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DOI
10.3846/jcem.2021.15612

Publication date
2021

Document Version
Final published version

Published in
Journal of Civil Engineering and Management

Journal of Civil Engineering and Management
ISSN 1392-3730 / eISSN 1822-3605
2021 Volume 27 Issue 8: 579–594
https://doi.org/10.3846/jcem.2021.15612

WHAT MOTIVATES STAKEHOLDERS TO ENGAGE IN COLLABORATIVE INNOVATION IN THE INFRASTRUCTURE MEGAPROJECTS?

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Received 24 January 2021; accepted 13 July 2021

Abstract. Collaborative innovation has become an innovation paradigm to improve innovation performance and firms' economic output. However, there is relatively little research investigating stakeholders' drivers for engaging in collaborative innovation and the relative importance of drivers in infrastructure megaprojects. This research aims to address this gap by identifying the drivers for collaborative innovation and their relative importance in the context of infrastructure megaprojects. We adopt the literature review and questionnaire survey methods to identify drivers, the Relative Importance Index to rank them, and exploratory factor analysis to group them. The results show that 18 drivers are grouped into 6 dimensions. Their rankings are as follows: responding to project and clients' requirements, improving efficiency, gaining rewards, learning, responding to competition, responding to environmental changes. The research contributes to stakeholders' drivers to engage in collaborative innovation and the relative importance of drivers in the context of infrastructure megaprojects. Identifying and prioritizing stakeholders' drivers can provide practitioners with suggestions on managing the collaborative innovation process in infrastructure megaprojects.

Keywords: infrastructure megaproject, collaborative innovation, drivers, relative importance, exploratory factor analysis, principal component analysis.

Introduction

Infrastructure megaprojects (hereafter, we use the term "megaprojects") are large-scale and complex projects that require substantial innovations during their planning, design, construction, and delivery stages. Megaprojects include different stakeholders who can affect or be affected by project implementation. These stakeholders have to collaborate by sharing knowledge and information to innovate the socio-technical systems, make necessary innovations to solve construction problems and achieve sustainability further (Lehtinen et al., 2019). Thus, collaborative innovation, which is defined as "the structured joint process for designing and developing new products, services or processes that require information sharing, joint planning, joint problem solving as well as integrated activities or operations" (Serrano & Fischer, 2007), has become an indispensable innovation paradigm in megaprojects.

Collaborative innovation is an innovation paradigm that improves innovation performance and achieves sustainable development (Rutten et al., 2009; Zhao et al., 2018). Compared with other innovation forms, such as open innovation and cooperation innovation, collaborative innovation integrates information, goals, performance, and actions (Wang & Hu, 2020). Thus, collaborative innovation has attracted more attention from researchers in various industries (e.g., the 3D printing industry) (Rong et al., 2018). However, relatively little research investigates collaborative innovation in megaprojects, as Chen et al. (2020) suggested. Indeed, according to retrieval on Web of Science in July 2020 (searched for: TOPIC: (collaborative innovation) AND TOPIC: ("mega project" or "megaproject" or "large project" or "major project")), only one journal article deals with collaborative innovation and megaprojects (Chen et al., 2020). Chen et al. (2020) demonstrated that a conventional innovation paradigm (e.g., one focal contractor engages in the innovation endeavors) is unsuitable for megaproject innovation because of the socio-technical complexity, project uniqueness, and triple constraints of megaprojects. Compared with traditional

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infrastructure projects, megaprojects (e.g., high-speed rail lines and airports) call for more substantial innovation collaboration among different stakeholders in different disciplines (Flyvbjerg, 2014; Worsnop et al., 2016). These stakeholders have to interact with each other by the exchange of reciprocal information, the joint arrangements of goals, the systematic matching of performances, and the synchronizing actions (Serrano & Fischer, 2007).

The innovation process relies heavily on the commitment of stakeholders who are self-motivated by an idea or are convinced by external incentives and requirements (Cinzia & Fabio, 2013). This also applies to the collaborative innovation process, which needs to integrate stakeholders with different goals, interests, motives, and plans in megaprojects (Davies & Mackenzie, 2014). Therefore, it is crucial to identify drivers for stakeholders to engage in collaborative innovation and the conditions that facilitate and drive it. Following Ozorhon and Oral (2017) and Hojnik and Ruzzier (2016), in this research, the driver refers to a stimulus for the collaborative innovation process to initiate, which can act as a motivation-based factor (e.g., regulatory pressure, expected benefits of implementation) or a facilitating factor (e.g., technological capabilities). The findings can provide practitioners with effective strategies to manage collaborative innovation (Fernandes & Remelhe, 2016). Remarkably, there is a lack of studies looking at drivers of stakeholders to engage in megaprojects' collaborative innovation process. Moreover, the relative importance of one driver to another has received less attention (Gunduz & Abdi, 2020). In practice, not all drivers are equally important. It is necessary to categorize and rank them, especially to identify the most crucial drivers that should be given enough attention to managing them.

Therefore, this research intends to fill research gaps by dealing with the drivers for stakeholders' collaborative innovation in megaprojects. More specifically, the following research questions are researched:

RQ1: What are the drivers for stakeholders to engage in collaborative innovation in megaprojects?

RQ2: What is the relative importance of drivers?

To address these research questions, this research combines the literature review and questionnaire survey methods to identify a list of drivers that motivate stakeholders to engage in collaborative innovation in megaprojects. The Relative Importance Index (RII) method is used to measure the relative importance of drivers. Besides, we adopt the exploratory factor analysis (EFA) method to achieve dimensionality reduction and derive six major underlying dimensions for collaborative innovation in megaprojects. Discussions and suggestions for practitioners based on the results are put forward.

1. Literature review

1.1. Collaborative innovation in megaprojects

Megaprojects are characterized by enormous complexity, large-scale investment, complicated decision-making, long implementation cycles, multiple public and private stakeholders, and significant impacts on sustainable development. Typical megaprojects consist of high-speed railways, integrated transport hubs, airports, motorways, and long-span bridges (Flyvbjerg, 2014). These megaprojects are usually unique and complex, which have created enormous opportunities for innovation theories and practices. According to Worsnop et al. (2016), megaprojects represented an ideal context for fostering innovation because of their complexity and involvement of many participants. Similarly, Locatelli et al. (2021) considered innovation an effective method to solve technological problems and improve project performance in megaprojects.

