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THE IMPACT OF TECHNOLOGY UNCERTAINTY ON EARLY SUPPLIER INTEGRATION IN PRODUCT DEVELOPMENT

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Abstract

This study examines how the presence of technology uncertainty affects the benefits of integrating suppliers in the product development process. A framework was created to cover the different aspects of technology uncertainty discussed in current empirical studies. From this a survey instrument was created and a sample of data collected from companies engaged in product development projects. The analysis confirmed most aspects of the technology uncertainty framework. A tendency towards strategic and long-term buyer-supplier relationships leading to better product development performance was shown. Thorough supplier assessment using cross-functional teams and formal IP and confidentiality agreements were shown to benefit supplier integration in the Fuzzy Front End of product development. The benefits from integrating suppliers in the Fuzzy Front End seem to be positively moderated by the level of experience the buying-organization has with the technology provided by the supplier. This runs counter to the prediction that supplier integration should be more beneficial if the buying-organization has less knowledge about the supplier's technology.

Keywords: Uncertainty, Supplier Integration, Design management, Integrated product development

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1 INTRODUCTION

1.1 Overview

Continuous innovation is one of the main success factors in staying competitive in many industries. Since the 1980s the continuous improvement of the innovation process has led to a more cooperative and integrative approach being taken with suppliers (Rothwell 1994). Today there is a consensus that the capability to effectively integrate suppliers in innovation and product development processes can give an organization a competitive edge (Johnsen 2009, p. 196). Expected benefits from integrating a supplier range from lower development costs, better product quality, and shorter development time (Johnsen 2009, p. 195) to getting access to the supplier's technical knowledge in general, which can be the source of a new innovation in the first place (Oke et al. 2013).

However, product development, especially in its early stages, is characterized by varying degrees of uncertainty about what knowledge will be needed, who should be involved in the process at specific stages, and what benefits their participation brings. Empirical research has produced conflicting results regarding the impact of technology uncertainty on supplier integration benefits (Johnsen 2009). In general, one can argue that high uncertainty leads to a greater need for the exchange of information and detailed technical knowledge (Tatikonda & Stock 2003, p. 452). Moreover, technology uncertainty can be attributed to technological innovations (Johnsen 2009, p. 190) and, as described above, integrating suppliers is seen as an important enabler of successful innovation processes. According to these arguments, one would expect empirical research to find an overall positive impact of supplier integration under conditions of technology uncertainty. Since this is not the case, it is important to further investigate the relationship between technology uncertainty and supplier integration benefits.

Atkinson et al. (2006, p. 689) argue that stakeholders should be more involved in such uncertain and ambiguous environments, because different perspectives have to be taken into account. In context of product development these early phases can be called 'predevelopment' phases and several studies have shown that they have a big impact on overall process performance (Brown & Eisenhardt 1995, p. 371). 'Fuzzy Front End' (FFE) is another term used to describe 'predevelopment' activities (Koen et al. 2001). Wagner (2012) is the first to investigate the impact of supplier integration in the FFE on the overall product development performance. The author observes a positive relationship between supplier integration and product development performance and confirms the criticality of the FFE for innovation processes. Wagner proposes that future research should generate practical advice for supplier integration process in the FFE and investigate what factors influence the intensity of integration (p. 46).

1.2 Problem Statement

In summary, integrating suppliers in product development processes as well as managing the FFE of product development are both seen as critical to overall product development performance. Moreover, innovation and the FFE of projects both imply the presence of uncertainty, which can be interpreted as the absence of required knowledge. Suppliers are a possible source of required information to enable better decision making in such circumstances. However, past studies produced conflicting results regarding the benefits of supplier integration in the new product development process under technological uncertainty. The adaptation of project management guidelines to specific circumstances and the presence of uncertainty in general is proposed as a promising field for further research.

The integration of suppliers in the FFE has only recently been investigated and the corresponding study found empirical evidence for the importance of this practice. A useful extension of existing research is to investigate the benefits of integrating suppliers in the FFE with consideration of the level of technology uncertainty.

The objective of this study is therefore to first define a framework for the assessment of technology uncertainty in product development projects. Based on that assessment, empirical research will be conducted to explore interdependencies between the level of technology uncertainty, the way a supplier is integrated in the product development project and the benefits that have been achieved by it.

