When to use a centralized or decentralized network approach for collaborative product innovations?

The influence of betweenness on the performance of architectural and non architectural innovations.

This research of collaborative innovation projects explores the impact of the level of betweenness on the innovation performance of architectural and non-architectural innovations. Data of a quantitative study among product innovation networks in four different industries in the United states is used to test two theoretical explanations on the effects of betweenness. While there are several studies that discuss the impact of different innovation network configurations on innovation performance, knowledge about the impact of betweenness is still underdeveloped. Consistent with past research, the results of a hierarchical regression analysis indicate that innovation managers which use a high level of betweenness, a centralized lead firm, will positively influence the architectural innovation performance. Surprisingly against the theoretical expectations the performance of non-architectural innovations are also positively influenced by a high level of betweenness. Although the type of innovation still has the most influence on the performance. Finally this paper concludes with implications of the study's findings for innovation managers that need to decide how to organize for innovations.

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Assignment: Master thesis

University: University of Twente
Master: Innovation & Entrepreneurship

Place and date: Enschede, 22 March 2012

Introduction

Over recent decades, it has become widely accepted that innovation is an interactive process involving the innovative firm and its environment (Andersen & Drejer, 2006). Businesses that collaborate with other organizations in order to develop and market innovations will be more successful than businesses that operate independently (Mitchell & Singh, 1996). However, there are different types of innovations that benefit from different ways of organizing the innovation process. Research distinguishes between innovation activities that are clearly separable or modular and strongly interdependent or architectural in nature (Henderson & Clark, 1990). In this study the focus is on architectural innovations, where the performance depends on related complementary innovations. Centralized or decentralized position of the lead firm has different implications for the innovation. A challenge for the innovation network leader is to find the organizational form that fits the type of innovation they are pursuing the best. Why is a high or low level of betweenness good or bad? The goal is to investigate the effects of the level of betweenness on the architectural or non-architectural innovation performance.

Previous research has examined that in case of architectural innovation, where the economic benefit depends on related complementary innovations, the best form to organize the innovation is when the lead firm uses a centralized approach, so the level of betweenness is high. Communication and knowledge transfer between the different innovation partners about the changing interfaces is very important for successful architectural innovation. In the case of a centralized approach there is a lot of control and activities can be coordinated by means of a hierarchy (Andersen & Drejer, 2006; Chesbrough & Teece, 1996). However will centralized tight coordination by the innovation network leader really improve architectural innovation?

Next to this, the effects of a network in which the lead firm uses a decentralized approach on the performance of a non-architectural innovation, are studied. It is argued that networks without a centralized lead firm can work more efficient, which has a positive influence on the performance. A centralized lead firm is not necessary for non-architectural innovations, the need for coordination and control between the different innovation partners is low. A decentralized approach has more speed and efficiency, not everything has to be reported to the central lead firm which will positively influence the performance (De Laat, 1999).

This research tries to contribute to our understanding of the impact of the level of betweenness of a lead firm on the performance of architectural or non-architectural innovations. The data of a quantitative study among product innovation networks in four different industries in the United States is used to test one hypothesis.

The paper is structured as follows. In the first chapter, the theoretical background of architectural innovation and the influence of betweenness on the innovation performance are reviewed. Next, a hypothesis is developed about the relationship between the level of betweenness and the architectural and non-architectural innovation performance. Following this, the method used for testing the hypothesis is explained. Finally the theoretical and managerial implications and limitations of the study are described.

Theoretical framework

Architectural innovation and the link to performance

Architectural innovation is described as an innovation that changed the way in which components of a product are linked together, while leaving the core design concept untouched as "architectural" innovation. The core design concept explains the basic knowledge underlying the components. It destroys the usefulness of a firm's architectural knowledge but preserves the usefulness of its knowledge about the product's components (Henderson & Clark, 1990).

In this description there is a distinction between the products as a whole (the entire system) and products in parts (components). The product as a whole explains how the components will work together, the components are defined as a distinct portion of the product that embodies a core design concept and performs a well defined function. An example of an architectural innovation provided by Henderson & Clark (1990) is the room air fan. The major components include the blade, the motor, the control system and the mechanical housing. The established technology is that of, large electrically powered fans, mounted in the ceiling. The introduction of a portable fan would be an architectural innovation. The primary components are largely the same, but the architecture of the product is quite different. There are also significant changes in the interactions between the components. For example the portable fan has a smaller size which means that there are new interactions between the motor size and the blade dimensions (Henderson & Clark, 1990).

An architectural innovation draws attention to innovations that use many existing core design concepts in a new architecture and that therefore have a more significant impact on the relationships between components than on the technologies of the components themselves. The essence is to link existing components in a new way. The components themselves are not untouched. The central point is that the core design concept behind each component and the associated scientific and engineering knowledge remain the same. An architectural innovation is often triggered by a change in the components. In the case of the room air fan the size is changed, that creates new interactions and linkages with other components in the established product. But it remains important that the core design concept behind the components stays the same (Henderson & Clark, 1990).

A successful innovation depends on the spread of information and the exchange and combination of resources. Consequently the focus of innovation is found to be in networks and relations rather than in individual firms alone (Moran, 2005). Organizations build architectural knowledge around their relationships. Therefore communication channels, information filters and problem solving strategies play a significant role in architectural innovations. An effective organization will organize itself around the product's primary components in the network. These are the key relationships around which the organization builds architectural knowledge. An architectural innovation's effect depends in a direct way on the nature of organizational learning about changes in architecture and about new interactions across components. The components are the key subtasks of the organization's design problem (Henderson & Clark, 1990).

Some authors use the term 'systemic innovations' instead of architectural innovations. Systemic innovations are described as innovations that require significant adjustments in other parts of the business system than where they are embedded in (Teece, 1986). Additional to this definition systemic innovation has been defined as "an innovation whose benefits can be realized only in conjunction with related, complementary innovations" (Chesbrough & Teece, 1996, p. 6). Architectural innovations are systemic innovations. Their benefits can only be realized if the different component producers work together. The example about the development of a portable air fan explains that this new fan requires interrelated changes in product design, supplier management, information technology, and so on. In a systemic innovation, members of a network are dependent on other members over whom they have no control. Systemic innovations therefore pose a unique set of management challenges regarding information exchange. In essence, systemic innovations require information sharing and coordinated adjustment throughout an entire product system (Chesbrough & Teece, 1996). The architectural innovation consists of more elemental units, so that the overall performance depends on the quality of every component. The characteristics of multiple interactions means that the components require close configuration for reliable performance (Mitchell & Singh, 1996).

How should the network be organized in order to improve the performance of an architectural innovation? It is argued that architectural innovation requires tight coordination across organizational boundaries. However it is unclear whether centralized, tight coordination by the innovation network's leader improves architectural innovation. Next part will elaborate on the different influences of the level of betweenness on the innovation performance.

Betweenness and the link to performance

In this chapter the advantages and disadvantages of the level of betweenness within a network are elaborated. When should the lead firm organize innovation by using decentralized network approaches and when by using centralized network approaches? Centralized networks are those in which suppliers are tied to a 'lead' firm. In decentralized networks suppliers have to meet the demands of diverse suppliers and customers by a market process or negotiation. Nobody in the network has total control (Robertson & Langlois, 1995). The level of betweenness indicates the information control, it measures the centrality of a focal firm in a network and the extent to which a firm falls between pairs of other firms on the communication paths that link them (Freeman, 1979).

Betweenness is, in some sense, a measure of the influence a lead firm has over the information through the alliance network (Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008). The information control can be measured by the amount of network flow which is controlled by this firm (Borgatti, 2005).

Centralized or decentralized positions of a lead firm have different implications for innovations. The challenge for the lead firm is to choose the organizational form that matches the type of innovation they are pursuing the best. Why is a high level of betweenness (bureaucracy) bad, and a low level of betweenness (flexibility) good? Chesbrough and Teece (1996) argue that decentralized structures will be more responsive to a changing marketplace. This is because they are more flexible. Therefore, a decentralized innovation network can also play a more distinctive role in innovations. Most of their business is coordinated through the marketplace, resulting in more responsiveness than in case of a centralized lead firm. It is also argued that a decentralized approach is more efficient because not everything has to be reported to the lead firm. This ultimately saves time and money (Andersen & Drejer, 2006). Unfortunately there is also a high risk. Every player will be driven to enhance their own positions and over time their common interests may diverge. Firms that are highly dependent on its network partners capabilities can in this case result in lower performance (Afuah, 2000). Moreover, collaborative relationships with partners, which are usually a source of competitive advantage, can become a handicap when the common interests diverge. The overall coordination cannot be prescribed; it depends on the loyal cooperation of partners (De Laat, 1999). A decentralized position of a lead firm inevitably produces more conflicts than centrally managed innovations do. The result: partners are unable to align strategically and coordinated development activity falters (Chesbrough & Teece, 1996).

A centralized lead firm can resolve conflicts in the network and coordinate all the activities that are necessary for successful innovation. All partners and suppliers are tied to a lead firm that controls the innovation. The control leads to a more common understanding and shared principles about the different parts of an innovation (Chesbrough & Teece, 1996). A centralized lead firm has the structural capacity to facilitate interactions between the partners in the innovation network (Granovetter, 1973). Sparrowe et al (2001) also found that a centrally positioned firm has a higher extra-role performance which includes helping other firms. This will engage in more knowledge sharing and therefore achieve a higher innovation performance than firms that are low in network centrality (Reinholt, Pedersen, & Foss, 2011; Sparrowe, Liden, Wayne, & Kraimer, 2001).

Next to these benefits the control and coordination of the lead firm can also facilitate rapid mutual adjustment because information is more centralized. The vertical integration of activities could also be seen as a way to avoid the capability-related vulnerability which a firm engaged in decentralized innovation processes is subject to (Andersen & Drejer, 2006). A centralized lead firm makes the network less vulnerable. Not every player will only be driven to enhance their own positions, the loyal cooperation of partners is organized and controlled by the central lead firm.