Collaborative innovation is a change to the "business as usual" model (Bucic & Ngo, 2012) and is a pursuit of innovation across firm boundaries through the sharing of ideas, knowledge, expertise, and opportunities (Esposito De Falco et al., 2017). Collaborative innovation in megaprojects is an R&D process where stakeholders work together toward creating new or significantly improved construction products, methods, processes, etc. (Xue et al., 2017). Many stakeholders such as clients (in megaprojects, which is usually the government), contractors, designers, consultants, suppliers, et al. are involved in collaborative innovation in megaprojects. Usually, clients play the leading role in the collaborative innovation in the project lifecycle, while other stakeholders (e.g., designers, supervisors) enter and exit the collaborative innovation in different project stages (Chen et al., 2020). This is quite different from collaborative innovation in other industries, such as the electric vehicle industry, where stakeholders enter the collaborative innovation networks and then maintain in the collaborative innovation networks (Lu et al., 2014). Generally, stakeholders in the innovation process would like to form a loosely coupled collaborative relationship by knowledge creation, knowledge sharing, and knowledge application (Wang & Hu, 2020; Zhao et al., 2018). Thus, we define collaborative innovation as the structured joint process for creating new or significantly improved construction products, construction processes, and services that require knowledge creation, knowledge sharing, and knowledge application and integrated information, goals, performance, and actions.

Collaborative innovation in megaprojects brings various benefits. On the one hand, it can reduce transaction costs among stakeholders (Esposito De Falco et al., 2017). In megaproject innovation, transaction costs include the cost of creating exclusive properties, obtaining a patent authorization or copyright, controlling the opportunistic behavior of competitors, writing contracts, and properties' transfer and compensation. On the other hand, collaborative innovation can achieve "mutual beneficial outcomes". Zhang et al. (2020) demonstrated that collaborative innovation among stakeholders could share knowledge and information, learn from each other, enhance the integrated effect, and achieve a better innovation performance.

Collaborative innovation involves stakeholders (e.g., contractors, designers, suppliers, and universities) who possess different interests and goals (Serrano & Fischer, 2007). It is necessary to motivate, monitor, and facilitate collaboration among stakeholders to achieve desired innovation outcomes and outputs. In the next subsection, we will review the drivers of collaborative innovation.

1.2. Drivers of collaborative innovation

Researchers pay considerable attention to what drives stakeholders to adopt collaborative innovation, using rubrics such as motivations, drivers, and stimuli (see Bossle et al., 2016; Hojnik & Ruzzier, 2016; Li-Ying et al., 2018). Consistent with other innovations (e.g., open innovation, cooperative innovation), stakeholders adopt collaborative innovation mainly in response to intrinsic demands and extrinsic requirements (Battistella & Nonino, 2013; Locatelli et al., 2017, 2021).

Though different stakeholders possess different goals and interests, their drivers to engage in collaborative innovation are similar to some extent (Walker & Lloyd-Walker, 2016). Indeed, collaborative innovation among stakeholders is motivated by both intrinsic and extrinsic drivers. Intrinsic drivers refer to interior interest pursing without obvious external incentives (Cai & Zhou, 2014). In contrast, extrinsic drivers are related to external incentives, such as gaining monetary or non-monetary compensation (Cai & Zhou, 2014). Table 1 summarizes the drivers that compel or encourage stakeholders to engage in collaborative innovation in infrastructure /construction projects.

Of all drivers, reducing R&D costs, transaction costs, and risks are three reasons for stakeholders to collaborate in the innovation process. On the one hand, innovations need additional research, leading to cost increase or even cost overruns (Davies et al., 2014). On the other hand, innovations are associated with uncertainties, for not all innovations will be successful (Davies et al., 2015). By collaboration, costs and risks are reduced or shared among stakeholders, and mutual benefits will achieve. Resource efficiency improvement is another driver that motivates stakeholders to engage in collaborative innovation. Xue et al. (2010) pointed out that the demand for more efficient use of organizations' resources and for promoting organizational operation's effectiveness were two drivers for collaboration in construction projects. Learning complementary/new technologies, knowledge, and skills also work as drivers because they are essential components for innovations (Sun et al., 2020). These technologies, knowledge, and skills can be shared and accessed during the collaborative innovation process. Also, by expressing their capability and creativity, stakeholders can build a good firm image and reputation and get more competitiveness in the market.

Clients play a leading role and promote two activities, namely system establishment and system collaboration, in the collaborative innovation system (Chen et al., 2020). Therefore, requirements and supports from clients facilitate collaborative innovation among stakeholders. Fur-

Table 1. Drivers of collaborative innovation among stakeholders

Category	Drivers	References	Variable
Internal drivers	To reduce relevant risks	Akintoye and Main (2007); Ozorhon (2013a)	C1
	To reduce R&D costs	Akintoye and Main (2007); Xue et al. (2018)	C2
	To improve resource efficiency	Locatelli et al. (2021); Akintoye and Main (2007)	C3
	To reduce transaction costs	Akintoye and Main (2007); Xue et al. (2018)	C4
	To learn complementary/new technologies	Locatelli et al. (2021); Nikas et al. (2007)	C5
	To learn complementary/new skills	Locatelli et al. (2021); Nikas et al. (2007)	C6
	To learn complementary/new knowledge	Locatelli et al. (2021); Bossink (2004)	C7
	To build a good firm image and reputation	Battistella and Nonino (2012); Nikas et al. (2007)	C8
	To express individual/firm ability and creativity	Battistella and Nonino (2012); Akintoye and Main (2007)	C9
	To improve the firm's skills and gain competitive advantages	Nikas et al. (2007)	C10
External drivers	In response to client's requirements	Akintoye and Main (2007); Bossink (2004)	C11
	Support from clients	Bossink (2004); Havenvid et al. (2016)	C12
	In response to high project complexities and uncertainties	Locatelli et al. (2021); Keskin et al. (2020)	C13
	Monetary rewards (e.g., financial compensation from governments)	Antikainen et al. (2010); Battistella and Nonino (2012); Locatelli et al. (2021)	C14
	Non-monetary rewards (e.g., feedback)	Füller (2010); Martínez-Cañas et al. (2016)	C15
	In response to technological change	Akintoye and Main (2007); Ozorhon (2013a)	C16
	In response to relevant regulations or rules issued by governments	Ozorhon (2013a, 2013b)	C17
	In response to market change	Bossink (2004); Papadonikolaki (2018)	C18

thermore, both reasonable monetary and non-monetary incentives can further stimulate stakeholders' interest in engaging in a collaborative innovation process (Martínez-Cañas et al., 2016) to gain more compensation. Moreover, relevant regulations and rules force stakeholders to take collaborative measures in the innovation process. The high complexities and uncertainties, quick change of construction market (e.g., prefabricated construction) and technology make it hard to conduct construction work by one stakeholder or traditional methods (Zhang & Xue, 2014).