2 TECHNOLOGY UNCERTAINTY FRAMEWORK

2.1 Elements of Uncertainty

Johnsen (2009) treats radical innovation as equivalent to high technology uncertainty (p. 187). In order to define a holistic technology uncertainty framework, these two related concepts are analysed. An extensive theoretical framework for technology uncertainty developed by Tatikonda and Stock (2003) is used as a basis, since it was developed specifically in the context of a technology transfer between two organizations. It is then compared with a framework for radical innovations developed by Green et al. (1995) to identify if there are opportunities to expand the former.

Tatikonda and Stock (2003) developed their framework based on New Product Development, Supply Chain Management and Technology Management literature. According to the authors, technology uncertainty can be described by three dimensions: Novelty, complexity and tacitness. Novelty describes how much knowledge the organization has regarding the involved technology, which is the newness of the technology, as well as to which extent the technology changed its characteristics since the last time it was applied by the organization. Complexity represents the scope of the technology, which is defined by the number of components or functions, as well as the number of internal and external interdependencies between components and the system in which they are integrated. Lastly, tacitness describes how implicit the technological knowledge is that has to be transferred to the organization. The more tacit or implicit a technology is, the harder it is to acquire the necessary knowledge. Tacitness is decreased through physical embodiment of the technology (e.g. a prototype), the codification of the technology (e.g. technical drawings), and the more complete the development of the technology already is.

A comparison between the technology uncertainty framework from Tatikonda and Stock (2003) and the one for radical innovation by Green et al. (1995) shows that while there is a considerable overlap between the two, there are also significant differences. Green et al. (1995) also include a measure for technical inexperience, which corresponds to the novelty dimension of technology uncertainty. Moreover, the technological change dimension in Tatikonda and Stock (2003) corresponds to the extent of progress in technology knowledge in Green et al. (1995), the codification of the technology to the certainty of technology knowledge, and the completeness of the technology to the technological maturity, respectively. An aspect from the radical innovation framework that can be added to the technology uncertainty framework used here is the predictability of technological change. It can be argued that the predictability of a technology is important when considering which supplier to involve in a product development project. For example, a supplier with strong R&D capabilities might be more desirable in an environment of rapid technological change, even if his technology is not the best on the market at this point in time. Green et al. (1995) propose a scale from slow to rapid to measure the predictability of technological progress. This scale seems more appropriate to measure the rate of progress than its predictability. Progress could be rapid and predictable at the same time. For this study this measure is therefore separated into two parts, one to measure the rate of progress, and one to measure the predictability of the progress.

Other aspects of the radical innovation framework by Green et al. (1995) that are not included in the technology uncertainty framework described in Tatikonda and Stock (2003) are the ease and rate of entry of other organizations into the knowledge base of the technology, the predictability of research cost, the business inexperience of a company with the technology, as well as the technology costs. These aspects are not considered here due to lack of a comprehensive argument for the relevance of these aspects to the selection of a supplier or the transfer of technological knowledge.

2.2 Development of the Uncertainty Framework

The result of the content analysis conducted to develop a technology uncertainty framework is summarized in Table 1. The analysis is based on 21 empirical studies on supplier integration in product development, which include technology uncertainty as a contingency factor. The studies were assessed regarding which technology uncertainty aspects they cover to help develop the technology uncertainty framework for completeness and the relevance of each chosen uncertainty aspect. Explicitly and implicitly addressed uncertainty aspects are differentiated, with the former being rated with one point and the later with half a point. The analysis led to the following conclusions.

First, the term technology uncertainty is used very inconsistently across studies. Second, most frequent and most explicitly measured is the complexity and the newness of the technology, followed by the rate and predictability of technological change and the extent of change since the last time a technology was used by the organization. This result is taken as a confirmation that the change rate and predictability should be added to the framework proposed in (Tatikonda & Stock 2003). Third, all the aspects defined in (Tatikonda & Stock 2003) as part of the 'tacitness' construct are not frequently addressed. These aspects are the physical embodiment of the technology, the degree of codification, and how complete the technology is before the supplier is integrated in the product development process. It is noteworthy that the completeness or maturity of a technology is addressed so rarely in a field of research which investigates product development processes. The assessment of the readiness of a new technology as part of the product development process is state of the art and also prominently included in basic literature like (Cooper 2011, p. 127). Frishammar (2011) reasons that it is easier to address uncertainty because it is more tangible and more familiar to engineers than equivocality, which centers on soft issues (p. 557). However, Frishammar finds that reducing equivocality is a prerequisite for reducing uncertainty. He concludes that the study "indicates that the previous bias toward studying only uncertainty in the fuzzy front end of innovation is problematic and needs to be addressed in future research" (p. 559). This statement is very important because it reinforces the finding that these aspects have not been addressed sufficiently in the past, that it is important to further analyse the influence of these aspects, and that uncertainty is especially relevant in the FFE of product development.

