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Managing uncertainty and equivocality in joint process development projects

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A B S T R A C T

Process development is key to competitiveness in process industries. However, budget overruns frequently plague process development projects which span organizational boundaries to involve both buyers and suppliers. We identify uncertainty and equivocality as key antecedents causing such negative effects, and investigate the reduction and performance implications of these two variables. An empirical survey of 52 joint process development projects show that project teams reduce uncertainty through early end-user involvement, whereas equivocality can be reduced by joint problem-solving activities among buyers and suppliers.

1. Introduction

Process development is regarded as a key for competitiveness in process industries and in other manufacturing industries, because it increases production yields, cuts costs, and allows firms to contend with competition (Aylen, 2013; Pisano, 1997; Robertson et al., 2009; van Rooij, 2005). Process development involves developing and implementing new or significantly improved process technology and machinery equipment (OECD, 2005). Process development projects are typically large, in terms of both time and money, entailing significant management challenges (Scott-Young and Samson, 2008). Indeed, a recent study by Ernst and Young (2011) found that process development projects within the metals and minerals industries (the industry on which the present study focuses) are commonly plagued by budget overruns of 70% or more. Consequently, developing and implementing new process technology is a necessary but risky endeavor that may seriously endanger long-term competitive advantages and the financial viability of firms if not managed proficiently (Filippou and King, 2011).

Adding to the management challenge, process firms often lack the internal resources and competences to design new process equipment on their own (Aylen, 2010; Arora and Gambardella, 1997; Reichstein and Salter, 2006), which necessitates collaborating with equipment suppliers and pooling resources in joint projects (Hutcheson et al., 1996; Robertson et al., 2012). Therefore, large-scale process development is often more open and collaborative than product development and brings about challenges in coordinating a multitude of development activities across organizational boundaries (Robertson et al., 2012).

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Collaboration among buyers from process firms and the suppliers of process equipment is vital in joint process development. Indeed, prior research has shown that joint projects of this type often fail when buyers and suppliers lack a shared basis to understand each other (Rönnberg Sjödin, 2013; van Rooij, 2005). Design and development in the context of joint development projects require a significant amount of information to be gathered, processed, and shared by the buyers and suppliers of the project team to facilitate development work and manage idiosyncratic design requirements. In doing so, buyers and suppliers must address the challenges of both uncertainty and equivocality in the early stages of development (Daft and Lengel, 1986; Galbraith, 1973).

Uncertainty is defined as the difference between the information available and the information needed to complete a task (Galbraith, 1973). Equivocality, on the other hand, is defined as the extent to which multiple and conflicting interpretations of information exist among participants in a project (Daft and Lengel, 1986). Equivocality may be particularly challenging when actors have different backgrounds, roles, and cultures, which is often the case in joint projects. In equivocal situations, individual interpretations of information are unambiguous, but collectively the interpretations differ (Zack, 2001). A lack of information or shared interpretations during the early stages of development can lead to significant problems in joint process development projects. For example, too much uncertainty and equivocality can lead to difficulties in creating explicit, stable, and robust process designs, causing time delays and wasting resources (Sicotte and Langley, 2000; Song et al., 2007).

From a management perspective, the differences between uncertainty and equivocality are critical, because they require different information processing approaches (Chang and Tien, 2006; Daft and Lengel, 1986). Reducing uncertainty is achieved primarily through information gathering and analysis that, if successful, significantly increases the chances of a fruitful project (Ullman, 2010). Consequently, in process development, the joint project team must gather and share information and conduct work analyses to answer questions related to equipment specifications, the design of process flowcharts, and the broader manufacturing environment (Schuman and Brent, 2005). Somewhat paradoxically, in an equivocal situation, new information can actually increase, rather than decrease, equivocality (Weick, 1995), which underscores the importance of distinguishing between uncertainty and equivocality. In contrast, reducing equivocality presupposes the exchange of subjective views among project participants to define problems and resolve conflicting interpretations by explaining different viewpoints and enacting a shared interpretation that can direct future activities (Daft and Lengel, 1986; Weick, 1979).

For several reasons, prior research in innovation-, technology-, and operations management does not provide detailed advice regarding how to reduce uncertainty and equivocality in joint process development projects (Koufteros et al., 2005; Stock and Tatikonda, 2008). First, most prior studies are qualitative with limited generalizability (e.g., Bruch and Bellgran, 2012; Frishammar et al., 2011; Song et al., 2007) or not focused primarily on activities for mitigating uncertainty or equivocality (Chang, 2002; Frishammar et al., 2012; Koufteros et al., 2005).

Second, prior research has been conducted primarily in the context of product development, rather than process development (Gales and Mansour-Cole, 1995; Koufteros et al., 2005; Sicotte and Langley, 2000; Song et al., 2007). Although findings from the product development literature may provide valuable insights for process development (Kurkkio et al., 2011), the effectiveness of different activities may vary according to the characteristics of the development work. In addition, due to industrial firms' heavy investment into process technology and its importance for each firm's competitive advantage (Robertson et al., 2012), the context of process development deserves attention in its own right. We thus lack knowledge on managing uncertainty and equivocality in joint process development projects.