Both approaches have different benefits and drawbacks. The goal is to find out how a network should be organized in order to improve the innovation performance. The next part will look specifically at the effects of betweenness on an innovation which is either architectural or not.

The effects of betweenness on architectural innovation

Centralized or decentralized positions of a lead firm have different implications for innovations that are autonomous. They can be pursued independently from other members and innovations that are fundamentally systemic (Chesbrough & Teece, 1996). The challenge for the lead firm is to choose the organizational form that matches the type of innovation they are pursuing the best. In case of systemic technology, so for architectural innovations, value is best realized when the lead firm is using a centralized network approach. The control of innovation activities provided by a centralized lead firm is necessary in order to coordinate and facilitate rapid mutual adjustment between the different component's producers. (Andersen & Drejer, 2006).

Architectural innovations have the characteristic of multiple interactions. This means that the components require close configuration for reliable performance (Henderson & Clark, 1990; Mitchell & Singh, 1996). By their very nature, architectural innovations need information sharing and coordinated adjustment throughout the entire network. This means that in order to successfully commercialize an architectural innovation profitably, a great amount of information from business contacts, customers, and sometimes scientist, needs to be gathered and understood. This requires a challenge regarding the information, exchange and coordination. The different innovation companies are dependent on complementary innovators which makes them vulnerable. As argued in the "weak tie theory" of Granovetter (1973), weak relations between business contacts often cannot achieve sufficient coordination, with the result that information sharing can be reduced or biased. Each company wants the other to do more, while each is also looking for ways to realize the most gain from the innovation. This indicates that a collaborative relationship can cause serious problems which can include: lost information, organizational disruption, and adaptation difficulties. Several authors have noted that collaborating businesses risk losing critical proprietary information to their partners (Hamel, 1991; Jorde & Teece, 1990).

Often the information exchange will be easier and safer when there is a centralized lead firm resulting in a high level of betweenness. This is especially important for a systemic innovation because firms are not only dependent on their own capabilities being updated and relevant, but also on the development of the capabilities of its collaboration partners. The expected conflicts and choices that take place by a systemic innovation can be resolved by a centralized lead firm (Chesbrough & Teece, 1996). This allows the developers of components for the architectural innovation to concentrate their capabilities more pointedly, and thus improve their piece of the system. A centralized lead firm is necessary for effective information sharing and to prevent the different suppliers from going their own way.

While some innovations are the result of the application of new knowledge, others result from reconfiguring existing knowledge to create "architectural innovations" (Henderson & Clark, 1990). The reconfiguration of existing knowledge by using new patterns of integration is more complex but is important for systemic innovations. The integration of knowledge is the driving force of an architectural innovation (Grant, 1996). For architectural innovation, a relative large transfer of tacit design knowledge is required. Communication about the changing interfaces requires the transfer of complex design knowledge. When interfaces within the product architecture are not well specified, the changing of one component can make the whole innovation incompatible. Tacit knowledge is difficult to transfer. Results indicate that it is more efficient to use strong ties to transfer tacit knowledge than weak ties (Reagans & McEvily, 2003). A centralized lead firm develops strong ties to suppliers and other partners, all the information passes the centralized lead firm. This will increase the transfer of tacit knowledge and benefits the performance of systemic innovations.

As a result, what is needed for successful architectural innovation? Networks, where different business contacts can freely share information about the components without worry of expropriation, where entities can commit themselves and not be exploited by that commitment and where disputes can be monitored and resolved in a timely way (Teece, 1996). As such it is expected that a high level of betweenness, when all information passes the lead firm, will have a positive impact on the performance of architectural innovation, which leads to the following hypothesis:

Hypothesis 1: *A high level of betweenness will have a positive impact on the performance of architectural product innovations.*

This hypothesis can also be explained in the other way, for non-architectural innovations. A low level of betweenness will have a positive effect on the performance of a non-architectural innovation because an innovation which is not architectural may proceed faster when the lead firm is using a decentralized network approach. This approach has more speed, flexibility and efficiency, not everything has to be reported to the central lead firm (De Laat, 1999). It is quite a complicated management task for a centralized lead firm to fit all the complementary bits and pieces of knowledge together. This can make the decision making process slow and ponderous, and also the coordination costs will increase (Teece, 1996).

A non-architectural innovation decreases the number of architectural interfaces, which suggests a decrease in dependence, and thus in the need for coordination (Mitchell & Singh, 1996; Sanchez, 1995). Therefore knowledge transfer and coordination is less important. The different partners are more independent from each other and the innovation can take place in a decentralized network approach. In an ideal case, interaction between the different innovation partners is only necessary at the beginning and at the end of the supplier task. In the beginning, the task has to be explained and information exchanged, and towards the end of the task, the results of the effort have to be transferred to the customer company and integrated with the overall design (Lakemond, Berggren, & van Weele, 2006). This provides the decentralized approach with greater flexibility (Mitchell & Singh, 1996).

Presumably the easier the transfer, the less time (Hansen, 1999) and effort required, and the more likely that a transfer will occur and be successful (Reagans & McEvily, 2003). Coordination is achieved via direct interaction and mutual adjustment between the different innovation partners. The knowledge transfer is more individualistic because there is no centralized lead firm. This makes the network more collaborative because the joint problems need to be solved jointly.

Next to these benefits of a decentralized approach, misalignment can also be avoided. Because effective organizational governance is complicated and costly, with the coordinated challenges involved, there is a higher chance of misalignment when the lead firm uses a centralized approach. If the market mechanisms are efficient, the hierarchical process is less efficient and more risky than the market process (Andersen & Drejer, 2006).

Based on these statements a decentralized approach will be more efficient in the case of a non-architectural innovation. As such it is expected that a low level of betweenness will have a positive impact on the performance of a non-architectural innovation.

Data and methodology

The purpose of this research is to investigate how companies can increase the performance of collaborative product innovation projects conducted in innovation networks. The focus is on the effects of the level of betweenness on the performance of architectural innovations. The hypothesis is tested on a sample of innovation networks which include a leading company and one or more partners responsible for different components of the entire product. The unit of analysis of this study is the product innovation project from the perspective of the lead firm (which can take a central or decentralized approach). The study focus is on different industries where the use of multiple subsystems composed to one product seems to be expected.

Data collection

The data used for this study is based on the dissertation data set of Dr. Ir. Erwin Hofman. These are empirical results of a large-scale research study of collaborative product innovation projects in innovation networks. The data came from the Dun & Bradstreet business database and consisted of 3000 U.S. companies which were randomly selected. For this research the following industries were selected in the data set: computer and software, household appliances, machinery and equipment, and construction.

The data is pre-tested to ensure that only appropriate companies with collaborative product innovation projects are in the final sample. The sample of 3000 companies all received a pre-survey. Finally there were 924 companies that met the criteria for inclusion in the final survey. The data was collected by a mail survey based on the prescriptions outlined by Dillman (1978), as outlined in the total design method for survey research and following the procedures used by Song, Song & Di Benedetto (2009). A mail survey has the advantage of being cheap and quick, surveys are flexible, many variables can be asked, and they have a great accuracy in measurement (Babbie, 2007).

The companies had to select their most recent completed innovation project which was completed in the last three years and has the following characteristics: the company partnered with one or several other companies that were responsible for different subsystems/areas of the end product, the company was the lead company of this innovation network, and the innovation project consists of multiple subsystems for which the different companies in the innovation network were responsible. The response resulted in 664 companies that completed a usable survey which is a sufficient amount to test the hypothesis (Hofman, 2010).

Measure purification

Missing values occur when no data value is stored for the variable in a current situation. (Vogt, 2005). Missing values arise when a respondent does not answer one of the questions in the survey. In order to detect these missing values and to ensure that they are not affecting the data, a missing value analysis is done. Missing values are replaced with a '0' in order to make sure that they are not affecting the results of the performed analysis.

Next to the missing value analysis, outliers were detected. An outlier is an extreme score that does not fit the overall pattern of data. When performing statistical analysis it is important to exclude the possible outliers because those could cause coefficients to change to a large extent and therefore they could seriously affect the results of the data analysis (Vogt, 2005). A commonly used border is 2 or 3 standard deviations of the mean. Following the guidelines of Reinard (2006), outliers may be deleted when they can be explained as coming from populations fundamentally different from the rest of the sample. Every measure outside -3 and 3 standard deviations of the mean is considered as an outlier.

After the outlier analysis, the extent to which a measure is reliable is investigated by using Cronbach's alpha. Reliability captures the internal consistency of a measure which is used to indicate whether the scales that are used are stable and give consistent results (Reinard, 2006). The Cronbach's alpha measures the consistency of items in an index. In the most reliable form, the coefficients should be as close to 1.00 as possible. The guidelines used within this research are based on Reinard (2006). The reliability scores are added to the variable descriptions in the next chapter.

The Kaiser-Meyer-Olkin score indicates the sampling adequacy and gives a score between 0 and 1. The closer the value is to 1, the more it indicates that patterns of correlation are relatively compact and so factor analysis should yield distinct and reliable factors. Values greater than 0,5 are acceptable according to Field (Field, 2005). The score for this data 0.80 is an acceptable score to perform a factor analysis (Appendix 2). The factor analysis is used to assess whether the different constructs are one-dimensional (Vogt, 2005).