Table 1. Aspects of Technology Uncertainty addressed in empirical studies on supplier integration in product development (1= explicitly addressed, 0.5= implicitly addressed)

Publication	Characteristics by Tatikonda & Stock (2003)						Added	
	Newness	Change Extent	Complex-ity	Embodi-ment	Codifi-cation	Complete-ness	Change Rate	Change Predict.
(Eisenhardt & Tabrizi 1995)							0.5	0.5
(Wasti & Liker 1997)		1	1					
(Swink 1999)	1					0.5		
(Primo & Amundson 2002)						0.5		
(Ragatz et al. 2002)	1		1				1	1
(Song & Di Benedetto 2008)		0.5						
(Hartley et al. 1997)		1						
(Simonin 1999)	1		1	0.5	1			
(Laseter & Ramdas 2002)			1					
(Koufteros et al. 2005)		1	1				1	
(Carson et al. 2006)							1	1
(Ettlie & Pavlou 2006)		0.5						
(Parker et al. 2008)	1							
(Azadegan & Dooley 2010)			1					
(Klioutch & Leker 2011)	1							
(Oosterhuis et al. 2011)		1					1	
(Lau 2011)	1		1					
(Wagner 2012)							1	
(Yan & Dooley 2013)	1		1					
(Blome et al. 2013)	1		1					
(Zhao et al. 2013)	1	0.5	1				1	1
Number of studies (total 21)	**9**	**5.5**	**10**	**0.5**	**1**	**1**	**6.5**	**3.5**

3 MODEL AND HYPOTHESES

The technology uncertainty framework was used to empirically investigate the influence of technology uncertainty on performance outcomes of supplier integration in the FFE of product development processes. The framework allows a differentiated analysis of the influence of uncertainty aspects to gather further insights on the reason for conflicting results found on the topic in earlier research (Johnsen 2009). The basic model to be investigated is depicted in Figure 1. The supplier integration practices are the independent variables, which influence the dependent variables of performance outcomes. The different aspects of technology uncertainty are intervening variables that change the way supplier integration impacts performance outcomes.

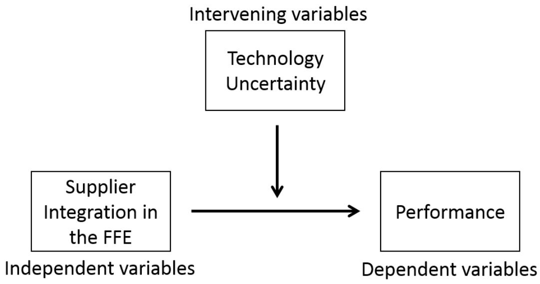

Figure 1. Investigated contingency model. Adapted from (Tatikonda & Stock 2003)

Empirical research suggests to integrate suppliers early on during the development process to maximize the positive impact (Ragatz et al. 2002, p. 398; Parker et al. 2008, p. 79, Wagner 2012). This leads to the following hypothesis about the relationship between the independent and the dependent variables.

Hypothesis 1: Supplier integration in the FFE of the innovation process has a positive impact on product development performance.

Eisenhardt and Tabrizi (1995, p. 105) as well as Ragatz et al. (2002, p. 398) argue that the integration of suppliers should be delayed as much as possible if there is rapid technological change. This is to avoid redesigns due to technology changes and to make sure that the latest technology is used in the product. Both studies do not report a separate measure for technological change. Further analysis should test if technological change calls for late integration of suppliers, and thus no integration in the FFE – and if other uncertainty aspects have the same influence on the timing of integration or not. This focus on the timing of integration follows suggestions for future research by academic literature (Ragatz et al. 2002, p. 399; Parker et al. 2008, p. 80). Green et al. (1995) conducted a factor analysis and found that technological uncertainty is a separate construct from technical inexperience of the organization developing a new product (p. 210). Based on this finding uncertainty aspects can be divided into two groups: Uncertainty in the technological environment on one hand and on the other hand a lack of knowledge of the product development organization about the technology itself. Applying this concept to the technology uncertainty aspects identified in the previous chapter results in the following two groups of hypotheses.

Hypotheses 2: **a)** Rapidly changing technology and **b)** unpredictable technological change moderate the relationship between the supplier integration process and performance outcomes in such a way that integrating a supplier in the FFE is less beneficial.