In light of these managerial challenges and theoretical gaps, we seek to contribute to the literature and management practice in two ways. First, we seek to study the performance effects of both uncertainty and equivocality in joint process development projects. Second, we identify two key collaborative information processing activities—early end-user involvement and joint problem solving—which help reduce uncertainty and equivocality. In doing so, we draw on a mixed-methods study of joint process development projects. After a qualitative pre-study, we rely on data from a multiwave, multiple-informant survey, including 251 responses from 52 joint process development projects involving both buyers and suppliers. The next section outlines the conceptual framework that guided the empirical study.

2. Conceptual framework

2.1. Addressing information gaps in joint process development projects

The traditional view of process development with equipment suppliers is primarily a unidirectional process of technology transfer (i.e., technology imports by the buyer side) (Lager and Frishammar, 2010). In contrast, joint process development is an integrative process requiring significant interactions among firms with input from a variety of members with different backgrounds (Abd Rahman et al., 2009; Rönnberg Sjödin et al., 2011; Robertson et al., 2012). The need for interaction and iterations emphasizes the processing of relevant information among the involved parties (Koufteros et al., 2002; Stock and Tatikonda, 2008; Swink et al., 2007).

According to information processing theory, organizational information processing must be matched with the specific task at hand (Galbraith, 1973; Tushman and Nadler, 1978). Central to this perspective is the idea that organizations should reduce potential information gaps in the form of uncertainty and equivocality arising from the context (Daft and Lengel, 1986; Galbraith, 1973). Specifically, research in a variety of settings supports the contention that, to be effective, work units

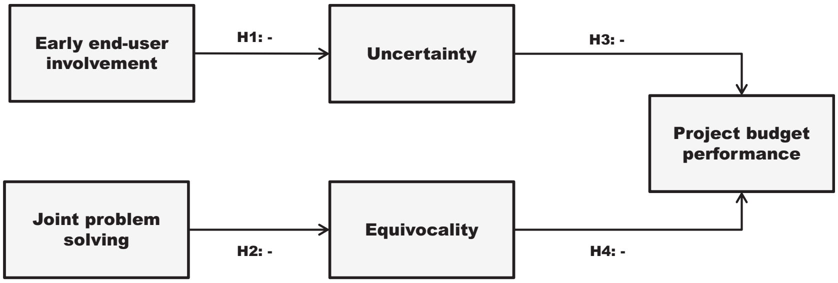

Fig. 1. Conceptual framework.

must match task uncertainty and equivocality with appropriate information processing activities (Gales and Mansour-Cole, 1995; Koufteros et al., 2005; Sicotte and Langley, 2000; Song et al., 2007).

In the early stages of joint process development projects, sharing and processing information about the technical and operational characteristics and requirements of the technology among the project participants is a key concern (Robertson et al., 2012). Therefore, information gaps in the form of uncertainty, equivocality (and the negative effects they may cause) often generate critical problems in process development projects (Bruch and Bellgran, 2012; McGovern and Hicks, 2006).

According to prior literature, reducing uncertainty and equivocality necessitates different activities (Chang and Tien, 2006; Daft and Lengel, 1986; Koufteros et al., 2005). We contribute to this research by studying how uncertainty and equivocality are reduced through collaborative information processing activities in the early stages of joint process development projects. Based on prior literature, our conceptual framework (Fig. 1) identifies two key activities for reducing uncertainty and equivocality: early end-user involvement and joint problem solving.

We argue that early end-user involvement, which entails the involvement of production and maintenance personnel during early development, can be a key activity for gathering required information and reducing uncertainty. End-users are highly knowledgeable about the production environment (Gales and Mansour-Cole, 1995; von Hippel, 1986) and can supply vital information about the operational requirements of the equipment (Bruch and Bellgran, 2012), which may otherwise be unavailable or difficult to grasp for a joint project team. Consequently, early end-user involvement is a way to fill key information gaps in joint process development projects and, as such, an important activity for uncertainty reduction.

In addition, we argue that joint problem solving, which refers to the mutual effort that the partners undertake to diagnose and overcome obstacles that are blocking project effectiveness, can reduce equivocality in the early stages of joint process development. In particular, joint problem sessions enable the enactment of shared meanings and interpretations of information (Bstieler and Hemmert, 2010) among project participants.

Fig. 1 displays the hypothesized effects of uncertainty and equivocality on project budget performance. Our argumentations for these hypotheses are explained in the following sections.

2.2. Early end-user involvement as the key to reducing uncertainty

Studies of industrial product and process development have highlighted the importance of user involvement for success in development projects (Alam, 2002; Eriksson, 2015; Laage-Hellman et al., 2014; Hwang et al., 2015; von Hippel, 1986; Voss, 1985). In the current context of joint process development projects, the user is the buyer firm. Typically, project participants from the buyer organization are sourced from the research and development (R&D) and project management functions within the firm. Thus, they are not actually using the production equipment in their daily work (Schuman and Brent, 2005). Operations and maintenance personnel in the buyer organization, those who work with the equipment as part of their regular work duties, constitute the end-users. We argue that this distinction is particularly important in process development projects, because firms often fail to capture end-user input on equipment that is implemented and used in the production environment (Leonard-Barton and Sinha, 1993; Rönnberg Sjödin et al., 2011).

