level study into the interactions effects of network forces on innovation journeys. Agent based modeling could be a suitable research strategy to do so (Wilkinson et al., 2010).

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