Hypotheses 3: **a)** Technology newness, **b)** extensive technological change since the last implementation of the technology, **c)** technology complexity, **d)** low physical embodiment, **e)** low codification, and **f)** low completeness of the technology moderate the relationship between the supplier integration process and performance outcomes in such a way that integrating a supplier in the FFE is more beneficial.

4 RESEARCH METHODS

A survey is used to collect data to test the hypotheses based on subjective data from completed product development projects. The research is conducted from the perspective of the product developer company that worked with suppliers to the project. Respondents were required to have worked on the project team and to have been knowledgeable enough to answer detailed questions about the project.

The sample to collect data for this study consisted of two mailing groups. One is a group of subject matter experts, which holds bi-weekly online-meetings to develop and discuss new content related to project management. The group consists of approximately 70 people. The second group is an extended community of practice, with which the research results are shared. This group counts around 250 people. The sample was extended via LinkedIn (www.linkedin.com), which is a popular online-network for professionals. A link to the survey was shared on discussion boards of interest groups from the fields of product development, innovation, program management, and project management.
The complete set of measures used to investigate the contingency model depicted in Figure 1 is shown in the appendix in Table 5. In addition to the variables of the contingency model the survey asked for organizational characteristics to describe the sample. Prior to distribution the survey was reviewed by a group of three experts regarding its ease of understanding and the clarity of the survey structure. Over the course of one month 27 responses were gathered. Roughly half of the responders were reached via the available mailing lists and half was reached via LinkedIn. The response rate from the mailing lists is about 4%. Respondents did not answer some of the questions if they were not applicable in their specific case. Two of the 27 respondents made use of this option. This resulted in 25 complete questionnaires for the data analysis. Because of the small sample size we restricted our statistical analysis for hypothesis testing to non-parametric methods.

5 RESULTS

5.1 Sample Characteristics & Validity of Measures

The sample is characterized by project durations at the lower end of the used scale, with two thirds of the projects taking up to three years. Two thirds of the projects took place in business units with up to 500 employees and about three fourths of the core teams consisted of up to 20 people (team members working on the project for at least 80% of its duration). About one fourth of the developed products are related to space and aviation. The rest is more or less evenly distributed across IT, mechanical engineering, electronic engineering, and various consumer goods. Two thirds of the respondents were project managers or members of the project management staff.
A Shapiro-Wilk test resulting in $p = 0.173$ shows that normal distribution can be assumed for the construct measuring product development performance (Shapiro & Wilk 1965). Internal consistency of the construct is measured using Cronbach's α (Cronbach 1951) and the result of $\alpha = 0.896$ lies above the threshold of 0.7 recommended by Flynn and Sakakibara (1990). To confirm construct validity a Principal Component Analysis was conducted based on the global product development performance. The result is shown in Table 2 and indicates that the product development performance construct only measures a single dimension (Hattie 1985).

Table 2. Principle Component Analysis of product development performance construct

Components of Global Product Development Performance	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	3.126	78.138	78.138
2	.466	11.646	89.784
3	.308	7.694	97.478
4	.101	2.522	100.000

The single item measures are tested for normal distribution to determine if parametric methods can be applied to analyse the survey data (Conover & Iman 1981). The Shapiro-Wilk test is significant at the 0.05 level for most of the items, indicating that the data is not approximately normally distributed and that therefore non-parametrical methods have to be applied. A visual inspection of the histograms for the items lead to the conclusion that items TU6 (physical embodiment) and TU7 (codification) can be excluded from further analysis. Only two and three respondents, respectively, agreed to some level that these uncertainty sources were relevant in their case. The remaining technology uncertainty aspects were tested for correlation using Spearman's ρ (Conover & Iman 1981). Based on the results shown in Table 3 it is assumed that the extent and rate of technology change (TU2 and TU3) as well as the completeness of the technology (TU8) are not independent variables in the analysed sample. They are combined in a single 'change' construct, which shows good internal consistency ($\alpha = 0.785$). It can be reasoned that fast changing technology is likely to have changed a lot since its last application and is perceived as less complete due to its ongoing development.