Prior literature has found that end-user involvement in process development projects is strongly associated with implementation success (McDermott and Stock, 1999; Stock and Tatikonda, 2008; Tait and Vessey, 1988). However, the timing of involvement is especially critical. Here, we focus on the early involvement of the end-users in the pre-study, development, and design stages. In contrast, late end-user involvement when implementing a project often cause significant problems in terms of costly design changes and re-work (Assaf and Al-Hejji, 2006; Eriksson, 2015; Rönnberg Sjödin et al., 2011).

Early end-user involvement is defined as involving operations and maintenance personnel in the early development stages of a project. Early end-user involvement is an important way to fill key information gaps in joint process development projects and thus serve as a vital activity for reducing uncertainty. End-users can supply information up front about the operational requirements of the equipment (Gales and Mansour-Cole, 1995), before significant resources have been committed (Hicks and McGovern, 2009). In particular, accessing information from the accumulated production experience of end-users may provide critical input that increases the quality of simulations and process flow charts (Pisano, 1996) and thus give valuable insights about the work organization.

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In a similar vein, involving end-users ensures that factors such as operability, maintainability, and robustness of the production process are considered (Schuman and Brent, 2005). For example, maintenance personnel can supply critical information about the wear of moving parts and suggest alternate and more robust designs, and process operators can supply vital information about the actual operation of the equipment in the production environment (Pisano, 1997). Gaining access to such information is therefore a key activity for the project team during the design stage and in joint work analysis activities (Bruch and Bellgran, 2012).

Furthermore, knowledge of the complex interdependence among material inputs, the specific process technology, and the overall production process, is typically tacit and gained through processes of learning-by-doing (Tyre and Hauptman, 1992). Such knowledge, therefore, is gained primarily through the equipment's users. To access tacit knowledge concerning production requirements, the project team should involve and interact with end-users (Leonard-Barton and Sinha, 1993) to close information gaps and reduce uncertainty.

In summary, we argue that early end-user involvement is an important way to fill key information gaps in joint process development projects and thus serves as a vital activity for reducing uncertainty. This leads to our first hypothesis:

H1. Early end-user involvement reduces uncertainty in process development projects.

2.3. Joint problem solving as the key to reducing equivocality

Joint problem solving refers to the mutual effort that collaborating partners undertake to diagnose and overcome obstacles that are blocking project effectiveness (Bstieler and Hemmert, 2010). In joint problem solving, parties gather and share views and interpretations and make collective decisions regarding possible solution pathways (McEvily and Marcus, 2005). Here, we argue that joint problem solving is a key activity for enacting shared meaning and interpreting information in the early stages of joint process development projects. Thus, it serves as a vital activity for reducing equivocality.

Daft and Lengel (1986) suggested that to reduce equivocality, firms should adopt practices that enable debate, clarification, and enactment rather than simply providing large amounts of information. Joint problem solving thus provides the forum for rich face-to-face interactions in the project team. It also facilitates communication and the enactment of shared interpretations from which a project team can move forward (Bstieler and Hemmert, 2010). In contrast, because it does not provide large amounts of new information, joint problem solving may be less suitable for reducing uncertainty.

Instead, joint problem solving sessions constitute arenas to experiment with different knowledge and ideas that can result in better solutions (Dyer and Nobeoka, 2000; Uzzi, 1997). For example, McEvily and Marcus (2005) observed that joint problem solving, in which suppliers can demonstrate new solutions in a hands-on setting, constitutes a highly effective way to solve problems and convey knowledge that is technically complex and difficult to articulate. Partners may provide alternative interpretations of technical problems and solutions, which enable a team to compare, contrast, and triangulate perspectives and potential solutions (Nonaka, 1994). In addition, they may also enact shared perceptions of joint work processes through work analysis (Nurcan, 1998). If the partners participate significantly in the decisions and actions at an early stage, joint problem solving will enable a shared understanding by drawing on the knowledge and skills of the involved partner firms (McEvily and Marcus, 2005). Therefore, we posit that:

H2. Joint problem solving reduces equivocality in joint process development projects.

2.4. Performance consequences of uncertainty and equivocality

Although the activities to reduce uncertainty and equivocality diverge, the negative consequences of these two constructs may actually converge. In other words, if not sufficiently reduced, they each may lead to wasted resources, time delays, difficulties in creating explicit and robust process designs, difficulties in performing feasibility analyses, and additional project planning (Frishammar et al., 2011; Sicotte and Langley, 2000; Song et al., 2007).

Information gaps, in terms of uncertainty and equivocality, during the early stages of joint process development projects may lead to significant challenges during implementation and will often require rework and late changes. The consequence of such implementation challenges is often severe since they come at a time when the project is much larger, both monetarily and in terms of the persons involved (Rönnberg Sjödin and Eriksson, 2010; Schuman and Brent, 2005). Altogether, these factors make the project suffer monetarily. Accordingly, both uncertainty and equivocality in the early stages of joint process development projects are negatively related to the project's budget performance.

When uncertainty has not been reduced sufficiently, several information gaps may occur that significantly increase the risk of budget overruns. In particular, technical information about the production equipment's properties and functions may not be specified satisfactorily (McGovern and Hicks, 2006). If project participants face high levels of such uncertainties (i.e., an inability to close important information gaps), significant resources may be wasted, because project participants lack information concerning the equipment's requirements (Frishammar et al., 2011; Moenaert et al., 1995).