2. Research methods

2.1. Identification of potential drivers

The identification of drivers is an important step for the research objectives of this research. Existing literature has investigated drivers of collaborative innovation in peer-reviewed journals. Relevant studies published from 2000 to 2020 in international journals indexed "Web of Science" and "Scopus" were reviewed to provide a comprehensive set of collaborative innovation drivers. The search keywords were "motivation" or "driver" or "motivational factor" or "antecedent" and "collaborative innovation" or "cooperative innovation" or "inter-organizational innovation" or "co-innovation" and "infrastructure project" or "megaproject" or "major project" or "large project" or "construction project". To ensure the quality of the literature review, only peer-reviewed journals and review papers were selected. After a deep screening of literature, 23 articles were considered, and 39 drivers were derived. The measures were re-arranged to reduce redundancy and duplication by comparing and merging when different measures were synonymous (e.g., time reduction and reduction in project duration). This re-analyze process reduced the number of drivers from 39 to 18, as shown in Table 1.

To ensure the drivers' rationality and suitability, we invited two professors whose research focuses on innovation in megaprojects and eight senior managers with more than ten-year experience in megaprojects in China to revise and improve the interpretation of drivers. All professors/experts were selected by authors based on their reputation and achievements in megaproject management. Two senior managers were from the Hong Kong-Zhuhai-Macao Bridge project (HZMB), three senior managers were from Beijing Daxing International Airport, two senior managers were from Shenzhen Qianhai New City Center, one senior manager was from Shanghai West Bund Media Port. These senior managers played a vital role in the management of megaprojects they participated in. They represented clients, consultants, designers, and contractors.

During this process, firstly, we introduced our research purpose and the sources of existing drivers. Secondly, experts were required to examine the suitability (0 – NO, 1 – YES) of the existing 18 drivers for collaborative innovation in view of megaprojects in China. Respondents were asked to make judgments from their perspectives and their practical experience. The interview was designed around three themes. The first was to help interviewers recall the collaborative innovation process they engaged in. The second required experts to comment on the accuracy of identified drivers. The third theme is to seek possible supplementary drivers (as shown in Appendix A). By doing so, we provided a qualitative method of inquiry that integrated an identified drivers from literature with the chance for an interviewer to define the potential drivers for collaborative innovation in megaprojects. During the interviews, the authors wrote down the main points mentioned by interviewees. After the interviews, the authors rechecked and discussed all the points. If conflicts in opinions between different interviewees were found, authors would conduct a new round of interviews to discuss. This process was repeated unless no conflicts occurred. Based on the results, interviewees agreed that 18 drivers could reflect a range of practical situations in megaprojects and be applied to the collaborative innovation; no more modifications were needed.

2.2. Questionnaire survey

We prepared a questionnaire survey (as shown in Appendix B) to investigate the importance of drivers for stimulating stakeholders to engage in collaborative innovation. The questionnaire was composed of two sections. The first section included questions on respondents' personal information. The second section aimed to investigate the respondents' opinions on the importance of drivers by a five-point Likert scale (where 1 represents significantly unimportant and 5 represents significantly important). The proposed two categories of drivers shown in Table 1 are not revealed to respondents to avoid preconceptions.

The reason to adopt a questionnaire survey is that many firms are involved in the collaborative innovation process. Thus, it is difficult to conduct face-to-face interviews to explore stakeholders' initial drivers to engage in collaborative innovation. Besides, a questionnaire survey was adopted because it could reach a large number of potential respondents. The questionnaire survey is a useful method that helps researcher obtain valuable data.

We first sent the questionnaire to three managers in the HZMB megaproject and two professors who had closed connections with practitioners in megaprojects to conduct an exploratory survey during the questionnaire survey. The survey results indicated suitable and comprehensive drivers. Then, we carried the formal survey from June 2020 to July 2020. We used the online questionnaire website (https://www.wjx.cn/) and e-mail to distribute the questionnaire to different stakeholders involved in megaprojects in China. We adopted a mixed sampling technique, including purposive and snowball sampling, to ensure sample diversity and maximize the number of qualified respondents. To guarantee all respondents had engaged in collaborative innovation in megaprojects before, the questionnaire gave a clear statement that only those who had engaged in innovation in megaprojects should fill it. After receiving the questionnaires, we rechecked them, and no specific pattern of ratings was found.

In all, 203 respondents received the invitation, and 181 respondents filled in the questionnaire survey within the given time. We deleted the invalid results and got 148 valid results. These 148 results were used for the RII analysis and factor analysis.

2.3. Respondents' profile

Respondents are from 6 megaprojects in China, including Expo 2010, HZMB, Beijing Daxing International Airport, Shenzhen Qianhai New City Center, Shanghai West Bund Media Port, and Beijing–Shanghai railway. Table 2 showed detailed information on respondents' profiles regarding working experience and position. Table 2 demonstrated that more than 81% of respondents had more than 5-year working experience, and about half of the respondents had more than 10-year working experience. It meant that respondents had sufficient experience to provide sound judgment on the questionnaire. Also, the respondents included contractors, designers, suppliers, supervisors, consultants, and clients. This extensive coverage could obtain enough data from different stakeholders to investigate drivers of collaborative innovation in megaprojects. Besides, about 66% of respondents were project managers or site managers, and 17.6% were engineers, indicating respondents' high quality.

2.4. Data analysis

Each driver's mean and standard deviation were not appropriate to evaluate the rankings because they cannot reveal the relative importance, as suggested by Doloi et al. (2012). Therefore, we used the criteria RII to rank them, and RII is calculated as Eqn (1), according to Gündüz et al. (2013):

$$\text{RII} = \frac{\sum W}{A * N}, \tag{1}$$

where W is weighting given to each driver by respondents. A is the highest weight given by respondents. N is the number of respondents.

The value of RII ranges from 0 to 1 (0 is not included) (Gündüz et al., 2013). The driver with the highest RII indicated that it had the maximum effect on collaborative innovation formation. Also, calculating the average RIIs of drivers in each dimension can obtain the RIIs of the mean for each dimension.