There are two types of factor analysis, exploratory and confirmatory factor analysis. Exploratory factor analysis is used to uncover the underlying structure of a large set of variables. This is used in which there is no hypothesis to guide predictions of factor structures. A confirmatory factor analysis is used to test whether the number of items are consistent with what is expected, based on a previous theory in which hypotheses are made about the expected factor structures. In this research a confirmatory factor analysis, using maximum likelihood estimations and varimax rotation, can be conducted in order to determine whether or not each of the proposed factors fit their associated questionnaire items. Maximum likelihood method is used because it is a good estimation procedure when the measured data are multivariate and normally distributed, and a relatively large sample size is available, all of which are true for this study (Bollen, 1989). Varimax rotation simplifies the interpretation of the factors by increasing the difference between the low and high values of the factor loadings (Reinard, 2006). Regarding factor analysis, there are no universally accepted rules. One of the guidelines provided by Reinard (2006) is that factor loadings of items need to be above

0.30. In Appendix 2 the outcome of the factor analysis is shown. Unfortunately the outcome for factor 6 does not satisfy this rule.

Nevertheless, the results of this factor analysis showed a good fit of the proposed model to the data. In the confirmatory factor analysis, 6 factors are specified. The model X^2 value is 260.3 with 114 degrees of freedom. The X^2 is statistically significant and the X^2 is 2.28, suggesting a strong fit relative to the degrees of freedom ($X^2 = 260{,}3$, df = 114, $p < 0.01$). In short, the fit statistics seem to suggest that each item is capturing a significant amount of variation in these latent dimensions. The chi square per degree of freedom is 2.28, which is acceptable because it is argued that values lower than 3.0 indicate a good fit (Bentler & Bonett, 1980). Further outcomes of the factor analysis are added to the variable descriptions in the next chapter.

At last the Harman's one factor test is used to check whether self-reporting led to common method variance (Podsakoff & Organ, 1986). The results from this analysis are reported in Appendix 3. There is one single factor that explains 24.3% which is a lot, but it is not a majority. These findings indicate that the results are unlikely to be distorted by common method bias.

Hierarchical regression analysis

In order to assess how much variance within architectural innovation performance is caused by the level of betweenness, a multiple regression analysis needs to be conducted. "Regression analysis is a method used to explain or predict the variability of a dependent variable using information about one or more independent variables" (Vogt, 2005, p. 269). Regression analysis is conducted to predict the values of the independent variables by knowing the values of another variable. Multiple regression analysis is the statistical method to evaluate the effects of more than one independent variable on a dependent variable (Vogt, 2005).

For this data the specific form of hierarchical moderated multiple regression analysis is used to verify the individual effects on innovation performance and to determine the interaction effects. The advantages of this analysis are that not only the linear effects can be tested, but also curvilinear relationships. Another advantage is that interactions can be tested and it is easier to determine the amount of variation in the dependent variable that is explained by a set of variables. Interaction effects occur when the relation between two variables differs depending on the value of another variable (Vogt, 2005). Interaction effects occur when independent variables not only have separate effects, but also have combined effects that are different from the simple sum of their separate effects. The benefit of hierarchical moderate regression is that the relative importance of each individual variable can be identified (Dunteman & Ho, 2006).

Hierarchical moderated multiple regression analysis is used to test the moderating relationships or interactions. The test can verify the different individual effects on the innovation performance. First, the control variables are added in a block next the main variables, so the main effect between betweenness and architecturalness shows up. And in the last block the two-way interaction terms, architecturalness x betweenness, is added.

Mean-centering

Mean-centering the variables is seen as a way to reduce the covariance between the linear and the interaction terms, thereby suggesting that it reduces multicollinearity (Aiken, West, & Reno, 1991). For mean centering, at first the mean of each independent variable needs to be computed. Next, replace each value with the difference between it and the mean. An example: if the mean of a variable is 10 then enter 7 for a variable of 17 and -3 for a variable of 7.

The statistical inference is not affected by this simple transformation. Even though the correlations between the mean centered variables and their product term are much smaller than the correlation between the original raw variables and their product term. The determinant of the independent variables is the same after mean-centering, as the sum of squares, R^2, F values, the product term coefficient and its standard deviation.

However, can such a simple shift in the location of the origin really help to see the pattern between variables? Literature states that mean centering does not affect multicollinearity at all (Echambadi & Hess, 2007). The complete analysis of mean-centering indicates that mean-centering often reduces covariance between the linear and the interaction terms However it does not add any new information to the estimation. Mean-centering does not change the main effects. Therefore it is clear that mean centering does not alleviate collinearity problems in moderate regression. One might argue that the simple effects are more preferable than the centered data because they provide a more fine-grained understanding of the patterns. Both methods, uncentered and centered, are mathematically equivalent and the results for the uncentered case can be obtained from the mean-centered model and vice versa. Mean-centering does not necessarily provide a better interpretation of the data; it just provides a different interpretation.

What is the reason so many researchers mean-center their moderated variables? Mean centering neither helps nor hurts. Without mean-centering it is difficult to distinguish the separate effects of the independent variables on the dependent variable. Subtracting the mean from the independent variable will make the regressor and the interaction terms typically smaller. This improves the ability to distinguish the effects, and hopefully improves the ability to distinguish the effect of changes in x1 from changes in x1x2 (Echambadi & Hess, 2007). Therefore, we conclude that mean-centering will be used for interpretive purposes.

Measures

All measures used in this study were adapted from the research of Hofman 2010. For the multi-item variables a confirmatory factor analysis is conducted. The representative items/questions asked for every variable are included in Appendix 1. Next the different main and control items are explained and underpinned by literature.

Main variables

Architecturalness: What is the level of architecturalness of the innovation? A high level of architecturalness is described as an innovation that involves improvement of sub-systems and which has a significant impact on the existing interactions with other subsystems (Henderson & Clark, 1990). This variable is measured by five questions from which the average score is used as indicator of architecturalness. The scale used is a 7 point likert scale ranged from 1 “strongly disagree” to 7 “strongly agree”; the higher the ratings, the higher the level of architecturalness. The obtained alpha reliability coefficient for this construct was 0.86 and the composite reliability value is 0.86. In the factor analysis a score of 0.57 for the average variance extracted is found. These measures indicate that the variable is reliable and characterized by convergent validity.

Dummy of architectural innovation: Is the innovation architectural or not? The type of innovation is assessed by a choice between two statements developed by Henderson and Clark (1990). One statement is a clear definition of a modular innovation while the second is a clear definition of an architectural innovation. The respondent was asked to characterize the type of innovation they had selected for the survey. The architectural innovation was defined as an innovation that involves (sometimes marginal) improvements of sub-systems that have a more significant impact on the existing interface standards and interactions with other subsystems. For example: a larger notebook display (=marginal improvement) draws more power (change in interaction) and requires simultaneous changes in other subsystems such as the battery, software and charging system in order to function. This variable was coded as a dummy, 1 if the innovation was categorized as a modular and 0 if it was categorized as architectural innovation.

Betweenness: To assess the position of a lead firm, is it a centralized or decentralized network approach? It measures the centrality of the focal firm in a network (Chesbrough & Teece, 1996). Betweenness is a measure of the influence a lead firm has over the information flow within a network. It is measured by the amount of network flow which is controlled by this firm (Gilsing, et al., 2008). The level of betweenness is based on the average of four different questions in which the following items are measured: the facilitation of communication, exchange of resources, the function of middleman, and the coupling function. The scale used is again a 7 point likert scale. The alpha coefficient for this construct is 0.58 and the composite reliability value is 0.55. This provides marginal evidence for the reliability of the construct. Deleting one item improves the reliability to 0.71. Therefore an alternative variable is developed without question or item 4, although both variables will be tested in the regression analysis. The variable of betweenness can be used for the analysis. Next, the obtained AVE value of 0.58 is satisfactory.

Innovation performance: The performance of the innovation is measured by the average of three items adopted from Gatignon, Tushman, Smith, & Anderson (2002) in order to measure the perceived commercial success of a product. The three items are: successful implementation by members of the innovation network, commercial success, and has the innovation met the expectations regarding the impact on sales. The scale used is a 7 point likert scale; the higher the ratings, the higher the innovation performance. The obtained alpha coefficient for this variable is 0.97, and the composite reliability value is 0.97. The AVE score is 0.92. This indicates that the construct is highly reliable.

Control variables

There are several control variables included in the analysis to prevent a possible confounding effect. The control variables are also based on the dissertation of Hofman (2010).

Bridging ties: When firms are in central positions and they can bridge ties in loosely coupled networks it can give the network access to sources of novel information (Burt, 1992). This 'brokerage argument' builds on the weak-tie theory of Granovetter (1973). A lead firm has an opportunity to access useful information which then improves collaborative innovation performance. This can have effects on the hypothesis. The effect of bridging ties is measured by four items based on Campion, Medsker, & Higgs (1993) and Teece (1986). These items measure the degree to which weak ties have linked innovation network partners with useful complementary resources and competences. Again the scale used is a 7 point likert scale. With a coefficient alpha of 0.82 and a composite reliability of 0.81 and an AVE value of 0.58, the variable bridging ties showed strong reliability.

Lead firm size: Several studies have proved that there is a relationship between firm size and innovation performance. Large firms have more resources (e.g. financial) and capabilities to invest in innovations (Teece, 1986). On the other hand small firms have the advantage of being more flexible and therefore they can recognize opportunities faster than larger firms (Bower & Christensen, 1995). The lead firm size is measured by the number of employees. To prevent the outcome of the hypothesis from the effect of firm size, this control variable is added to the analysis.

Project size: To make innovation projects comparable, project size needs to be controlled. Larger projects resulting in more resource inputs which will boost the innovation performance (Dyer & Singh, 1998). The project size is controlled for the total estimated dollar cost of each product innovation project.

Marketing resource input: Next to the financial cost of an innovation project, large marketing expenditures can also significantly influence the innovation performance (Gatignon & Xuereb, 1997). This item is measured by the relative marketing resource inputs that the innovation network devoted to the innovation project.