Both general technical information (e.g., hydraulics and electric requirements) and project-specific technical information (e.g., material loads, throughput) need to be shared among the partners (Bruch and Bellgran, 2012). If such critical information is not shared, development work may be either delayed or continue based on unclear assumptions rather than

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clear information. This often leads to design errors, followed by rework or late changes (Assaf and Al-Hejji, 2006; Chang, 2002).

In contrast, when equivocality is not effectively reduced, the situation may differ, but result in similar outcomes. Project participants then have conflicting interpretations of what needs to be done. Differences in experience, assumptions, knowledge bases, values, and problem-solving styles among the project participants may cause confusion, distrust, or a lack of understanding (Daft and Lengel, 1986). In this case, development work will be especially problematic, because project participants then lack a clear and shared view of the path forward. Such misunderstandings and conflicting interpretations concerning production requirements may lead to developing designs that do not match the project's objectives (Chang, 2002; Hicks and McGovern, 2009). In addition, conflicts among the parties may ensue. Resolving these conflicts occupies valuable resources in terms of personnel and time, causing further delays in the development work (Vaaland and Håkansson, 2003).

In sum, whereas the characteristics of uncertain and equivocal situations differ fundamentally, we hypothesize that the consequences converge. Thus, equivocal and uncertain situations will likely both lead to an increased workload and time pressures during the implementation stage. Consequently, additional resources will need to be committed to the project to resolve the problems, with budget overruns the likely result. Based on the discussion above, we suggest the following two hypotheses:

H3. Uncertainty decreases project budget performance in joint process development projects.

H4. Equivocality decreases project budget performance in joint process development projects.

3. Methods

The present work combines an exploratory case study with a multiwave, multiple-informant survey of joint development projects. Thus, we adopt a mixed-methods approach applicable to intermediate theory research as suggested by Edmondson and McManus (2007).

3.1. The qualitative pre-study

Data from 39 exploratory interviews conducted at two process firms and eight of their equipment suppliers served as a pre-study to the survey (Table 1). First, the exploratory interviews provided knowledge about the research setting—joint development projects in the context of process development, which is a particular type of innovation project of high importance within the process industries. Second, the qualitative pre-study complemented the literature study and guided the development of the research framework by identifying relationships among variables (Eisenhardt, 1989; Yin, 2008). In particular, it highlighted the importance of early end-user involvement and joint problem solving. Third, the pre-study assisted with operationalizing key variables and in choosing among items and composing scales (Edmondson and McManus, 2007). Fourth, the pre-study was helpful in identifying suitable joint development projects for the survey study. Finally, the case study activities and interviews helped build trust and secure commitment from the surveyed firms.

3.2. The multiple informant survey

3.2.1. Sampling of projects and data collection

The sample of projects was gathered from four Swedish process firms within the mineral and metals industry. Projects were identified through discussions with senior managers at these firms and were sampled based on the criteria of time since completion (less than 5 years), project team size (multiple actors from both buyer and supplier sides), and study

Table 1
Descriptive information about the firms in the qualitative pre-study.

Firm pseudonym	Main products	Employees	Annual turnover (USD$M)	Country	Interviews
		Process firms			
Alphacorp	Iron ore and iron pellets	4100	3079	Sweden	8
Betacorp	Metal powders	1600	813	Sweden	9
		Equipment suppliers			
Griffin	Sieves	200	28	United Kingdom	3
Nippon	Blenders	170	33	Netherlands	2
Tiger	Automated lifting cranes	8	8	Sweden	3
Alpine	Press tools	50	8	Switzerland	2
Delphi	Presses	450	79	Germany	3
Gold	Mill linings	200	148	Sweden	2
Silver	Separation equipment and slurry pumps	240	132	Sweden	4
Lakeland	Mineral processing equipment	3200	1163	Finland	3

relevance (i.e., joint process development projects). This sampling procedure is largely consistent with published project-level studies in leading journals (Bonesso et al., 2011; Hoegl and Wagner, 2005; Hoegl and Parboteeah, 2007).

For each studied project, five questionnaires were sent out. Two went to respondents at the buyer side of the project team and two went to the supplier side. To avoid common method variance, the fifth was sent to a project external manager at the buyer firm to rate project performance (Lindell and Whitney, 2001). To mitigate source bias, we used multiple key informants on both the buyer and supplier sides (Hoegl and Wagner, 2005). For each project, a key informant was identified through the qualitative pre-study. This informant subsequently assisted with identifying additional respondents.

Data collection for the survey was conducted over a period of six months. Each respondent was first contacted by phone, briefed about the study's purpose and content, and asked about participating. In total, more than 500 phone calls were made to assure participation, and more than 1000 emails were exchanged with respondents throughout the data collection process. The surveys were then mailed to each individual respondent.

The final total sample consisted of 52 joint development projects involving four process firms in Sweden and 29 equipment suppliers located throughout Europe. These equipment suppliers were headquartered in Sweden, Finland, Germany, the Netherlands, and France. Due to globalized operations, respondents in the supplier firms were also located in China, Chile, South Africa, and Switzerland. In total, 251 completed and usable surveys were obtained, consisting of 52 responses from project external managers (i.e., higher level executives in the buyer organization), 100 responses from project participants in the buyer organizations, and 99 responses from project participants in the supplier organizations.