Though RII could present relative importance among drivers, it cannot reveal the relationships of drivers. In project management literature, EFA was frequently used to explore the underlying structures of a set of variables (Liu et al., 2018; Yan et al., 2019). EFA could simplify a large number of the matrix of correlations and extract a small number of dimensions that could reveal most of the variables observed. Therefore, we used EFA to analyze relationships among 18 drivers and group them. In this research, we use the IBM SPSS Statistics 24.0 software to conduct EFA, and the principal component analysis (PCA) was adopted to extract dimensions. As suggested by Pallant (2012), we also used "parallel analysis" to ascertain the dimensions before making decisions on the number of dimensions to retain. The parallel analysis compares the size of the eigenvalues with those calculated by a randomly generated data set of the same size (Pallant, 2012).

Table 2. Respondents' profile

		Number	Percentage
Working experience	< 5	16	10.8%
	5–10	63	42.6%
	> 10	69	46.6%
Position	Project manager	38	25.7%
	Site manager	59	39.9%
	Engineer	26	17.6%
	Consultants	25	16.9%

Reliability and validity were two essential measures in conducting factor analysis. In this research, Cronbach's alpha coefficient was used to measure the questionnaire survey items' internal consistency to ensure factor reliability (Wang et al., 2017, 2018). Cronbach's alpha coefficient could show whether the results were consistent and the degree of reproducibility when adopting a similar method (Yan et al., 2019). The value of Cronbach's alpha if item deleted was also used to check whether deleting an item could increase the total alpha.

Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of spherical were performed on the primary data to test the correlation of the variables and the validity of factor analysis. The KMO tested the homogeneity between variables based on the ratio of squared correlation coefficients between variables to the squared partial correlation coefficients between variables (Kaiser, 1974). It ranged from 0 to 1. A value closer to 1 meant a stronger correlation between variables, and 0.5 is a minimum value that is accepted (Kaiser, 1974).

Common method bias (CMB) may be a concern because it could distort the estimates of the relationships among drivers (Balaji et al., 2016). To control it, we used both procedural and statistical remedies, as suggested by Podsakoff et al. (2003). Procedurally, we obtained the onions of the importance of drivers from both first-tier suppliers (e.g., contractors, designers) and clients. We did not show the classification of internal and external drivers and guaranteed anonymity. Respondents were also assured that there were no standard answers. Statistically, we used Harman's single-factor test to check the existence of CMB (Podsakoff et al., 2003).

3. Results

3.1. Ranking of drivers

Before conducting factor analysis, ranking analysis was performed to determine the relative importance of drivers. To show clearly respondents' opinions, we also presented the number of each scale and scores of each type of stakeholder. The RII of all the variables was calculated and shown in Table 3.

From Table 3, we find that more than 80% of respondents select "4 – important" or "5 – significantly important" for all variables. Less than 7.4% of respondents choose "1 – significantly unimportant" or "2 – unimportant". It is also clear that each type of stakeholder regard "Support from clients (C12)", "In response to client's requirements (C11)", "In response to high project complexities and uncertainties (C13)" as huge drivers for their collaborative innovation, though different stakeholders have different average scores. This may be because clients often require stakeholders to collaborate and innovate to achieve project delivery and deal with construction problems. Clients also provide the necessary support (e.g., constructing an industry-research institution-university collaboration system) to these stakeholders to help achieve their goals.

Overall, "Support from clients (C12)", "In response to client's requirements (C11)", "In response to high project complexities and uncertainties (C13)", "To reduce transaction costs (C4)", and "Monetary rewards (C14)" are five relatively more important variables with 0.877, 0.872, 0.864, 0.846, and 0.830 in RII, respectively. It reflects that most collaborative innovation in megaprojects is driven by clients' requirements and economic incentives (Chen et al., 2020). "In response to technological change (C16)" is the least important variable with 0.773 in RII.

3.2. Reliability and validity testing

Cronbach's alpha is the basis for examining internal consistency (He et al., 2019). In this research, Cronbach's alpha coefficient for all the drivers is 0.842 (Table 4), greater than the minimum value of 0.7, which indicates a high reliability of total questionnaire survey items. Further, the value of Cronbach's alpha for each dimension is more than 0.7 (Table 5).

Composite Reliability (CR) and AVE (Fornell & Larcker, 1981) were used to test convergent validity. The CR of all extracted dimensions is larger than the recommended threshold, ranging from 0.91 to 0.96 (Table 5). AVE value of six dimensions ranges from 0.717 to 0.918 (Table 5), larger than the minimum value of 0.5, suggesting an acceptable convergent validity.

Besides, the KMO value is 0.705 (see Table 4), which is larger than the minimum value of 0.5, thereby demonstrating the sample's validity and adequacy for factor analysis. Furthermore, Bartlett's spherical test shows a statistically significant correlation between variables with χ^2 = 2047.503 and P = 0.000. This result demonstrates that the population correlation matrix is not an identity matrix. Therefore, the sample is suitable to conduct a factor analysis with high reliability and validity.

Table 4. KMO and Bartlett's validity test

Test	Value
Cronbach's alpha coefficient	0.842
KMO	0.705
Bartlett's test of spherical	
χ^2	2047.503
Significance level (P)	0.000

Table 3. RII and ranking of 18 variables

Variable	Respondents Score					Mean						RII	Rank
	1	2	3	4	5	Contractor	Designer	Supplier	Supervisor	Consulting firm	Client		
C1	1	8	13	76	50	4	4.36	4.2	3.92	4.09	4.32	0.824	7
C2	1	7	17	70	53	4.2	4.32	4.12	3.92	4	4.2	0.826	6
C3	0	7	20	73	48	4.08	4.44	4.23	3.76	4.17	4.12	0.819	8
C4	0	3	21	63	61	4.16	4.32	4.32	3.92	4.43	4.24	0.846	4
C5	1	9	8	106	24	4.32	4.2	3.92	3.72	3.52	4.08	0.793	13
C6	1	6	14	99	28	4.36	4.2	3.92	3.8	3.57	4.08	0.799	10
C7	1	8	20	82	37	4.4	4.36	4.04	3.8	3.39	3.88	0.797	11
C8	1	10	17	83	37	3.96	4.24	3.92	4	3.96	3.8	0.796	12
C9	1	8	15	105	19	3.96	3.84	3.88	3.92	4.09	3.72	0.78	14
C10	2	2	21	110	13	3.96	4	3.8	3.76	3.96	3.8	0.776	15
C11	1	2	3	79	63	4.28	4.24	4.3	4.4	4.26	4.56	0.872	2
C12	1	2	5	71	69	4.35	4.24	4.32	4.48	4.39	4.48	0.877	1
C13	2	2	4	79	61	4.42	4.24	4.17	4.44	4.22	4.4	0.864	3
C14	3	6	15	66	58	4.37	4.56	4.04	3.8	4	3.96	0.83	5
C15	3	6	16	74	49	4.26	4.28	4.04	3.68	4.04	3.96	0.816	9
C16	1	2	22	114	9	4	3.76	3.76	3.88	3.83	3.96	0.773	18
C17	1	2	22	112	11	4	3.68	3.72	3.76	4	4.12	0.776	15
C18	1	2	21	110	13	3.88	3.72	3.76	3.88	4	4.04	0.776	15