Environmental uncertainty: Market characteristics that have an impact on the commercial performance of innovations is covered by environmental uncertainty (Gatignon & Xuereb, 1997). Environmental uncertainty in literature is often not a one-dimensional construct. It is broken down into: technological uncertainty and customer uncertainty. The customer uncertainty is defined as the rate of change of customer preferences. Technological uncertainty refers to the probability of technological changes in the product. The technological uncertainty is measured using three items adopted from Jaworski & Kohli (1993) and Walker & Weber (1984). Also customer uncertainty was measured with a three-item measure adopted from Joshi & Sharma (2004). The higher the ratings the greater the environmental uncertainty. The rating scale is based on a 7 point likert scale ranged from 1 “strongly disagree” to 7 “strongly agree”. The obtained alpha coefficient for the construct is 0.70 and the construct reliability is 0.73 with a score of 0.50 for AVE makes this a reliable construct. The alpha coefficient for technical uncertainty is 0.71 and the construct reliability is 0.72 with a score of 0.49 making it a reliable construct.

Composition of the innovation network: This control factor is added to measure the degree of horizontal collaboration. Firms with a high level of collaborating competitors have a lower innovation performance (Rindfleisch & Moorman, 2001). A firm might gain inside knowledge of a partners unique skills and expertise. This associates with a higher potential for misappropriation than in an alliance with vertical partners (Katila, Rosenberger, & Eisenhardt, 2008). To control for the degree of horizontal collaboration, the amount of competitors needs to be known. The network composition is measured by dividing the number of competitors by the total number of companies in the innovation network.

Contract structure: Having an equity share provides companies with a certain control. A firm can control other firms and may in this way affect the commitment and cooperation, which can in turn influence the innovation performance (Krishnan, Martin, & Noorderhaven, 2006). This control variable is measured by a binary variable. Alliances that involve equity assign a 1 and non-equity alliances assign a 0.

Industry: Collaborative innovations in some industries are known to perform better than in other industries (Krishnan, et al., 2006). To control this, the variable industry type is added. Dummy variables are used for the different industries in the sample. The different industries are based on the two digit SIC codes.

Analysis and results

The different outputs: means, standard deviations, and correlations among the variables are shown in table 1. All variables are added and checked on correlation. Unfortunately, the variables bridging ties and betweenness show some problems with an R value of 0.66 when they correlate with each other. This correlation is no surprise because both variables measure the central position of a firm.

A hierarchical moderated regression analysis is used to investigate the proposed hypothesis. The analysis is performed for the two different measures of architectural innovation, the measure architecturalness and for the dummy innovation type. To ensure that both variables measure architecturalness in a reliable way, an independent t-test is conducted in Appendix 3. The mean score of architecturalness for architectural and non-architectural innovations differ in a significant way, so the dummy is a reliable alternative for the measure of architecturalness.

Since the goal of this research is to determine the separate effects on architectural innovation performance, the variables included in the interaction terms, ‘architecturalness’ and ‘betweenness’, are mean-centered before creating the interaction terms. This is done to improve the ability to distinguish the different effects (Echambadi & Hess, 2007). To detect potential multicollinearity, the variance inflation factor (VIF) for all variables used in the regression are calculated. The VIF scores are presented in table 2 and 3. Large VIF coefficients indicate that the regression coefficient variance is increasing, suggesting instability associated with multicollinearity problems (Reinard, 2006). A VIF factor >4.0 indicates a problem of multicollinearity and in weaker models values above 2.5 can be troublesome (O'Brien, 2007). There are no VIF values higher than 2.35 so based on the literature of O’Brien (2007) it can be concluded that there are no problems with collinearity in this dataset.

TABLE 1: Correlations and descriptive statistics

	Variable	Mean	s.d.	N	1	2	3	4	5	6	7	8	9	10
1	Performance	3.43	1.37	664	1									
2	Architecturalness	4.13	1.40	367	-0.23**	1								
3	Betweenness	4.07	1.25	664	0.29	-0.09	1							
4	Project size	3.99	0.65	664	0.03	0.14**	0.09*	1						
5	Leadfirm size	2.01	0.59	664	-0.03	0.15	0.02	0.25**	1					
6	Bridging ties	3.91	1.63	664	0.21**	-0.15**	0.66**	-0.01	-0.02	1				
7	Customer uncertainty	3.80	1.34	664	0.14**	-0.09	0.06	0	0	0.05	1			
8	Technological uncertainty	4.90	1.22	664	-0.12**	0.28**	-0.03	-0.03	0.14**	0	0.04	1		
9	Composition of the innovation network	0.27	0.09	664	-0.13**	-0.06	-0.27**	0.02	-0.1	-0.15**	-0.06	-0.05	1	
10	Marketing resource input	4.40	1.44	664	-0.06	0.4**	0.14**	0.03	0.17**	0.13**	0.08	0.29**	-0.11**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

TABLE 2: Result of Hierarchical Moderated Regression Analyses for Architecturalness

	Collaborative Innovation Performance								
Variables	**Model 1**		**s.d.**	**Model 2**		**s.d.**	**Model 3**		**s.d.**
Constant	3.19	**	0.67	3.05	**	0.69	3.16	**	0.69
Control variables									
Construction industry	0.00		0.22	-0.07		0.22	-0.07		0.22
	2.03			*2.04*			*2.04*		
Computer industry	-0.09		0.21	-0.16		0.21	-0.17		0.21
	1.68			*1.70*			*1.70*		
Machinery industry	-0.05		0.22	-0.13		0.22	-0.14		0.22
	1.56			*1.57*			*1.58*		
Household appliances industry	0.05		0.22	0.00		0.21	0.01		0.21
	1.60			*1.61*			*1.61*		
Bridging ties	0.24	**	0.04	0.11	**	0.06	0.11	**	0.06
	1.10			*2.05*			*2.05*		
Relative number of competitors in innovation network	-1.17	*	0.71	-0.91		0.72	-0.92		0.72
	1.07			*1.14*			*1.14*		
equity alliances	-0.41	**	0.14	-0.34	**	0.14	-0.36	**	0.14
	1.06			*1.07*			*1.07*		
Customer uncertainty	0.10	*	0.05	0.08		0.05	0.07		0.05
	1.07			*1.08*			*1.08*		
Technological uncertainty	-0.10	*	0.06	-0.04		0.06	-0.06		0.06
	1.08			*1.15*			*1.19*		
Marketing resource input	-0.03		0.05	0.03		0.05	0.04		0.05
	1.11			*1.31*			*1.31*		
Total dollar cost innovation project	-0.04		0.11	-0.01		0.11	-0.01		0.11
	1.18			*1.21*			*1.21*		
Number of employees lead firm	0.12		0.13	0.13		0.13	0.12		0.13
	1.34			*1.34*			*1.34*		
Main effects									
Architecturalness				-0.18	**	0.05	-0.17	**	0.06
				1.39			*1.41*		
Betweenness				0.20	*	0.08	0.21	**	0.08
				2.13			*2.14*		
Two-way interactions									
Architecturalness X Betweeenness							0.06		0.04
							1.07		
Model F	5.15			5.90			5.69		
R^2	0.15			0.19			0.20		
Adjusted R^2	0.12			0.16			0.16		
S.d. of the estimate	1.27			1.25			1.24		
ΔR^2				0.04			0.01		
F change	5.15	**		9.01	**		2.35		

Values in italic are VIFs.

* $p < .10$

** $p < .05$

TABLE 3: Result of Hierarchical Regression Analyses for the dummy of architectural innovation

	Collaborative Innovation Performance								
Variables	**Model 1**		**s.d.**	**Model 2**		**s.d.**	**Model 3**		**s.d.**
Constant	3.19	**	0.67	3.24	**	0.37	3.23	**	0.37
Control variables									
Construction industry	0.00		0.22	-0.11		0.12	-0.10		0.12
	2.03			*2.03*			*2.03*		
Computer industry	-0.09		0.21	-0.15		0.11	-0.12		0.11
	1.68			*1.70*			*1.72*		
Machinery industry	-0.05		0.22	-0.06		0.12	-0.04		0.12
	1.56			*1.57*			*1.58*		
Household appliances industry	0.05		0.22	-0.01		0.12	-0.01		0.12
	1.60			*1.60*			*1.61*		
Bridging ties	0.24	**	0.04	0.04		0.03	0.04		0.03
	1.10			*2.02*			*2.02*		
Relative number of competitors in innovation network	-1.17	*	0.71	0.38		0.40	0.26		0.40
	1.07			*1.14*			*1.17*		
equity alliances	-0.41	**	0.14	0.04		0.08	0.02		0.08
	1.06			*1.10*			*1.12*		
Customer uncertainty	0.10	*	0.05	-0.01		0.03	-0.01		0.03
	1.07			*1.09*			*1.09*		
Technological uncertainty	-0.10	*	0.06	0.06	*	0.03	0.06	**	0.03
	1.08			*1.13*			*1.13*		
Marketing resource input	-0.03		0.05	0.12	**	0.03	0.12	**	0.03
	1.11			*1.15*			*1.15*		
Total dollar cost innovation project	-0.04		0.11	0.00		0.06	0.00		0.06
	1.18			*1.19*			*1.19*		
Number of employees lead firm	0.12		0.13	0.10		0.07	0.10		0.07
	1.34			*1.34*			*1.34*		
Main effects									
Dummy AI				-2.36	**	0.08	-2.36	**	0.08
				1.26			*1.26*		
Betweenness				0.08	**	0.04	0.14	**	0.05
				2.15			*2.92*		
Two-way interactions									
Dummy AI X Betweeenness							-0.14	**	0.06
							1.99		
Model F	5.15			430.96			4.84		
R^2	0.15			0.75			0.75		
Adjusted R^2	0.12			0.743			0.746		
S.d. of the estimate	1.27			0.69			0.68		
ΔR^2				0.60			0.03		
F change	5.15	**		9.01	**		2.35		

Values in italic are VIFs.