The sampled projects concerned the design and implementation of new mechanical process equipment, electrical equipment, control systems for production processes, and similar technologies. Overall, the projects represented significant innovations and performance increases for the sampled buyer firms' operations. The project durations varied between 12 and 120 months, with an average of 35 months. The monetary size of the projects fell between USD$0.2M and USD$230M, with an average of USD$45M.

3.2.2. Measures

All constructs were specified at the project level. The questionnaires were pretested by four academics and three practitioners with experience from similar projects. As a result, minor changes were made to eliminate or alter ambiguous items and phrases. This procedure helped increase the face validity of our measures. The complete measurement scales are included in Appendix. Informants rated the dependent, independent, and control variables on 7-point scales anchored by *1 = I strongly disagree* and *7 = I strongly agree*.

Data for the dependent and control variables were collected from project external managers. Project budget performance was measured using the 2-item scale by Rijsdijk and van den Ende (2011) (items 1 and 2) complemented by one additional item (item 3) adapted from Bstieler and Hemmert (2010). The control variables were entered as the logarithm of project monetary size (USD$M) and project duration (months).

Data on all other variables were collected from project participants on the buyer and supplier sides of each project. Data was aggregated at the project level, where input to the analysis was the mean of the responses, typically including two buyer and two supplier responses for each project. The scales for uncertainty and equivocality were based on Park (2011). The measures were adapted to fit the current project context and align with prior theoretical conceptualizations of uncertainty and equivocality (Daft and Lengel, 1986; Frishammar et al., 2011). The scale for joint problem solving was adopted from Bstieler and Hemmert (2010) and Heide and Miner (1992). Early end-user involvement was measured with a new 2-item scale focusing the intensity of end-user involvement in the pre-study and development stages.

3.2.3. Analytical procedures

Data was analyzed using partial least squares (PLS) (Wold, 1982; Hair et al., 2012). The original research objectives and, to some extent, the exploratory nature of the study made PLS an appropriate technique (Hair et al., 2012; Peng and Lai, 2012). Moreover, although we draw on more than 250 unique survey responses, the relatively small size remaining when these were aggregated to compose projects (52 projects) made PLS an appropriate technique (Chin and Newsted, 1999; Haenlein and Kaplan, 2004). The software used was Smart PLS (Ringle et al., 2005).

4. Results

Our use and presentation of PLS estimates and our results follow a two-stage sequence. First, the measurement model was assessed in terms of item and construct reliability, as well as convergent and discriminant validity. Second, when the measures proved reliable and valid, the structural part of the model was evaluated based on a bootstrapping technique, variance explained of the endogenous constructs (R^2), predictive value (Stone–Geisser statistic), and the overall quality of the model in terms of goodness-of-fit (Tenenhaus et al., 2005).

4.1. Measurement model results

First, we checked the loadings, or item reliability, of each indicator used to measure the constructs. One item (JPS3; see Appendix) was below the suggested 0.7 acceptable cutoff value (Table 2); however, we kept it because of the suitable construct reliability and average variance extracted (AVE). Furthermore, the scale is theoretically well established in the

Table 2
Convergent validity.

Construct name/items	Factor loading	*t*-Value	AVE	Composite reliability	Cronbach Alpha
Uncertainty			0.894	0.962	0.941
Unc1	0.934	39.274			
Unc2	0.968	130.622			
Unc3	0.935	43.862			
Equivocality			0.895	0.962	0.941
Eq1	0.956	84.530			
Eq2	0.962	111.269			
Eq3	0.919	25.062			
Joint Problem Solving			0.642	0.874	0.814
JPS1	0.907	12.701			
JPS2	0.877	10.273			
JPS3	0.558	3.019			
JPS4	0.816	7.681			
Early End-User Involvement			0.862	0.926	0.851
EEUI1	0.890	8.116			
EEUI2	0.965	18.547			
Project Budget Performance			0.809	0.926	0.879
BP1	0.960	57.799			
BP2	0.966	79.187			
BP3	0.756	7.185			

Table 3
Discriminant validity.

Constructs	Mean	SD	BP	EEUI	Eq	JPS	Unc
Project budget performance	4.58	1.87	**0.899**				
Early end-user involvement	4.79	.862	0.215	**0.928**			
Equivocality	2.62	.767	−0.486	−0.245	**0.946**		
Joint problem solving	5.56	.576	0.287	0.369	−0.442	**0.801**	
Uncertainty	2.77	.844	−0.580	−0.330	0.620	−0.252	**0.946**

Note: Bold numbers indicate the square root of the average variance extracted. Numbers below the diagonal represent construct correlations.

literature (Chin, 1998). Second, the measures have a high internal consistency in terms of composite reliability above the 0.7 threshold (i.e., the constructs are reliable) (Table 2, Column 5) (Werts et al., 1974). Third, the amount of the constructs' variance explained by their respective measures (Table 2, Column 4) exceeds the 0.5 threshold level (Fornell and Larcker, 1981). Fourth, the constructs differ from one another, because the cross loadings are much lower than the square root of the AVE; that is, they demonstrate a high discriminant validity (Table 3). In summary, our measurement model was based on reliable and valid measures.