Table 5. Rotated component matrix

Variables	Components					
	1	2	3	4	5	6
C1	0.877	0.115	0.209	0.050	0.122	0.041
C2	0.895	0.129	0.045	0.098	0.050	–0.002
C3	0.788	0.059	0.103	0.200	0.036	0.133
C4	0.823	0.085	–0.014	–0.034	0.032	0.091
C5	0.130	0.935	0.043	0.035	0.021	0.056
C6	0.138	0.926	0.061	0.083	0.069	0.093
C7	0.091	0.917	0.019	0.135	0.036	0.131
C8	0.094	0.098	0.082	0.873	0.140	0.068
C9	0.084	0.054	0.252	0.873	0.029	0.052
C10	0.084	0.091	0.016	0.895	0.007	0.028
C11	0.115	0.072	0.851	0.119	0.085	0.079
C12	0.093	0.002	0.948	0.140	0.109	0.019
C13	0.076	0.042	0.930	0.067	0.048	0.043
C14	0.128	0.154	0.053	0.059	–0.012	0.957
C15	0.096	0.102	0.078	0.075	0.087	0.959
C16	0.117	0.122	0.145	0.075	0.885	0.024
C17	0.020	0.021	0.011	0.086	0.894	0.073
C18	0.069	–0.015	0.080	0.007	0.875	–0.018
Initial eigenvalues	4.983	2.527	2.134	2.090	1.818	1.611
Variance after rotation (%)	16.703	14.949	14.765	13.703	13.467	10.645
Cumulative variance (%)	16.703	31.652	46.417	60.121	73.588	84.233
Cronbach's alpha	0.888	0.937	0.920	0.880	0.873	0.957
AVE	0.717	0.858	0.829	0.775	0.783	0.918
CR	0.910	0.948	0.936	0.912	0.915	0.957

Note: Extraction method: principal component analysis. Rotation method: Varimax with Kaiser's normalization. Bold values are the factor loading values for variables on each construct.

3.3. Exploratory factor analysis

The rotated component matrix is operated to establish the components of each item (Chua, 2009). Two types of rotations, including orthogonal (Varimax) rotation and oblique rotation, are commonly used (Chua, 2009). Field (2000) proposed that both types of rotation should be attempted to examine whether factors were interacted and to select the most suitable rotation. In this research, EFA was conducted by using PCA, where Varimax rotation was selected for that the results generated by oblique rotation showed a negligible correlation among extracted dimensions.

Using PCA to extract factors, EFA generates six dimensions with eigenvalues greater than 1.0, as shown in Table 5. The results of the EFA for all drivers did not display a predominant driver. The six dimensions explained 84.233% of the total variance for variables, with the first dimension accounting for 16.703% of the variance. This indicated that 18 drivers manifested on one dimension did not reveal the majority of the variance. Therefore, according to the rules of Podsakoff et al. (2003), CMB was not likely to influence the results. Table 5 also indicated that the extracted principal components could explain most of the 18 selected variables' information and showed the factor loading matrix results after rotation based on the Varimax method. From Table 5, it was clear that the loading of 18 variables was higher than 0.7, and each variable belonged to one of the six dimensions.

The results of the parallel analysis are shown in Table 6. Based on the assumption of parallel analysis, it is clear that all dimensions of the eigenvalue gained by the PCA are larger than the random eigenvalue from the parallel analysis. Thus, the six dimensions are retained for further analysis.

Table 6. Comparison of PCA eigenvalue with parallel analysis eigenvalue

Dimension	Actual eigenvalue from PCA	Random eigenvalue from parallel analysis	Decision
1	4.983	1.8086	Accept
2	2.527	1.6009	Accept
3	2.134	1.4955	Accept
4	2.090	1.4074	Accept
5	1.818	1.3202	Accept
6	1.611	1.2388	Accept

The six grouped dimensions are given a new interpretation by combining the content of included variables. The six dimensions are improving efficiency, learning, responding to project and clients' requirements, responding to competition, responding to environmental changes, and gaining rewards, as shown in Table 7. We also construct a diagram to show RII among six dimensions, as shown in Figure 1. The dimensions are ranked from the most important to the less important from top to bottom.

4. Discussions

This research extends previous research on the stakeholders' drivers to engage in collaborative innovation in megaprojects. Although existing studies have investigated the stakeholders' drivers in collaborative innovation, most focus on the traditional construction project. This research fills this gap by considering the particular characteristics of megaprojects in China. The analysis and results sup-

Figure 1. Division of 18 drivers into 6 main dimensions

Table 7. Factor analysis of drivers of collaborative innovation

Dimension	Variables contained	Factor interpretations	RII	Rank based on RII
1	C1–C4	Improving efficiency	0.829	2
2	C5–C7	Learning	0.796	4
3	C11–C13	Responding to project and clients' requirements	0.871	1
4	C8–C10	Responding to competition	0.784	5
5	C16–C18	Responding to environmental changes	0.775	6
6	C14–C15	Gaining rewards	0.823	3

port Gunduz and Abdi (2020) that understanding drivers and challenges of cooperative partnering is the premise of managing complex relationships among stakeholders. We will discuss each dimension and contributions in this section.

4.1. Responding to project and clients' requirements

We find that responding to project and clients' requirements (Dimension 3) is one of the main drivers to encourage stakeholders to engage in collaborative innovation in megaprojects. It is also the most important driver as most megaprojects in China are initiated by governments and politically sensitive. The results are contrary to existing studies that regard internal drivers (e.g., reducing development risks) as the most important drivers (Leverick & Littler, 1993). This is because the governments often put forward grand innovation goals (e.g., building the longest bridge in the world with new technologies), requiring stakeholders to work closely in megaprojects. Besides, many megaprojects are constructed in an extreme natural environment, for example, the HZMB have to deal with ocean current, hydrological, and other terrible weather conditions during the construction stage. Therefore, high complexities and clients' requirements are major drivers for intensive collaboration in megaprojects in China, which compel stakeholders to take collective behaviors.