* $p < .10$

** $p < .05$

The three different models for collaborative innovation performance include control variables. In the first model these control variables are added. In the second model all first-order associations are added so for table 2: architecturalness and betweenness and for table 3: the dummy of architectural innovation and betweenness. At last in model 3 all second order association are added so the two way interaction terms: architecturalness X betweenness and dummy AI X betweenness. Next to these results all analysis are also completed for the variable betweenness without item 4, with a higher reliability score, and for all control factors without Bridging Ties. These results are presented in Appendix 4 and they indicate only a negligible change in outcome.

If we look at the results of table 2, the outcome of the hierarchical regression analysis shows that the main variables increase the overall model R^2 by 0.04 (F = 9.01, p < .01). Next, introducing the interaction term further improves the regression model with an R^2 of 0.01 (F = 2.35, p > 0.1). Unfortunately the improvement of the interaction term is not significant. The hypothesis would require a statistically significant increase in variance explained in model 3. Therefore the dummy variable is used to test the hypothesis.

The results of table 3, in which the dummy variable of architectural innovation is used, show a higher level of explained variance. The main variables increase the overall model R^2 by 0.60 (F = 76.71, p < .05). Next, the introduction of the two-way interactions led to a statistically significant improvement in the regression model with an R^2 change of 0.03 (F = 72.70, p < .05). Consequently it is appropriate to examine the nature of the investigated relationships.

To gain a further insight into the different effects on innovation performance, a plot is made in figure 1. The level of betweenness is divided in three equal categories: low, moderate and high. On the horizontal axis, the dummy is added which is equally distributed. The figure shows that the effects of betweenness on the performance are low, and that the influence of the type of innovation or architecturalness is high. Also the effect of the two-way interaction effect is low, this conclusion can be seen in the output of the regression analysis. The R^2 increases from 0.753 in model 2 to 0.756 in model 3, which is equivalent to an increase of 3 percent. While the added value of the main variables in model 2 was rather high, 60 percent an increase from 0.15 to 0.75. In figure 2 a second plot is made from the two-way interaction effect to gain further insight into the interaction effects on both architectural and non-architectural innovations (Aiken, et al., 1991).

FIGURE 1: Type of innovation and three levels of betweenness

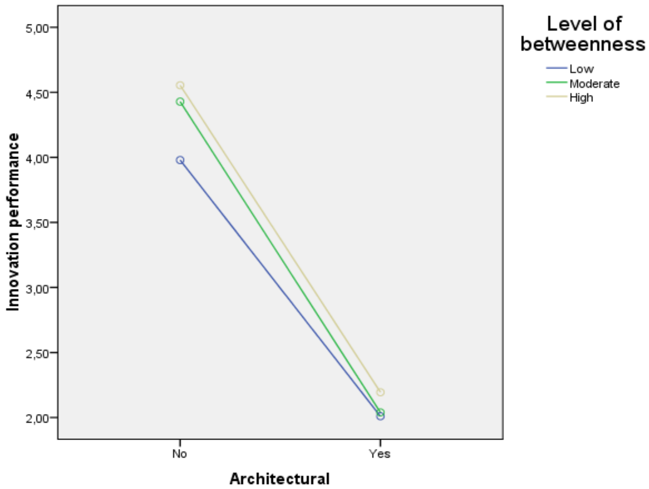
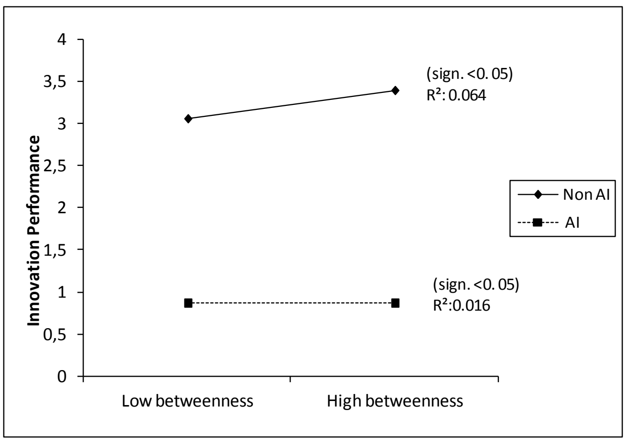


FIGURE 2: Interaction between level of betweenness and the dummy of architectural innovation



To further investigate the unbiased beta weights for each slope, a t-test for each pair wise comparison is made (Dawson & Richter, 2006). The results indicate that the two slopes significantly differ (figure 2). To compare the dummy and the measure of architecturalness in Appendix 5 a plot is made for the measure architecturalness.

Hypothesis 1 proposes that a high level of betweenness will have a positive impact on the performance of architectural product innovations. What can be concluded based on these results is that this model indeed indicates that a higher level of innovation performance can be achieved by using a high level of betweenness ($\beta = 0.14, p < 0.05$). However the combined effect of betweenness with the dummy of architectural innovation is small but positive. Consequently the influence caused by betweenness is minimal compared to the effect of the dummy of architectural innovation ($\beta = -2.36, p < 0.05$). But indeed the model (figure 2) indicates that the level of betweenness has a positive effect on the architectural innovation performance. We can conclude that this hypothesis can be accepted.

The opposite argumentation for non-architectural innovation is not valid. This argumentation states that a low level of betweenness will have a positive impact on the performance of non-architectural product innovations. This needs to be rejected, based on the outcome of this analysis (figure 2). Surprisingly a high level of betweenness is positively related to the performance of a non-architectural innovation. The regression line shown in figure 2 visualizes this relationship between a non-architectural innovation and the performance.

Discussion

The goal of this study was to achieve a better understanding of the influence of betweenness on architectural product innovation performance. This research shows that the factor betweenness has a statistically significant effect on the performance of architectural innovations. This outcome has different implications for theory and practice which will be discussed in this chapter.

Implications for theory

In general this study makes several contributions to the theory of social network literature. Research investigating the effects of network characteristics on innovation performance has highlighted that a centralized lead firm can have different influences on the innovation performance (Chesbrough & Teece, 1996). Subsequently there is also specific evidence for the effects of architecturalness on innovation performance (Henderson & Clark, 1990). However, in existing literature the combined effect of a centralized or decentralized lead firm on the performance of an architectural or non-architectural innovation remains unclear. This research therefore provides new and interesting insights that can be used to further investigate the different effects on a collaborative innovation network.

Literature argues that a high level of betweenness is likely to improve the coordination and it can facilitate rapid mutual adjustment between the different components producers. In addition the exchange of critical resources and knowledge among innovation network members will improve due to better coordination (Andersen & Drejer, 2006). This should be especially important for systemic or architectural innovations as these innovations ask for reconfiguration of existing knowledge by using new patterns of integration. A complex process in which the network partners are highly dependent on each other's products. The integration of knowledge is the driving force of an architectural innovation (Grant, 1996).

The main finding of this study is in line with the given arguments, the outcome indicates that the higher the level of betweenness the higher the performance of an architectural innovation. This finding confirms the theoretical results that architectural innovations require an integrated firm, a guiding hand that can centralize authority, and promote knowledge sharing. A network where different business contacts can freely share information about the components without having to worry about expropriation, where entities can commit themselves and not be exploited by that commitment, and where disputes can be monitored and resolved in a timely way (Teece, 1996).

As such it is concluded that a high level of betweenness will have moderate positive impact on the performance of architectural innovations. However, the effect of the factor beweenness and the two-way interaction is small compared with the main effect of type of innovation. Only 3% of the factor innovation performance can be explained by the two way interaction effect. Additionally the results also show that non-architectural innovations perform much better than architectural innovations. This confirms the theory of Henderson and Clark (1990), a high amount of innovation performance can be explained by the type of innovation.

The opposite explanation of this hypothesis states that, a low level of betweenness will have a positive impact on the performance of a non-architectural innovation. This explanation is rejected by the outcome of the analysis. Social network literature argues that a centralized lead firm can make an innovation less flexible so a non-architectural innovation may proceed faster when the level of betweenness is low (De Laat, 1999). A non-architectural innovation decreases the number of architectural interfaces, which suggests a decrease in dependence, and thus in the need for coordination (Mitchell & Singh, 1996; Sanchez, 1995). Presumably, the easier the transfer of information the less time (Hansen, 1999) and effort required and the more likely that a transfer will occur and be successful (Reagans & McEvily, 2003). This theory needs to be rejected but it needs to be argued that the effect of the two way interaction is minimal.

Surprisingly a high level of betweenness has a positive impact on the performance of non-architectural innovations. Both types of innovations are positively influenced by a higher level of betweenness. However, the effect from betweenness on a non-architectural innovation is higher than the effect on architectural innovations. There is only partial support for these observations found in general theories of betweenness. Borgatti, Jones and Everett (1998) argue that high betweenness is positive for each type of innovation because it can link together actors who are otherwise unconnected, creating opportunities for exploitation of information & control benefits. Especially these coordination and control benefits can be more important for non-architectural innovations than for architectural innovations. Architectural innovation partners are dependent on each other, there is social control. For non-architectural innovations the control from a centralized lead firm can be more beneficial because there is less social control between the different innovation partners since they are not dependent on each other.

A factor that have possibly effected this unexpected outcome is the communication between the different business contacts. It would be valuable to measure the level of communication in a network between the different business contacts and use this factor in the analysis. For this research the focus is only on the communication from the different contacts with the lead firm. Despite various differences with respect to the type of innovation, the communication within a network is argued to effect the innovation activities positively (Arndt & Sternberg, 2000; Todtling, Lehner, & Kaufmann, 2009). Recent studies in network literature confirm the advantages of easy communication and access to information and knowledge (Ebadi & Utterback, 1984; Todtling, et al., 2009). This is primarily true for non-codified knowledge based on more complex innovations,

innovations which cannot be standardized and in which information is only transmittable through direct communication (Arndt & Sternberg, 2000). The effects of communication within a network would therefore be higher for architectural innovations than for non-architectural innovations. Based on the theoretical part of this study it can be concluded that communication is especially important for architectural innovations. This is possibly more the communication within a network instead of the communication with a centralized lead firm. Architectural innovations ask for reconfiguration of existing knowledge by using new patterns of integration. A complex process in which the network partners are highly dependent on each other's products. This can be a partial explanation for the results of this research. This study adds understanding by showing that a high level of betweenness will have an additive positive effect on non-architectural innovations.