4.2. Structural model results

The structural model results, based on a 5000 subsample bootstrap, suggest that H1–H3 are all supported ($p < 0.05$). In particular, the relationship between joint problem solving and equivocality ($\beta = -0.414$) is highly significant. Moreover, the relationships between early end-user involvement and uncertainty ($\beta = -0.288$) and uncertainty and project budget performance ($\beta = -0.395$) are both significant (Table 4). However, the negative relationship between equivocality and project budget performance ($\beta = -0.222$) is not significant. H4 is therefore rejected.

Furthermore, the controlled relationships for project duration and size are not significant. The variance explained by the endogenous variables (R^2) is 0.390 for project budget performance, 0.208 for equivocality, and 0.195 for uncertainty. This indicates that the model has moderate power for explaining variations in project budget performance, whereas the explanations of uncertainty and equivocality are somewhat less powerful. The Stone–Geisser Q^2 statistic (Geisser, 1975; Stone, 1974) had a positive value for all reflective endogenous constructs, suggesting that the model has predictive value. Considering the measurement and structural models together, their goodness-of-fit (GoF) value (Tenenhaus et al., 2005) was 0.480, indicating that the model is of reasonably high quality (GoF ranges between 0 and 1; the higher the better). Fig. 2 displays all relationships among the constructs used in the present study.

5. Discussion

The present work has presented a study on uncertainty and equivocality in joint process development projects, and the collaborative information processing activities that help reduce uncertainty and equivocality in the early stages of such projects. Our findings underscore the negative consequences of uncertainty for project budget performance, strongly

Table 4
Results of the structural model.

Effects on Endogenous Variable	Direct effect	*t*-Value (bootstrap)	Variance Explained (R2)	Stone–Geisser Q^2
Effects on Uncertainty			0.195	0.187
H1: Early End-User Involvement	−0.288 **	2.120		
Joint problem solving	−0.200	1.269		
Duration (control variable)	0.216	1.393		
Size (control variable)	0.161	0.877		
Effects on Equivocality			0.208	0.214
H2: Joint Problem Solving	−0.414 ***	2.694		
Early end-user involvement	−0.145	1.032		
Duration (control variable)	0.141	0.267		
Size (control variable)	0.119	0.588		
Effects on Project Budget Performance			0.390	0.326
H3: Uncertainty	−0.395 **	2.514		
H4: Equivocality	−0.222	1.229		
Early end-user involvement	0.120	0.033		
Joint problem solving	0.144	1.103		
Duration (control variable)	−0.146	1.153		
Monetary size (control variable)	−0.114	0.509		

indicate that early end-user involvement reduces uncertainty, and show that joint problem solving reduces equivocality. The importance of the findings are underscored because of the increasingly distributed nature of innovation (Grönlund et al., 2010; Parida et al., 2015), where not only product and service development, but also process development becomes more open (i.e., in the form of joint projects between firms) (Robertson et al., 2012). The present results apply directly to the metal and minerals industry, the industry in which the present study was conducted. However, it may also be relevant to other sectors of process industries, such as oil exploitation and production, chemical processing, bulk producers of pharmaceuticals, and food producers that face similar process development challenges. We encourage actors in these similar industries to learn by analogy and evaluate what the results of the present research imply in the context of their firms.

5.1. Theoretical implications

Our study provides several important theoretical implications. From an operations management perspective, successful joint development of process technology can provide significant firm-level competitive advantages through improved manufacturing operations (Scott-Young and Samson, 2008; Stock and Tatikonda, 2008). Our results indicate how collaborative information process activities in terms of early end-user involvement and joint problem solving can reduce uncertainty and equivocality in the early stages of joint process development projects. By including uncertainty and equivocality in the same study, a rare occurrence in prior studies, we were able to distinguish which activities lead to reducing uncertainty and equivocality respectively.

We show that the primary impact of joint problem solving is reducing equivocality. This is an interesting finding, because prior research has neglected to study the effects of joint problem solving on uncertainty and equivocality

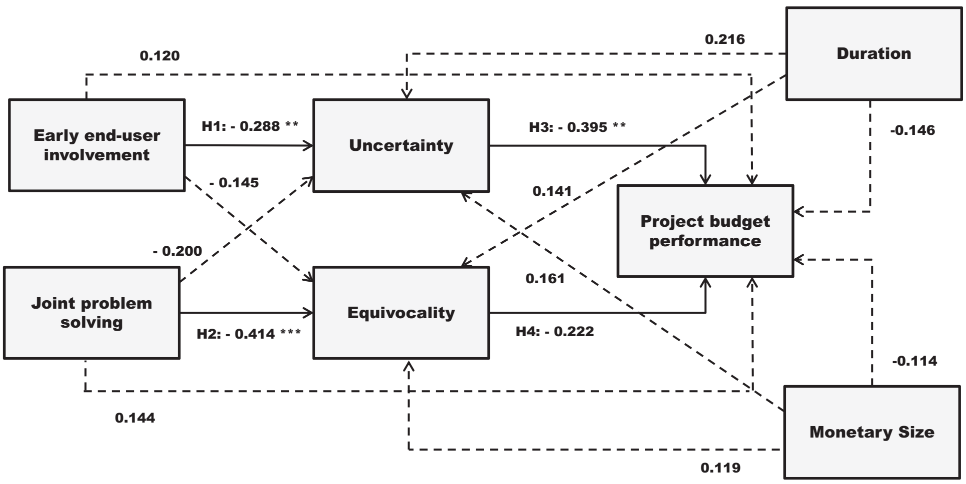

Fig. 2. Full model path values and variance explained.