Table 3. Spearman correlation between technology uncertainty aspects

Items	TU1	TU2	TU3	TU4	TU5	TU8
TU1: Newness	1					
TU2: Change Extent	0.261	1				
TU3: Change Rate	0.207	0.720**	1			
TU4: Unpredictability	0.207	0.356	0.306	1		
TU5: Complexity	0.128	0.097	0.223	0.104	1	
TU8: Incompleteness	-0.079	0.480*	0.381^{+}	0.102	-0.212	1
* significant at the 0.05 level (2-tailed), ** significant at the 0.01 level (2-tailed), $^{+}$ p = 0.060						

5.2 Testing of Hypotheses

To test hypothesis 1 the sample is split into two groups on the basis of item SI1. The first group (N = 16) was integrated in the FFE while the second group (N = 9) was integrated only after the concept of the product was already defined. A Mann-Whitney test is used to determine whether the performance distribution of the two groups significantly differ from each other (Conover & Iman 1981). The result shows a tendency towards better product performance in cases were suppliers were integrated during the FFE, but with $p = 0.07$ significance at the 0.05 level cannot be established.

The hypotheses 2 and 3 have to be adapted based on the analysis results up to this point. Hypotheses 3d and 3e cannot be tested because technology embodiment (TU6) and codification (TU7) are not relevant factors in the available sample. Moreover, hypotheses 2a, 3b and 3f need to be combined into a new hypothesis 2c. The new set of hypotheses to be tested are:

Hypotheses 2: b) Unpredictable technological change (TU4) and **c)** high technological change (TU2/3/8) moderate the relationship between the supplier integration process and performance outcomes in such a way that integrating a supplier in the FFE is less beneficial.

Hypotheses 3: a) Technology newness (TU1) and **c)** technology complexity (TU5) moderate the relationship between the supplier integration process and performance outcomes in such a way that integrating a supplier in the FFE is more beneficial.

The group of 16 cases in which the supplier was integrated during the FFE is used to test hypotheses 2 and 3. For each uncertainty aspect the group is split into two at the mean of the uncertainty distribution to obtain subgroups with low and high uncertainty. Again, the Mann-Whitney test is used, this time to explore if the different uncertainty levels have a significant impact on the performance outcomes for supplier integration in the FFE. The results are presented in Table 4. For the newness of the technology (TU1) the difference in performance between low and high uncertainty is statistically significant at the 0.05 level ($p = 0.006$). The histograms for the two performance distributions are depicted in Figure 2. The integration of suppliers in the FFE led to better product development performance if the buyer-organization already had previous experience with the technology provided by the supplier. This result is contrary to the hypothesized positive impact of technology newness on early supplier integration benefits. Hypothesis 3a is therefore rejected. There were no significant results regarding the other hypotheses.

Table 4. Mann-Whitney test for performance of supplier integration in the FFE under low and high levels of uncertainty

Uncertainty Level	TU4 Unpredictable			TU2/3/8 Change			TU1 Newness			TU5 Complexity		
	N	U	p	N	U	p	N	U	p	N	U	p
Low	7	20.0	0.239	4	13.0	0.199	9	7.0	0.006	7	30	0.897
High	9			12			7			9		
N = Number of cases, U = Mann-Whitney-U, p = Exact significance (2-tailed)												

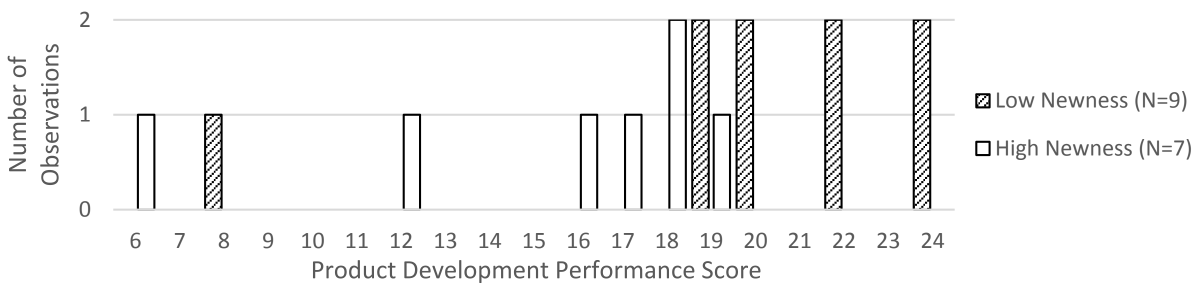

Figure 2. Distribution of product development performance scores for supplier integration during the FFE for high and low newness of the technology for the receiving organization

6 DISCUSSION AND CONCLUSION

An analysis of technology uncertainty aspects considered in existing empirical research on supplier integration in product development led to the conclusion that technology uncertainty aspects are used very inconsistently across studies and that they are often combined into a single uncertainty construct. This makes is very difficult to compare the results of different studies with each other and it may also contribute to conflicting findings of these studies identified by Johnsen (2009). Green et al. (1995) empirically tested the same issue in the context of radical innovation and found that different dimensions of the radical innovation theory should be measured separately. In the sample analyzed in this study four uncertainty aspects could be identified that did not correlate with each other, further emphasizing that a holistic and differentiated approach is needed when addressing the topic of technology uncertainty.