Implications for practice

Innovation managers can use the outcome of this research to direct their innovation strategies. It can help them to successfully implement the innovation. Consequently they can better meet the innovation network members expectations regarding the impact on sales and of course to maximize the profits of their product innovations. Overall this research indicates that the type of innovation has a high impact on the outcome. Non-architectural innovations perform better than architectural innovations. Next it can be concluded that for both types of innovation it is the best to keep the level of betweenness high. This will maximize the performance. However for non-architectural innovations it has a greater impact on the innovation performance than for architectural innovations.

From a managerial point of view, this research shows that fostering coordination and communication facilitates the exchange of resources. Communication from the network members through the lead firm will improve the outcome of innovation projects. Innovation managers can take into account that a high level of betweenness will show the best results for their collaborative product innovation. A way to increase the possibility for innovation partners to increase their connectivity could be to create arenas and meeting points where exchange of information and knowledge relevant for innovation can take place. For example the creation and support of communities, the use of idea generation techniques in projects and other groups, increased formal collaboration between different innovation partners, and improved sharing of information and knowledge by other available means, such as Knowledge Management systems and idea databases (Bjork & Magnusson, 2009).

Limitations and future research

The contributions of this study should be considered in the light of its limitations. Within this study there are several limitations that could have affected the results.

The limitations lie in that for the measure of architecturalness, there was data available from only 367 respondents. This measure is therefore less reliable than the other measures which include 664 respondents. Subsequently, the results from this measure did not provide significant results. Therefore the dummy is used as alternative. These results were usable within this research and are comparable with the results of architecturalness (Appendix 3 and 5). However future research could and should focus upon the results of architecturalness in order to show the effects of betweenness more precisely.

Second, the measure used for the variable performance is based on subjective performance scales. It is a common used method in marketing and innovation literature to make use of subjective performance data. There are also studies that indicate that there are high correlations between subjective and objective measures of performance (Damanpour & Evan, 1984; Dess & Robinson, 1984). However it would have been more reliable when objective data was used.

Third, the data is examined from the perspective of the lead firm which is less informative than full network analysis. Although research findings also suggest that egocentric network analyses provide efficient and effective network analysis. For example the level of betweenness. Marsden (2002) argues that the extent to which egocentric and sociocentric versions of Freeman's betweenness centrality measure correspond is found to be relatively close. "Findings suggest that research design has a relatively modest impact on assessing the relative betweenness of nodes, and that a betweenness measure based on egocentric network data could be a reliable substitute for Freeman's betweenness measure when it is not practical to collect complete network data" (p. 407) This method is not a serious concern for this research.

Fourth, the research method of surveys has a lot of advantages in flexibility, anonymity, speed and reliability, however it is also a very standardized method. This makes it inflexible and not able to deal with situations where an innovation manager wants to explain more about the innovation (Babbie, 2007). There is also a risk that self-report surveys running incorrect results, which indicates common method variance. This common method variance and multicollinearity have been statistically tested and there are no indications that the results are inflated (Podsakoff & Organ, 1986). Nevertheless a qualitative research has the possibility to explain more in detail how architectural an innovation is. The use of interviews as an addition to the questionnaire can also be an option to get a more clarified view of the given answers. Future research could adopt different methods, the method adopted here is not a serious concern.

At last, one must use care in generalizing the results of any empirical study or any theoretical argument. Based on the large sample of data from four different industries in the U.S. the central message of this analysis is clear and important. The factor betweenness has only a marginal effect on innovation performance. This study extends previous research of Hofman (2010) in which the impact of different innovation network configurations on innovation performance is examined. In future research it would be interesting to investigate the effects of the total network density and the previous mentioned factor of collaboration within a network. In contrast to the effects of betweenness, network density measures the extent to which one's partners are linked. This may help in dealing with technological distance between the different partners (Gilsing, et al., 2008).

The four firm concentration ratio of the U.S. manufacturing industry is a commonly used concentration ratio to measure the density of an industry. The relative size of leading firms in relation to the industry as a whole is the indicator of the concentration. The combined market share of the four largest firms as a percentage of the total industry indicates the looseness of a network. The Standard Industrial Classification (SIC) codes can be matched with the criteria provided by the Census Bureau of the U.S. department of commerce. Several other authors make use of the four firm concentration ration which indicates that it is a reliable method. For example Casciaro and Piskorski (2005) use the ratio to operationalize the notion of dependence between firms in different industries based on input-output patterns of transactions across economic sectors. Schilling and Steensma (2001) use the four firm ratio to measure the competitive intensity in the industry. They combine the number of industry competitors, with the inverse of the four firm market concentration and the inverse of the Herfindahl-Hirschmann index of market share to measure the competitive intensity (Casciaro & Piskorski, 2005; Schilling & Steensma, 2001).

Conclusion

Despite the limitations of this study, there are significant results which have both a scientific and practical implication. Several recent studies have indicated that a centralized lead firm influences the innovation performance. There is also specific evidence about the effects of architecturalness on innovation performance. However the combined effect of a centralized/decentralized lead firm on an architectural or non-architectural innovation was still unclear.

The most important result derived from this research shows that a high level of betweenness is advantageous for both types of innovations. The factor betweenness is of key importance for stimulating the innovation performance. This positive effect on the performance is higher for non-architectural innovations than for architectural innovations. But overall the influence of innovation type on the performance is much higher than the stimulating effects of the factor betweenness.

This study has established foundations for new empirical research to invest the impact of different innovation network configurations on innovation performance.

Appendix 1: Items measuring constructs

All variables are adopted from the research of Hofman (2010).

Main variables:

Type of innovation:
How would you characterize the type of innovation you have selected for this survey? (check one box)

▪ Modular innovations: These innovations involve significant improvements of sub-systems that leave the existing interface standards and interactions between the improved subsystems and other subsystems largely unchanged. *Example: a notebook incorporating a higher resolution display.*

▪ Architectural innovations: These innovations involve (sometimes marginal) improvements of subsystems that have a more significant impact on the existent interface standards and interactions with other subsystems. *Example: a larger notebook display (=marginal improvement) draws more power (change in interaction) and requires simultaneous changes in other subsystems like the battery, software and charging system in order to function.*

Performance:
We are interested in your assessment of the product innovation's overall performance. Please indicate, with what you know today, how successful the innovation project was, by using the following criteria.
PERF01 Innovation was successfully implemented by the members of the innovation network.
PERF02 Innovation has been commercially successful for the members of the innovation network.
PERF03 Innovation has met the innovation network members' expectations regarding the innovation's impact on sales.

Betweenness:
BETW01 We often facilitated communication among companies in this innovation network.
BETW02 We often facilitated the exchange of resources among companies in this innovation network.
BETW 03 We often served as 'middleman' for companies in this innovation network.
BETW 04 Our innovation network members often communicated each other through us.

Control Variables
Bridging ties:
BT01 Companies in this innovation network varied widely in their areas of expertise
BT02 Companies in this innovation network had a variety of different backgrounds and experiences
BT03 Companies in this innovation network had skills and abilities that complemented each others
BT04 Companies in this innovation network had resources and assets that complemented each others

Competitive environment
Please consider the following statements about possible market and technological uncertainties in your industry concerning the products you develop and produce.

Customer uncertainty:
For our end-products and/or subsystems we use and supply:
CU01 Customers' preferences for product features have changed quite a bit over time.
CU02 We are witnessing demand for our products from customers who never bought them before.
CU03 New customers tend to have product-related needs that are different from those of our existing customers.

Technological uncertainty:
For our end-products and/or subsystems we use and supply:
TU01 Specifications for products and subsystems change frequently.
TU02 Future technological improvements of products and subsystems are very likely.
TU03 The technologies used in our products are changing rapidly.

Single item control variables:
INPUT01 Relative to other product innovation projects the marketing resources devoted to this innovation project by the innovation network partners is high.
SIZE01 What was approximately the total estimated dollar cost of this product innovation project? (___ dollar)
COMP01 How many companies in the innovation network could be classified as competitors? (___ companies)
SIZE01 How many employees does your company approximately have? (___ employees)
EQ01 Can the relationship among companies in the innovation network predominantly be described as equity relationships? Yes ▪ No ▪

Appendix 2: Output factor analysis

Rotated Factor Matrix

	Factor					
Variables	**1**	**2**	**3**	**4**	**5**	**6**
BT01	0.79	0.04	0.16	-0.02	-0.04	0.14
BT03	0.73	-0.03	0.07	-0.05	0.02	-0.03
BT04	0.72	0.00	0.10	0.00	0.02	0.08
BETW01	0.69	0.01	0.12	0.13	-0.05	0.11
BT02	0.66	-0.20	0.08	0.09	-0.09	0.23
AI02	-0.12	0.80	-0.11	-0.05	0.13	-0.12
AI03	-0.01	0.75	-0.10	0.00	0.12	-0.07
AI01	-0.04	0.74	-0.10	-0.06	0.09	-0.11
AI05	-0.01	0.70	-0.03	-0.06	0.20	0.01
AI04	-0.10	0.63	-0.13	0.05	0.03	-0.04
BETW04	0.09	0.49	0.24	-0.17	0.03	0.06
PERF01	0.17	-0.11	0.97	0.08	-0.04	0.03
PERF02	0.16	-0.11	0.91	0.08	-0.06	0.04
PERF03	0.21	-0.08	0.91	0.06	-0.06	0.06
PCU01	0.01	0.01	0.00	0.86	0.01	0.01
PCU02	-0.05	-0.14	0.19	0.64	0.01	0.01
PCU03	0.10	-0.03	-0.01	0.52	-0.01	0.00
PTU02	-0.02	0.20	-0.09	0.00	0.78	-0.10
PTU03	0.03	0.12	-0.02	0.06	0.68	0.00
PTU01	-0.09	0.10	-0.01	-0.04	0.55	-0.01
BETW03	0.44	-0.14	0.06	-0.03	-0.05	0.88
BETW02	0.43	-0.21	0.10	0.05	-0.12	0.48

Extraction Method: Maximum Likelihood.