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(Bstieler and Hemmert, 2010; McEvily and Marcus, 2005). However, although the correlation coefficient was negative ($\beta = -0.222$), equivocality did not have a significant negative effect on project budget performance. This could be due to the relatively low levels of equivocality found in the present study's sample (mean value 2.62). Perhaps the problems associated with equivocality are not severe enough to harm budget performance in the studied projects. The implication, however, is not that reducing equivocality is pointless. On the contrary, equivocality may be unfavorable for many other aspects of development projects as well, such as user satisfaction, quality, and speed of development (Frishammar et al., 2011).

It is also possible that equivocality has a more complex relationship with performance than typically stated and acts as a double-edged sword in development activities. On the one hand, equivocality increases conflicts and makes development work more challenging (Daft and Lengel, 1986), because it reduces the ability to coordinate and combine different partners' information and knowledge. On the other hand, facing equivocality may provoke the partners to engage in deeper sensemaking (Weick, 1995), which in itself may stimulate debate and comparing different alternatives. Following this line of reasoning, equivocality may also have some positive effects in providing variations in interpreting information and tasks from which better solutions might emerge. Therefore, more research on the effects of equivocality in joint development projects is needed.

Furthermore, the present study contributes to the technology and operations management literature by indicating that involving end-users early in the process reduces uncertainty. This is especially important because uncertainty was found to have a significant negative effect on project budget performance. In prior studies, end-user involvement is typically cited as an important success factor in industrial development projects (McDermott and Stock, 1999; Stock and Tatikonda, 2008; Tait and Vessey, 1988). However, few studies address when their involvement should take place (Eriksson, 2015). Our findings highlight the importance of involving end-users early to reduce uncertainty at the beginning of projects. This adds further detail to prior research that has emphasized the importance of interdepartmental collaboration for process development (Aalbers and Dolfsma, 2015; Rönnberg Sjödin and Eriksson, 2010).

Another set of implications relates to the empirical context of the present study. Most prior studies on uncertainty and equivocality have been conducted on product development in high-tech industries, where high levels of uncertainty and equivocality prevail (Song et al., 2007; Sicotte and Langley, 2000). The present study indicates that even relatively low levels of uncertainty (mean value of 2.77) can be problematic, whereas the negative effect of equivocality was not significant. Nevertheless, the effects of uncertainty and equivocality in innovation settings such as process development and low-tech industries seem relevant yet neglected in prior studies (Dedehayir et al., 2014).

Finally, the way uncertainty and equivocality was operationalized provides implications for the project management literature. Our operationalization measures uncertainty and equivocality as the perceived lack of information and the existence of multiple and conflicting interpretations of the information, closely following the conceptual definitions of Daft and Lengel (1986). In contrast, many prior operationalizations measure these concepts by inherent project characteristics, such as novelty or complexity (Stock and Tatikonda, 2008) or by environmental influences, such as dynamism or hostility (Koufteros et al., 2005). Although these other ways of operationalizing may have their advantages, they are insufficient from a project management perspective that focuses on how managers can work actively to reduce uncertainty and equivocality. Although novelty and complexity may impose managerial challenges, they may also be inherent or even desirable characteristics of development projects that should not be reduced. Both novelty and complexity may lead to better and more innovative process solutions that are more difficult for competitors to imitate and may thus lead to improved competitiveness. In contrast, situations when project management is unable to reduce uncertainty and equivocality can become problematic and typically lead to failures. Our operationalization recognizes the importance for project management to reduce the negative aspects of uncertainty and equivocality to improve project performance (Chang and Tien, 2006).

5.2. Managerial implications

The present study emphasizes the importance of selecting distinctive activities for reducing uncertainty and equivocality at the early stages of joint process development projects, a topic lacking in prior research (e.g., Koufteros et al., 2005; Stock and Tatikonda, 2008).

First, joint problem solving should be applied with the purpose of reducing equivocality among project participants. To facilitate joint problem solving, an environment of open communication, sharing, and trust is typically required (McEvily and Marcus, 2005). This may sound obvious, but is difficult to accomplish in practice. Collaborative activities such as joint goal setting, a joint project office, and team-building activities at the start of the project are often suitable (Rönnberg Sjödin and Eriksson, 2010). Furthermore, project management could arrange workshops or similar meeting forums in which experts from partner companies gather face-to-face to exchange knowledge and discuss opinions of various technical solutions, production processes, and subsystems. These interactive discussions, where diverging and opposing views and interpretations surface, may result in a more coherent view of what should be done. Unfortunately, prior research shows that large projects often lack these critical activities or perform them deficiently (Rönnberg Sjödin, 2013).