In the sample supplier integration in the FFE was significantly more beneficial if the buying-organization already had experience with the technology contributed by the supplier. This finding contradicted the hypothesis, which predicted that the integration of a supplier should be more beneficial the less knowledge the buying-organization already has about the technology provided by the supplier. A possible explanation for this result of the survey could be found in a study by Koufteros et al. (2012), in which the authors argue that the assessment of suppliers is more important than the integration process. Hartley et al. (1997) found that the capabilities of the supplier are more important than the way the buyer-supplier-relationship is organized. An interpretation of the greater benefits found for supplier integration in the FFE in cases where the buying-organization had more experience with the technology could therefore be that those organizations were more capable of assessing and selecting the right supplier for that technology.

This would mean that supplier integration in product development cannot entirely replace the need for the buying-organization to acquire the relevant technological competencies itself. To be able to successfully manage a collaborative product development project, the buying-organization needs to be capable of identifying suitable suppliers and what exactly they could contribute. The buying-organization should assess its own technological competence when analysing the risks associated with selecting and integrating technology suppliers in order to design and develop a new product.

In conclusion it can be said that this study points to a possible source of conflicting results in empirical research on supplier integration benefits under technological uncertainty and the need to investigate that topic specifically for supplier integration in the FFE. A holistic technology uncertainty framework was developed and validated based on an extensive literature analysis. Based on that framework a survey study was conducted, which found that within the analyzed sample supplier integration in the FFE was more beneficial if the buying organization already had experience with the involved technology.

7 LIMITATIONS AND OUTLOOK

The statistical testing of the hypotheses was limited to non-parametric methods by the small sample size of 25 observations. For the same reason the results of the survey study cannot be generalized beyond the scope of the gathered sample. Besides a larger sample size it would also be preferable to have a more homogeneous sample and thus to have more knowledge about the specific context of the projects for the interpretation of the results.

Two areas for future work are proposed based on this research. First, the influence of technology uncertainty aspects related to tacitness, ambiguity or equivocality on supplier integration benefits is rarely addressed in existing research and should be investigated further. Second, it would be interesting to analyze interdependencies within the developed technology uncertainty framework based on a bigger sample. By empirically validating the framework and improving the reliability of the scales to measure uncertainty aspects a basis for future research in this field can be developed. It would help to improve the comparability of future studies and their integration into useful guidelines for practitioners.

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APPENDIX

Table 5. Measures to investigate the contingency model and the sample characteristics

Constructs & Items		Scale
Supplier Integration in the FFE		
SI1	Please indicate the first stage at which the supplier was involved in the project, based on (Parker et al. 2008; Koen et al. 2001)	nominal
Product Development Performance (construct)		
ProP1	The collaboration with this supplier benefited the overall quality of the product, based on (Wagner 2012)	6 point Likert
ProP2	.. enabled us to develop the product more quickly, based on (Wagner 2012)	6 point Likert
ProP3	.. resulted in a better design of the overall product, based on (Wagner 2012)	6 point Likert
ProP4	.. had a positive impact on overall development costs	6 point Likert
Technology Uncertainty (single items)		
TU1	Our organization had precious experience with this technology, based on (Tatikonda & Stock 2003)	6 point Likert*
TU2	The technology had changed a lot since the previous project in which it was used, based on (Tatikonda & Stock 2003)	6 point Likert
TU3	In our industry this technology was likely to change significantly during the project, based on (Wagner 2012)	6 point Likert
TU4	Future technology developments are difficult to predict within the timeline of the project, based on (Zhao et al. 2013)	6 point Likert
TU5	How does the complexity of this supplier's technology compare with other available options, based on (Tatikonda & Stock 2003)	Much less - Much more
TU6	The technology is a physical artifact that you can touch, based on (Tatikonda & Stock 2003)	6 point Likert*
TU7	The technology was already described in a way that allowed detailed technical discussions, based on (Tatikonda & Stock 2003)	6 point Likert*
TU8	The techn. was completely developed, based on (Tatikonda & Stock 2003)	6 point Likert*
6 point Likert: Strongly disagree/agree, disagree/agree, somewhat disagree/agree		* reverse coded