As presented in Table 7, RII of "Responding to project and clients' requirements" (Dimension 3) has the highest value, indicating that it has the greatest power to inspire stakeholders to engage in collaborative innovation. Responding to project and clients' requirements (Dimension 3) explains 14.765% of the total variance and contains three variables.

The first variable, "support from clients (C12)", contributes to collaborative innovation because clients' support can facilitate stakeholders' willingness to construct and operate the collaborative innovation system (Chen et al., 2020). Support from clients is a vital driver that helps form a sustainable collaborative innovation system and helps achieve higher innovation outcomes (Dodgson et al., 2015). The second variable, "In response to client's requirements (C11)", promotes collaborative innovation. Usually, clients play the innovation champions role (Sergeeva & Zanello, 2018) in megaprojects' collaborative innovation system and dominate the collaborative innovation system's formation and operation. Under the guidance and requirements of clients, stakeholders (e.g., contractors, designers) have to collaborate in megaprojects' innovation process.

"In response to high project complexities and uncertainties (C13)" makes less contribution to motivate stakeholders to engage in the collaborative innovation compared with "support from clients (C12)" and "In response to client's requirement (C11)". This may be because innovations in megaprojects involve huge uncertainties and no stakeholders are willing to make changes without mandatory requirements and positive supports. However, it still ranks third in all 18 variables. Compared with general infrastructure projects, megaprojects contain several technological/managerial problems that are more complex and cannot be solved by traditional methods and existing knowledge possessed by only a single stakeholder (Davies et al., 2009; Locatelli et al., 2021). Tight collaboration among stakeholders has become a useful tool to deal with these problems in megaprojects.

4.2. Improving efficiency

Efficiency measures stakeholders' performance and megaproject innovation outcomes (Shao & Müller, 2011). Consistent with Akintoye and Main (2007), improving efficiency (Dimension 1) is regarded as a driver for collaborative innovation. It also confirms the practice in China that megaproject innovation outcomes are assessed by efficiency (e.g., cost and time). Thus, stakeholders choose to collaborate to improve their efficiency. According to the respondents, the RII of Dimension 1 ranks second, demonstrating that it also possesses a great driver for collaborative innovation in megaprojects. Improving efficiency (Dimension 1) explains 16.703% of the total variance.

"To reduce transaction costs (C4)" is the most important variable identified in Dimensions 1. Different types of transaction costs are involved in megaproject innovation, such as the cost of creating exclusive properties, obtaining a patent authorization or copyright, and controlling the opportunistic behavior of competitors (Baldwin & Hippel, 2009; Chang & Chou, 2014). Stakeholders in the collaboration process will provide their resources following the prescribed norms. This not only reduces uncertainty and transaction costs but also increases the frequency of transactions.

Faced with the complexity and uncertainty in megaprojects, stakeholders need to conduct research and tests to make innovations. However, it would be difficult for only one stakeholder to carry out all research work and bear all research costs (Akintoye & Main, 2007). Collaboration has become a popular method to integrate various stakeholders in the R&D process, share the costs, and achieve more useful innovation outputs. For example, the consortium is common in the HZMB project to meet innovation and construction goals. Thus, as the second variable in Dimension 1, "To reduce R&D costs (C2)" largely promotes collaborative innovation in megaprojects.

"To reduce relevant risks (C1)", as the third variable in Dimension 1, demonstrates the risk aversion of stakeholders. Innovation in megaprojects is constrained by triple requirements (Derakhshan et al., 2019) and contains unforeseeable risks, such as technology and market risk (Davies et al., 2009, 2015). This leads to the fact that most stakeholders are unwilling to innovate if existing technologies work (Chen et al., 2020). However, it is challenging to use existing technologies to achieve megaprojects' goals. In practice, particular stakeholders often seek external supports and collaborate with others to reduce the risks of failure if they have to make innovations. For instance, to reduce the failure to form the artificial island in HZMB, suppliers, manufacturers, contractors, and consultants studied the possible schemes together and shared all the information and resources.

"To improve resource efficiency (C3)" also motivates stakeholders to take collaborative behaviors in megaproject innovation. In practice, innovation resources such as knowledge, technology, information, human resources, or money are the key to achieve success in innovation. However, these innovation resources may be possessed by different stakeholders and cannot be fully used. Thus, integrating these distributed resources and collaboration has become a valuable vehicle for stakeholders.

4.3. Gaining rewards

Gaining rewards (Dimension 6) refers to earn monetary and non-monetary rewards by engaging in collaborative innovation, which Akintoye and Main (2007) have confirmed. Rewards provide stakeholders with a perception of fairness about the megaproject's benefit distribution system and increase their interest in collaborative innovation. As shown in Table 7, RII of gaining rewards (Dimension 6) ranks third, suggesting that it can attract stakeholders' interest to engage in collaborative innovation to a large extent. Gaining rewards (Dimension 6) explains 10.645% of the total variance and contains two variables.

"Monetary rewards (C14)", such as financial compensations and monetary benefits (Füller, 2010), are common methods used by governments/clients to encourage stakeholders to engage in collaborative innovation. It is common that government/client issues a regulation to encourage collaborative innovation and provide monetary rewards (e.g., tax relief) to those who behave perfectly in China. As rational men, stakeholders are driven by the economic benefits and try to collaborate in megaprojects innovation to obtain the greatest benefits.

Non-monetary rewards (C15)", such as feedback, empowerment, competency development, or client recognition, are primary measures adopted by clients" (Füller, 2010; Mustafa & Ali, 2019). In practice, by granting one of these non-monetary rewards, the clients/governments involved in megaprojects convey a message to stakeholders that their capability is cared for and that their contributions/works are highly valued and appreciated. Moreover, these non-monetary rewards imply that stakeholders have great potential to develop and achieve better in the future (Mustafa & Ali, 2019).

4.4. Learning

As shown in Table 7, RII of learning (Dimension 2) ranks fourth, indicating that it can motivate stakeholders to engage in collaborative innovation in megaprojects to some extent. Learning (Dimension 2) explains 14.949% of the total variance and contains three variables.