Second, early end-user involvement should be applied with the goal of reducing uncertainty. It is important to note that on the buyers' side, it is often the R&D or project function running the project, whereas the end-users in the production function will eventually use the actual equipment. End-users, however, are seldom responsible for the project's performance. Prior research highlights the difficulties of involving competent end-users in early project stages (Eriksson, 2015). One important implication for both project managers and production managers is thus to ensure that competent and qualified end-users are given the opportunity to be strongly involved at the beginning of process development projects. This requires agreements between the production and project management functions at the start of the project, specifying when, how, and which specific end-users should be involved and to what extent.

Third, recognizing the activities that lead to reducing uncertainty and equivocality is a particularly important implication for managers. This is perhaps best illustrated by the situation where an activity best suited to reduce uncertainty is applied to reduce equivocality, or vice versa. For example, a manager striving to reduce equivocality could erroneously conclude that more involvement by end-users would reduce apparent conflicting interpretations among projects participants. The present results suggest such an approach provides no meaningful reduction of equivocality. Rather, it incurs increased costs and other negative effects, such as frustration on the part of project participants.

Fourth, the systemic nature of process development makes reducing uncertainty and equivocality in early stages especially critical, but also more difficult. Uncertainty and equivocality in one specific activity and on which a set of other activities are contingent, can have devastating consequences for project performance, even though the overall levels of uncertainty and equivocality are modest in the system of activities as a whole. Managers must therefore focus on identifying and reducing uncertainty and equivocality in specific key activities. Implementing joint problem solving and early end-user involvement minimally over the entire system of development activities may therefore provide limited value. In a similar vein, uncertainty and equivocality do not need to reach high levels for severe problems to occur. The present study's results highlight the importance of reducing relatively low levels of uncertainty (whereas the effects of equivocality were negative but not statistically significant). Still, managers need to be highly cognizant of the signs of uncertainty and equivocality in joint development projects. Therefore, a regular and structured assessment of such problems should be included in the project manager's tasks. In particular, identifying areas in which the absence of information or conflicting interpretations among participants may hinder development work in the project should be prioritized.

5.3. Limitations and outlook

Despite our comprehensive data collection process, consisting of a qualitative pre-study and 251 survey respondents, the total sample for the present study was limited to 52 projects conducted by four Swedish process firms and their equipment suppliers. The nonrandom sample and limited sample size of the present study limit the potential to make generalizations to a larger population beyond the scope of the present study. In particular, our cross sectional research design can only imply, rather than prove, causality. To this end, an even larger sample and longitudinal research design with data collection over several years, as well as in other cultural settings (e.g., North America, Asia), would be beneficial for future research.

The negative impact of equivocality on project budget performance was not supported in the present study. However, it is possible that equivocality has a more complex relationship with performance than typically stated and acts as a double-edged sword in development activities. Therefore, we encourage further research to study the concept of equivocality in the context of joint innovation and process development projects. In particular, focusing on activities to effectively manage and reduce equivocality in developing and delivering advanced services seems interesting for further study (Parida et al., 2014; Reim et al., 2016). This track of further research seems especially important given the increasingly interactive relationships and value co-creation among suppliers and buyers of advanced services in process industries (Rönnberg Sjödin et al., 2016).

Moreover, while our results underscored the importance of early end-user involvement for reducing uncertainty, there may be additional advantages of involving end-users early in the project. Prior case-based literature has suggested that the early involvement of end-users instills a sense of ownership in the project by giving end-users the potential to contribute to the project at an early stage (Rönnberg Sjödin, 2013; Schuman and Brent, 2005). Enhancing commitment among end-users in the early stages of process development projects is important for facilitating work in the later implementation stages, where end-user commitment is critical to smoothly hand-over the process technology from the project team to the end-users (Lager and Frishammar, 2010; Rönnberg Sjödin and Eriksson, 2010). We therefore encourage further studies to look into the effects of early end-user involvement on other variables such as commitment and user-satisfaction.

The present study's findings thus set the foundation for further research on inter-organizational aspects of process development, a practical technology management concern, that to date has seen little quantitative research.

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Appendix. Measures

Construct name/items	Item
Uncertainty	*The information (e.g., about requirements, project scope, technical solution) available in the early stages of the project relationship...*
Unc1	...was inadequate for our purposes.
Unc2	...was too vague to be very helpful.
Unc3	...was incomplete for our needs.
Equivocality	*The information (e.g., about requirements, project scope, technical solution) available in the early stages of the project relationship...*
Eq1	...was interpreted differently by different project participants.
Eq2	...had conflicting interpretations.
Eq3	...was confusing due to different interpretations.
Joint problem solving	*In this project...*
JPS1	...we jointly planned how this project should be run.
JPS2	...adjustments to project specific agreements were mutually agreed upon.
JPS3	...we jointly reevaluated the progress of our working relationship throughout the project.
JPS4	...problems that arose during the project were treated by the parties as joint rather than individual responsibilities.
Early end-user involvement	*Please indicate the extent to which end-users in the customer organization were involved in the following stages:*
EEUI1	Pre-study/feasibility study.
EEUI2	Development, engineering, and design.
Project budget performance	
BP1	The actual costs of the project were lower than or equal to the estimated costs.
BP2	This project has been as costly as or cheaper than expected.
BP3	The project was undertaken in a cost-efficient manner.

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