Rotation Method: Varimax

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure		0.80
Bartlett's Test of Sphericity	Approx. Chi-Square	4433.42
	Df	231.00
	Sig.	0.00

Harman’s one factor test

Common method bias

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.34	24.26	24.26	5.34	24.26	24.26
2			3.27			
3	2.29	10.39	49.51			
4	1.90	8.62	58.13			
5	1.64	7.44	65.57			
6	0.91	4.14	69.70			
7	0.79	3.59	73.29			
8	0.72	3.29	76.58			
9	0.64	2.90	79.48			
10	0.60	2.73	82.21			
11	0.55	2.49	84.70			
12	0.52	2.38	87.08			
13	0.48	2.20	89.28			
14	0.42	1.90	91.18			
15	0.36	1.66	92.84			
16	0.34	1.54	94.39			
17	0.31	1.40	95.79			
18	0.29	1.30	97.09			
19	0.26	1.20	98.29			
20	0.22	1.01	99.30			
21	0.11	0.52	99.82			
22	0.04	0.18	100.00			

Extraction Method: Principal Component Analysis.

Appendix 3: T-test to compare both measures of architectural innovation

T-test to check both measures of Architecturalness:

With a p value of which is smaller than 0.01 we can say that both values are significantly different, this is what we also can see in the table. The mean score for an architectural innovation is 4.89 and the mean score for a non-architectural innovation is 3.56. Based on this test we can say that the level of architecturalness is significantly higher for an architectural innovation than for a non- architectural innovation.

Group statistics

	N	Mean	Std	Std. Error
Architectural	157	4.89	1.22	0.098
Non-architectural	210	3.56	1.24	0.086

	Levene's test		T-test for equality of means				
	F	**P**	**T**	**DF**	**P (2-tailed)**	**Mean difference**	**Std. Error Difference**
Equal variances assumed	.253	.615	10.25	365	0.00	0.13	0.13
Equal variances not assumed			10.27	338.4	0.00	0.13	0.13

Appendix 4: Alternative regression outputs

Architecturalness X Betweeenness (excl q4)

	Collaborative Innovation Performance								
Variables	**Model 1**		**s.d.**	**Model 2**		**s.d.**	**Model 3**		**s.d.**
Constant	3.19	**	0.67	2.78	**	0.69	2.88	**	0.70
Control variables									
Construction industry	0.00		0.22	-0.07		0.22	-0.07		0.22
	2.03			*2.04*			*2.04*		
Computer industry	-0.09		0.21	-0.12		0.21	-0.13		0.21
	1.68			*1.70*			*1.70*		
Machinery industry	-0.05		0.22	-0.11		0.22	-0.12		0.22
	1.56			*1.57*			*1.57*		
Household appliances industry	0.05		0.22	0.03		0.21	0.03		0.21
	1.60			*1.60*			*1.60*		
Bridging ties	0.24	**	0.04	0.18	**	0.06	0.18	**	0.06
	1.10			*2.04*			*2.05*		
Relative number of competitors in innovation network	-1.17	*	0.71	-1.24		0.72	-1.25	*	0.72
	1.07			*1.12*			*1.12*		
equity alliances	-0.41	**	0.14	-0.36	**	0.14	-0.37	**	0.14
	1.06			*1.07*			*1.07*		
Customer uncertainty	0.10	*	0.05	0.08		0.05	0.08		0.05
	1.07	*		*1.09*			*1.09*		
Technological uncertainty	-0.10		0.06	-0.05		0.06	-0.07		0.06
	1.08			*1.14*			*1.19*		
Marketing resource input	-0.03		0.05	0.04		0.05	0.04		0.05
	1.11			*1.30*			*1.31*		
Total dollar cost innovation project	-0.04		0.11	0.01		0.11	0.01		0.11
	1.18			*1.20*			*1.20*		
Number of employees lead firm	0.12		0.13	0.14		0.13	0.14		0.13
	1.34			*1.34*			*1.34*		
Main effects									
Architecturalness				-0.18	**	0.06	-0.17	**	0.06
				1.42			*1.44*		
Betweenness (excl q4)				0.05		0.06	0.05		0.06
				2.16			*2.16*		
Two-way interactions									
Architecturalness X Betweeenness (excl q4)							0.04		0.03
							1.06		
Model F	5.15			5.37			5.13		
R^2	0.15			0.18			0.18		
Adjusted R^2	0.12			0.143			0.145		
S.d. of the estimate	1.27			1.26			1.26		
ΔR^2	0.15			0.03			0.00		
F change	5.15	**		5.82	**		1.58		

Values in italic are VIFs.

* $p < .10$

** $p < .05$

Dummy AI X Betweeenness (excl q4)

Variables	Collaborative Innovation Performance Model 1		s.d.	Model 2		s.d.	Model 3		s.d.
Constant	3.70	**	0.51	3.18	**	0.28	3.18	**	0.28
Control variables									
Construction industry	0.13		0.17	-0.09		0.09	-0.09		0.09
	2.02			*2.03*			*2.03*		
Computer industry	0.03		0.16	-0.01		0.09	-0.01		0.09
	1.63			*1.65*			*1.65*		
Machinery industry	-0.04		0.17	-0.06		0.09	-0.06		0.09
	1.55			*1.55*			*1.55*		
Household appliances industry	0.08		0.16	-0.02		0.08	-0.03		0.08
	1.62			*1.62*			*1.62*		
Bridging ties	0.17	**	0.03	0.02		0.02	0.02		0.02
	1.06			*1.93*			*1.93*		
Relative number of competitors in innovation network	-1.80		0.58	0.11		0.32	0.10		0.32
	1.06			*1.11*			*1.13*		
equity alliances	-0.46	**	0.11	0.04		0.06	0.04		0.06
	1.04			*1.09*			*1.10*		
Customer uncertainty	0.11	**	0.04	-0.01		0.02	-0.01		0.02
	1.04			*1.07*			*1.07*		
Technological uncertainty	-0.11	**	0.04	0.06	**	0.02	0.06	**	0.02
	1.12			*1.15*			*1.15*		
Marketing resource input	-0.06		0.04	0.13	**	0.02	0.13	**	0.02
	1.16			*1.23*			*1.23*		
Total dollar cost innovation project	0.06		0.08	0.05		0.04	0.05		0.04
	1.17			*1.18*			*1.18*		
Number of employees lead firm	-0.06		0.10	0.06		0.05	0.06		0.05
	1.37			*1.38*			*1.38*		
Main effects									
Dummy AI				-2.46	**	0.06	-2.46	**	0.06
				1.29			*1.29*		
Betweenness (excl q4)				0.04	*	0.02	0.05	*	0.03
				2.02			*2.74*		
Two-way interactions									
Dummy AI X Betweeenness (excl q4)							-0.01		0.04
							1.81		
Model F	7.39			138.37			128.96		
R^2	0.12			0.74			0.74		
Adjusted R^2	0.10			0.749			0.749		
S.d. of the estimate	1.29			0.69			0.69		
ΔR^2	0.12			0.63			0.00		
F change	7.39			813.48			0.05		

Values in italic are VIFs.

* $p < .10$

** $p < .05$

Architecturalness X Betweeenness, without the control factor: Bridging Ties

	Collaborative Innovation Performance								
Variables	**Model 1**		**s.d.**	**Model 2**		**s.d.**	**Model 3**		**s.d.**
Constant	4.33	**	0.67	3.46	**	0.66	3.58	**	0.66
Control variables									
Construction industry	0.05		0.23	-0.06		0.22	-0.06		0.22
	2.02			*2.04*			*2.04*		
Computer industry	0.06		0.22	-0.15		0.21	-0.16		0.21
	1.66			*1.70*			*1.70*		
Machinery industry	-0.13		0.23	-0.17		0.22	-0.18		0.22
	1.56			*1.56*			*1.56*		
Household appliances industry	0.13		0.22	0.01		0.21	0.01		0.21
	1.59			*1.60*			*1.61*		
Relative number of competitors in innovation network	-1.92	**	0.73	-0.89		0.72	-0.91		0.72
	1.03			*1.14*			*1.14*		
equity alliances	-0.38	**	0.15	-0.33	**	0.14	-0.34	**	0.14
	1.06			*1.06*			*1.07*		
Customer uncertainty	0.11	**	0.05	0.08		0.05	0.07		0.05
	1.07			*1.08*			*1.08*		
Technological uncertainty	-0.13	**	0.06	-0.03		0.06	-0.05		0.06
	1.07			*1.15*			*1.19*		
Marketing resource input	0.01		0.05	0.04		0.05	0.05		0.05
	1.08			*1.29*			*1.29*		
Total dollar cost innovation project	-0.04		0.11	-0.02		0.11	-0.02		0.11
	1.18			*1.21*			*1.21*		
Number of employees lead firm	0.07		0.13	0.11		0.13	0.11		0.13
	1.33			*1.33*			*1.34*		
Main effects									
Architecturalness				-0.20	**	0.05	-0.19	**	0.10
				1.36			*1.37*		
Betweenness				0.30	**	0.06	0.31	**	0.06
				1.20			*1.21*		
Two-way interactions									
Architecturalness X Betweeenness							0.06		0.00
							1.069		
Model F	2.48			6.01			5.76		
R²	0.07			0.18			*0.19*		
Adjusted R²	0.04			0.15			0.15		
S.d. of the estimate	1.32			1.25			1.25		
ΔR²	0.07			0.110			0.005		
F change	0.01			0.00			0.14		

Values in italic are VIFs.