Different skills, such as integrated management skills, communication skills, and problem-solving skills, are essential inputs for achieving innovation goals in megaprojects (Davies et al., 2014). However, not all stakeholders possess these skills, and thereby collaborating with other stakeholders has become a straightforward method to benefit all participants. Moreover, critical skills related to collaborative relationship building, trust, and flexibility can only be developed and applied in practice. Therefore, "To learn complementary/new skills (C6)" is an important driver to engage in collaborative innovation.

According to the innovation and knowledge management theory, the nature of innovation is the dynamic process of knowledge creation, external acquisition, and the application of new knowledge (Zhao et al., 2018). Knowledge creation in megaprojects is a rather complicated process that has to aggregate value from different stakeholders in a few methods, such as sharing mental, emotional, cognitive, and active knowledge (Kao & Wu, 2016). These integrations will provide stakeholders with beneficial experiences and complementary/new knowledge. Besides, applying new knowledge to the construction processes helps stakeholders understand the complementary/latest knowledge and its application, which will further bring many short-term and long-term benefits (e.g., gain a competitive advantage and increase income in the long run). Therefore, "To learn complementary/new knowledge (C7)" facilitates stakeholders' collaborative innovation in megaprojects.

Stakeholders involved in collaborative innovation also aim to learn complementary/new technologies (C5). Innovation in megaprojects needs to construct an organizational process that creates and acquires value by combining and collaborating various technologies to achieve the desired outcome (Davies et al., 2014). New technologies (e.g., ICT control and Building Information Modelling) are considered a cost-effective element to the innovation process and a reasonable method to create more value in megaprojects (Cao et al., 2015, 2016). However, not all stakeholders involved in megaprojects have an excellent command of the new technologies. With the rapid development of technology, traditional stakeholders (e.g., constructors) are forced to collaborate with stakeholders in other industries to absorb the complementary/new technologies.

4.5. Responding to competition

Responding to competition (Dimension 4) describes the incentives that induce a stakeholder to take action or respond to an attack by competitors. As shown in Table 7, the RII of Dimension 4 ranks fifth, indicating a relatively weak driving force for stakeholders to engage in collaborative innovation in megaprojects. Dimension 4 explains 13.703% of the total variance and contains three variables.

The firm's image shows the impression and evaluation of the public and employees on it, and it is also an external manifestation of corporate spiritual culture. The firm's reputation describes the stakeholders' accumulated impressions resulting from their interactions with the stakeholders (Foroudi et al., 2020). Both image and reputation are of significance as a means of differentiation in today's economy, creating a competitive advantage. In China, megaprojects have significant political and social influence and attract people's attention. Thus, stakeholders try to involve in the collaboration work to promote a firm image and reputation. Therefore, stakeholders are positively engaged in collaborative innovation in megaprojects to build a good firm image and reputation (C8).

Creativity is an element that enhances firms' ability to retain their competitive advantage and stay ahead of their competitors (Parjanen, 2012). For construction firms and other firms in megaprojects, clients, governments, or collaborators' perspectives are crucial for short-term and long-term development. Thus, many firms are willing to be involved in collaborative innovation to express their ability and creativity (C9) in dealing with construction problems.

Innovation in megaprojects is a complex process that aims to solve technical issues by collaboration among stakeholders. These rigid processes force stakeholders to improve their capability together in a limited time, which is a valuable experience for most stakeholders to face similar problems. Thus, improving a firm's skills and gaining competitive advantages (C10) can motivate stakeholders to engage in collaborative innovation in megaprojects.

4.6. Responding to environmental changes

Consistent with Akintoye and Main (2007), responding to environmental changes (Dimension 5) can also force stakeholders to take collaborative behaviors in response to changes in the market, technology, and relevant regulation and rules issued. However, the RII of Dimension 5 is the smallest compared with the other five dimensions in the context of China as presented in Table 7. This is common in the infrastructure industry that stakeholders are slow in making changes. When they have to do so, they often choose to work together with others to reduce risks. Responding to environmental changes (Dimension 5) explains 13.467% of the total variance and contains three variables.

Megaprojects are "projects which transform landscapes rapidly, intentionally, and profoundly in obvious ways and require coordinated applications of capital and state power" (Gellert & Lynch, 2003). Indeed, to achieve goals in megaprojects, governments often promulgate regulations, or rules, which guide stakeholders' behaviors. For example, to promote the application of public-private-partnership mode in megaprojects, the Central Government of China has issued a few regulations, "setting up PPP guiding funds to accelerate the construction of megaprojects" to guide the practice. Under the guidance of these rules, private firms begin to participate and collaborate in the construction of megaprojects and made contributions to megaprojects' innovation. Thus, in response to relevant regulations and rules issued by governments (C17) is a driver for stakeholders to some extent but has fewer drivers than on project-level requirements and rewards.

The market environment plays an essential role in collaborative innovation in megaprojects. Recently, macro-market globalization and market changes have posed enormous challenges and opportunities for megaproject innovations (Xue et al., 2010). Risks usually accompany these challenges, and collaboration has become a rational choice for stakeholders to deal with these risks and improve innovation outcomes. The market changes also result in economic and technical opportunities to collaborate among stakeholders or the timely use of professional knowledge available within the firm to respond to the opportunity created (Akintoye & Main, 2007). Thus, market change is an essential driver for stakeholders to engage in collaborative innovation in megaprojects.

According to the respondents, the RII of in response to technological change (C16) ranks last in all 18 drivers for collaborative innovation. This may be because the infrastructure industry is relatively conservative compared to other sectors, especially the manufacturing industry. The changes in technology have limited drivers for stakeholders to take collaborative behaviors.

4.7. Theoretical contributions

This research is novel in that it investigates drivers and their relative importance for collaborative innovation in megaprojects. The six extracted principal components in Section 3 represent six dimensions of drivers of collaborative innovation in megaprojects. Each dimension has a unique impact on the shaping of collaborative innovation, as discussed from section 4.1 to section 4.6. The findings can provide new insights into drivers of stakeholders to engage in collaborative innovation in megaprojects, especially for some emerging economies (e.g., China, India, Brazil) that are undergoing massive megaprojects.

These six dimensions of drivers may have interrelationships. For example, the use of suitable reward plans to stimulate the stakeholders to improve efficiency. In a traditional construction project, this strategy is commonly used to motivate employees effectively to innovate (Ogwueleka & Udoudoh, 2018). However, it has not been verified in megaprojects. Therefore, we suggest testing the relationships in the context of megaprojects.

Learning may contribute to responding to competition, environmental changes, and project and client requirements. Consistent with Xue et al. (2010), learning is regarded as one of the critical drivers that encourage individuals/organizations to engage in collaborative innovation of megaprojects in China. Complementary/new skills, knowledge, and technologies are confidential from competitors in China, but can be learned in the collaborative innovation process. The knowledge/skill/technologies learned can also be used in future megaprojects, helping compete with others and deal with clients' specific requirements.

Also, the combination of all of the drivers may contribute to the formation of collaborative innovation. In this research, we demonstrate that stakeholders engage in collaborative innovation with different drivers. These drivers may collectively affect the formation of collaborative innovation. Future research can use both qualitative and quantitative methods to examine these relationships.

4.8. Practical implications

The results and findings provide a few practical implications. First, clients need to understand that the formation of collaborative innovation is a complex process and is motivated by many drivers. They need to understand the drivers of stakeholders and their relative importance and take effective measures, for example, paying more attention to making detailed requirements in the early stage as it has the greatest power, to facilitate them to form a healthy collaborative innovation system and achieve megaproject innovation goals. Second, stakeholders need to take opportunities in the collaborative innovation process to achieve their internal goals, such as learning complementary knowledge and technology, gaining more competitive advantage, improving efficiency.

Conclusions

This research investigates drivers of stakeholders to engage in collaborative innovation in megaprojects and their relative importance. By literature review, questionnaire survey, and EFA, six underlying dimensions of drivers of stakeholders to engage in collaborative innovation in megaprojects were revealed. The six dimensions are prioritized based on the criteria RII as follows:

– Responding to project and clients' requirements, including "Support from clients", "In response to client's requirements", and "In response to project complexities and uncertainties".
– Improving efficiency, including "To reduce transaction costs", "To reduce R&D costs", "To reduce relevant risks (e.g., construction development risk)", "To improve resource efficiency".
– Gaining rewards, including "Monetary rewards (e.g., financial compensation from governments)" and "Non-monetary rewards (e.g., feedback)".
– Learning, including "To learn complementary/new skills", "To learn complementary/new knowledge", and "To learn complementary/new technologies".
– Responding to competition, including "To build a good firm image and reputation", "To express individual/firm ability and creativity", and "To improve firm's skills and gain competitive advantages".
– Responding to environmental changes, including "In response to market change", "In response to relevant regulations or rules issued by governments", and "In response to technological change".

The research findings contribute to the existing research in drivers of collaborative innovation in two ways.

First, this research fills the research gaps that lack studies looking at drivers of stakeholders by identifying six dimensions in stimulating stakeholders to engage in collaborative innovation. These drivers identified can be adopted by practitioners involved in the megaprojects to manage collaborative innovation activities better. As a number of megaprojects are constructed in developing countries (e.g., India, China), the findings can provide theoretical guidance for practitioners, decision-makers, or policymakers in megaprojects to take effective measures to inspire stakeholders to engage in collaborative innovation.

Second, the rankings of drivers also fill research gaps and show the relative importance of drivers in motivating stakeholders to engage in collaborative innovation activities. The rankings can offer stakeholders some recommendations on how to behave in collaborative innovation to get more benefits. They can also explore how to achieve better innovation outcomes by combing some of these drivers.

The research has two limitations that need to be solved in further research. First, it is hard to access respondents from different megaprojects, and there are insufficient whole lifecycle data of the drivers in the collaborative innovation process. Future research can use the case study to validate the applicability and reliability of the drivers identified in this research and make necessary improvements. Second, this research adopts the Varimax rotation method, which assumes no interrelationships among the dimensions. However, the results showed that dimensions have a very weak correlation. Future research can explore the precise methods to extract drivers.

Acknowledgements

The views presented here are those of the authors and should not be taken as representative of the position or policy of the organisations involved. The work was supported by the National Natural Science Foundation of China (Grant No. 71971161).

Funding

The work was supported by the National Natural Science Foundation of China (Grant No. 71971161).

Disclosure statement

The author declares that they have no know competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX A

The questions in the interview are designed around three themes to identify the drivers of collaborative innovation in megaprojects.

1. Please introduce the latest megaproject you participated in.
2. Please explain your responsibilities in the latest megaproject.
3. Please describe which stakeholders your firms/teams cooperated with.
4. Please describe the cooperation process with firms A, B, C, etc.
5. Please describe the suitability of drivers based on your experience and, if possible, provide examples.
6. Please suggest any possible supplementary drivers.

APPENDIX B

Dear Sir/Madam,

This questionnaire survey aims to investigate the importance of drivers in stimulating stakeholders to engage in collaborative innovation in megaprojects. Megaprojects are large-scale and complex projects that involve large investments, extreme complexity and uncertainty, and multiple stakeholders, require substantial innovations during their planning, design, construction, and delivery stages.

The below questions focus on investigating the importance of drivers in stimulating stakeholders to engage in collaborative innovation in megaprojects by a five-point Likert scale (1 – significantly unimportant, 2 – unimportant, 3 – neutral, 4 – important, 5 – significantly important).

Please answer the questions based on your innovation experience in a specific megaproject. If you have no such experience, please ignore it. Thank you for your time!

1. Please choose your gender

   A. Male B. Female

2. How many years have you been working in megaprojects?

   A. 1–5 years B. 5–10 years C. more than 10 years

3. What kind of stakeholder are you in megaprojects?

   A. Clients B. Consultants (except supervisor) C. Supervisor D. Contractors E. Suppliers F. Designers G. others, please indicate

4. What is your position in your company?

   A. Project manager B. Site manager C. Engineer D. Architect E. Planning and Cost Control Manager F. Consultants

5. Please indicate the importance of drivers to engage in collaborative innovation in megaprojects by a 5-point Likert scale (1 – significantly unimportant, 2 – unimportant, 3 – neutral, 4 – important, 5 – significantly important).

Number	Drivers	1	2	3	4	5
1	To reduce relevant risks					
2	To reduce R&D costs					
3	To improve resource efficiency					
4	To reduce transaction costs					
5	To learn complementary/new technologies					
6	To learn complementary/new skills					
7	To learn complementary/new knowledge					
8	To build a good firm image and reputation					
9	To express individual/firm ability and creativity					
10	To improve the firm's skills and gain competitive advantages					
11	In response to client's requirements					
12	Support from clients					
13	In response to high project complexities and uncertainties					
14	Monetary rewards (e.g., financial compensation from clients/governments)					
15	Non-monetary rewards (e.g., feedback)					
16	In response to technological change					
17	In response to relevant regulations or rules issued by governments					
18	In response to market change					