* p < .10

** p < .05

Dummy AI X Betweeenness, without the control factor: Bridging Ties

Variables	Collaborative Innovation Performance								
	Model 1			**Model 2**			**Model 3**		
Constant	4.33	**	0.67	3.39	**	0.35	3.38	**	0.35
Control variables									
Construction industry	0.05		0.23	-0.10		0.12	-0.10		0.12
	2.02			*2.03*			*2.03*		
Computer industry	0.06		0.22	-0.15		0.11	-0.12		0.11
	1.66			*1.70*			*1.72*		
Machinery industry	-0.13		0.23	-0.07		0.12	-0.05		0.12
	1.56			*1.56*			*1.57*		
Household appliances industry	0.13		0.22	-0.01		0.12	-0.01		0.12
	1.59			*1.60*			*1.61*		
Relative number of competitors in innovation network	-1.92	**	0.73	0.40		0.40	0.28		0.40
	1.03			*1.14*			*1.17*		
equity alliances	-0.38	**	0.15	0.05		0.08	0.03		0.08
	1.06			*1.09*			*1.12*		
Customer uncertainty	0.11	**	0.05	-0.01		0.03	-0.01		0.03
	1.07			*1.09*			*1.09*		
Technological uncertainty	-0.13	**	0.06	0.06	*	0.03	0.06	**	0.03
	1.07			*1.13*			*1.13*		
Marketing resource input	0.01		0.05	0.12	**	0.03	0.12	**	0.03
	1.08			*1.14*			*1.14*		
Total dollar cost innovation project	-0.04		0.11	-0.01		0.06	0.00		0.06
	1.18			*1.18*			*1.19*		
Number of employees lead firm	0.07		0.13	0.09		0.07	0.09		0.07
	1.33			*1.33*			*1.33*		
Main effects									
Dummy AI				-2.37	**	0.08	-2.38	**	0.10
				1.24			*1.24*		
Betweenness				0.12	**	0.03	0.17	**	0.04
				1.24			*2.05*		
Two-way interactions									
Dummy AI X Betweeenness							-0.13	**	0.1
							1.993		
Model F	2.48			82.42			77.68		
R^2	0.07			0.75			*0.76*		
Adjusted R^2	0.04			0.74			0.75		
S.d. of the estimate	1.32			0.68			0.68		
ΔR^2	0.07			0.681			0.003		
F change	0.01			0.00			0.03		

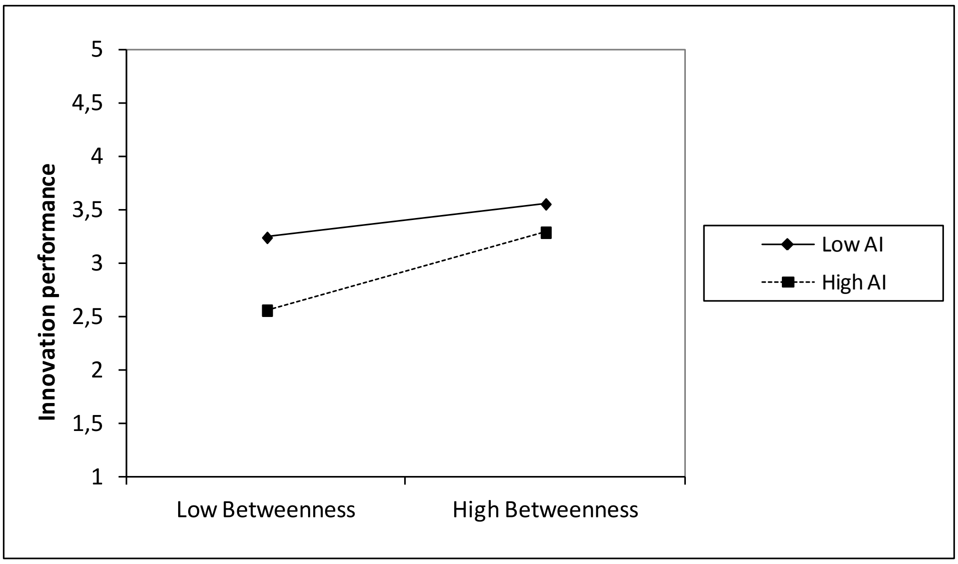
Values in italic are VIFs.

* p < .10

** p < .05

Appendix 5: Plot for the measure of architecturalness

This plot shows results which are almost equal to the results of the dummy of AI.



Appendix 6: Project description and reflection

Start

As starting point for my thesis I used the dissertation of E. Hofman (2010) titled: Modular and architectural innovation in loosely coupled networks. My focus was especially on the chapter "when to use loose or tightly coupled networks for product innovation? Empirical evidence". At the end of this chapter there were some recommendations for future research. One of the recommendations is to study the behavior of innovation network leaders that can actively compensate for the negative impact on architectural innovations. This recommendation is used as one of the principles of the literature study for my thesis.

Literature

I started my literature study with theories about different sources of power and investigated the influence of power on network relations. The main question I asked myself is: How is a network influenced by the factor power and how can this effect the innovation performance? This part is backed up by theories of Emmerson (1962), Ibarra (1993) and Provan, Beyer & Kruytenbosch (1980). This literature offered me valuable ideas and insights about network relations and different sources of power. During the next step I investigated several network theories to get an understanding of the effects of network centrality, a middleman and the different functions of a middleman within a collaborative innovation network. To arrive at that point I used the general network theories of Burt (1995), Ahuja (2000), Granovetter (1974), Zaheer & Bell (2005) and Tsai (2001). At last I focused on innovation types and their influence on the performance. This all together represented my first research proposal.

After this extensive literature review I had a meeting with my supervisor and we decided to focus on the combined effects of the level of betweenness from a lead firm and the density of a network on architectural product innovations. My purpose was to write my end thesis as an academic paper. Fortunately I could use parts of the data of the dissertation of E. Hofman. For the factor network density there was no data available.

During the sequel of writing my theoretical framework the focus was on the effects of betweenness and network density on architectural product innovations. I searched for a solution for the problem of the missing data about network density. From the U.S. census bureau I was able to get data about the four firm concentration ratio which I could link to the other data by using the industry codes. While analyzing the data it was unfortunately not that easy to link the data from the U.S. census bureau with the other data. There were two types of coding for the industries: NAICS and SIC codes. Luckily there was a translation table, however the results were not satisfactory. Nevertheless I did also the analysis for this data and the results were not significant. Therefore I decided to focus only on the effects of betweenness on architectural product innovations. Betweenness was one of the measures which was not used in the dissertation of E. Hofman so I was able to create new results.

I rewrote my theoretical framework and decided to create two clear explanations for the hypotheses. One in which a higher level of betweenness is positive for the performance of architectural innovation and the second describing that a low level of betweenness is positive for non-architectural innovations. There was enough support for these two explanations, therefore I expected satisfactory results.

Data analysis

Before I carried out the hierarchical moderate regression analysis, I performed the following tests: missing value analysis, outliers analysis, test on normality, test on multicollinearity, test on correlation, factor analysis, reliability analysis and Harman's one factor analysis. After all these tests I discovered some problems with the measure of betweenness which indicates minimal reliability and the control factor bridging ties which correlates with the measure betweenness. Therefore I conducted three alternative regression analyses. One including all normal measures, one with a modified measure of betweenness and one without the control factor bridging ties. The alternative results indicated some marginal changes in the outcome. Therefore I decided to focus my paper on the original measures.

I planned to use the measure of architecturalness. This measure is based on 5 questions and indicates the level of architecturalness of an innovation. The analysis in which this measure was used unfortunately did not provide a significant result. The alternative measure was the measure: type of innovation, which indicates whether an innovation is architectural or modular. For this research I decided to name it architectural or non-architectural. Otherwise my theoretical framework would not fit to the analysis. The outcome of the hierarchical moderate regression analysis in which the dummy was used was significant and these results also indicate the same results compared to the continuous measure of architecturalness.

Conclusion/discussion

The results partly match the assumptions made in the theoretical framework. A high level of betweenness does have a significant impact on the innovation performance. However this impact was higher for non-architectural innovations than for architectural innovations. This was not in line with my expectations and surprised me because several authors wrote the opposite. Also the effect of betweenness on architectural innovations was not clearly what I expected. Based on the theory I expected a much higher effect for architectural innovations than for non-architectural innovations.

At last I tried to find support for this outcome. Partial support is found in the general theories of betweenness in which is argued that a high level of betweenness will link together actors which are otherwise unconnected. This results in more creativity and more input from different sources, which will positively influence the innovation performance. Unfortunately this support was more focused on innovations in general, and not specific for non-architectural innovations.

From my own point of view a plausible explanation for this outcome could be that for non-architectural innovations a centralized lead firm is important to coordinate the production of all different modules. For non-architectural innovations it is more important for the innovation partners to communicate through a lead firm than with each other. The different partners are not dependent on each other, they only have to design their innovation within the design rules. For example a producer of new telephone batteries only has to communicate with the lead firm. It is not important for the battery producer to communicate also with the producer of a keyboard or screen. There are some fixed rules for this producer about the power required and the dimensions of the battery. Besides that the battery producer is free to develop this part.

On the other hand, for architectural innovations the communication between the different partners is for sure important; they are all dependent on each other because they create a whole new product, there are significant changes within the interactions between the components. Next to a centralized lead firm which provides coordination, also the communication with all different partners is important for the performance.

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