

INNOVATION STIMULANTS, INNOVATION CAPACITY, AND THE PERFORMANCE OF CAPITAL PROJECTS

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Abstract. Identifying the critical determinants of innovation performance is crucial. However, few studies explore and quantify systematically the relationships between innovation factors and the performance of capital projects. This study of 121 capital projects shows that the relationships among project innovation stimulants, innovation capacity, and project performance are indeed significant. Hierarchical robust regression analyses using a maximum R-square improvement procedure show that technology management has the highest effect on the variation in our project performance data. Validating out-of-sample data demonstrates that our optimal model explains 34.42% of the variation in the performance of capital projects. Ultimately, our findings suggest that project human factors are essential stimulants in innovation performance, which in turn affect the performance of capital projects. Our findings also reveal that the stimulant factors do not have a direct impact on capital project performance, but rather have an indirect impact *via* project innovation capacity.

Keywords: project management, project innovation, project performance, performance measurement, capital project construction, empirical research.

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Introduction

Successful innovation management largely depends on identifying the critical determinants of innovation performance. Accordingly, extensive research examines and identifies a wide variety of measures of innovation and the inputs that affect innovation outcomes (e.g., Jassawalla, Sashittal 2002; Miller *et al.* 2007; Vaccaro *et al.* 2011).

One recent finding, for example, is that the firms with more slack resources and higher levels of managerial ownership innovate less when firm performance declines (Latham, Braun 2009). Another finding is that the network density of a firm's partners strengthens the influence of technological diversity, which in turn increases the firm's innovation performance (Phelps 2010).

However, relatively few studies explore innovation from a project perspective. Although several published studies investigate the relationships between innovation and project performance, they primarily examine the relationships between innovation capacity and stimulants (e.g., DeTienne, Koberg 2002; Ebadi, Utterback 1984), between innovation capacity and project performance (e.g., Danneels 2002; Davies, Hobday 2005), or between innovation stimulants and project performance (e.g., Sundström, Zika-Viktorsson 2009; Oke, Idiagbon-Oke 2010).

Furthermore, these published studies principally focus on new product development (NPD) and research and development (R&D) – despite the fact that capital projects contribute significantly to the growth of economy. The capital projects industry includes both the delivery and the maintenance of facilities (e.g., commercial, institutional, industrial, and residential buildings; as well as transportation, energy, water, sewage, and communication systems).

Our focus is on the delivery process of capital projects. As a result, there appears to be a lack of research that models and quantifies the triangular relationships between innovation factors (stimulants and capacity) and the performance of capital projects to provide management a complete picture of how innovation affects project performance.

The first objective of this study, therefore, is to explore and assess the relationships between innovation factors and the performance of capital projects. The second objective is to quantify systematically the effects of innovation performance on project performance. Both objectives help stakeholders better measure the impact of improved innovation performance on capital projects.

The rest of the paper is organized as follows. “Research background” reviews related studies, “Hypotheses” delineates the test hypotheses, “Research methods” presents the research methodology and describes the sample collection, and “Results” depicts the statistical tests, model-building, and validation. “Discussions” discusses the implications of the research results. “Conclusions” presents the research summary and conclusions.

1. Research background

Innovation is often thought of as a change in thought process or a useful application of new inventions or discoveries (McKeown 2008), and it often manifests itself in either a new product, service, procedure, or method (Brady, Söderlund 2008). Innovation has been an essential source of competitive advantage since the beginning of the Industrial Revolution (Prajogo, Ahmed 2006), and existing research (e.g., Prajogo, Ahmed 2006; Sampson 2007) demonstrates a wide range of benefits for corporations that are successful in innovation (e.g., increases in operation efficiency, sales, profitability, and market share). Not surprisingly, numerous researchers and practitioners (e.g., Abbey, Dickson 1983; Sampson 2007) conduct extensive studies to develop innovation models through examining and identifying the key determinants of success in innovation.

Whilst numerous models (e.g., Miller *et al.* 2007; Motohashi *et al.* 2012; Ooi *et al.* 2012; Wu *et al.* 2008) developed for organizational innovation embody technological and human aspects, one group of scholars (e.g., Adams *et al.* 2006; Jassawalla, Sashit-

tal 2002; Prajogo, Ahmed 2006; Prajogo, Sohal 2006) highlights the need to integrate technological aspects with human aspects when modeling innovation performance. The rationale is straightforward: innovation practices should be executed within a suitable environment (i.e., leadership, management, and culture).

For example, Amabile and Conti (1999) show that work environment plays a particularly important role in team creativity based on the study of a large high-technology firm before, during, and after a major downsizing. Shalley *et al.* (2000) use a survey of 2,200 adults to illustrate how organizations can foster creativity by ensuring that work environments complement the creative requirements of jobs. Jassawalla and Sashittal (2002) note that cultures that highly support innovation, foster teamwork, and promote risk-taking and creative actions positively affect innovation performance. They propose that organizations could develop such cultures by listening to the participants in the NPD processes at high-technology organizations.

Based on a study of 235 professional R&D workers in large and small technology-based firms, Bommer and Jalajas (2004) note that policies supportive of informal communications affect the extent to which engineers can obtain more valuable information from suppliers, customers, and employees in other departments, which in turn affect innovation performance. Additionally, Elenkov and Manev (2005) show that sociocultural context directly influences leadership and moderates its relationship with organizational innovation based on a sample of 1,774 individuals from 12 European countries. Using a sample of 463 R&D alliances in the telecommunications equipment industry, Sampson (2007) finds that an alliance environment contributes far more to firm innovation when technological diversity is moderate, rather than when it is low or high.

Recently, subsequent work based on a sample of 145 firms suggests that service suppliers that retain management control over their intellectual output are more innovative (Leiponen 2008). Based on a longitudinal investigation of 77 telecommunications equipment manufacturers, Phelps (2010) concludes that the network density of a firm's allies and partners strengthens the influence of technological diversity, which in turn increases the firm's innovation performance. More recently, Vaccaro *et al.* (2012) conclude that smaller, less complex organization environments benefit more from transactional leadership in realizing management innovation. The study is based on a sample of 151 companies.

In addition, Tang *et al.* (2012) use Tobit-censored normal regression analysis to examine the relationships among executive hubris, organization environment, and firm innovation. Based on a sample of 2,820 manufacturing firms in China and 3,285 U.S. firms in high-tech industries, they conclude that executive hubris positively affects firm innovation performance, but the relationship between executive hubris and firm innovation becomes weaker when the environment is more munificent and complex.

Despite the paucity of studies that use a wide variety of measures to describe innovation outcomes and the input characteristics that affect those outcomes as well as firm performance (e.g., Kessler, Chakrabarti 1996; Tang *et al.* 2012; Vaccaro *et al.* 2012), most studies focus on firms engaged in innovation (e.g., Nohria, Gulati 1996; Sampson 2007); relatively few studies explore projects engaged in innovation.

Further, although some existing studies describe the relationships between innovation and project performance (e.g., Oke, Idiagbon-Oke 2010; Sundström, Zika-Viktorsson 2009), these studies principally focus on examining the relationships between the technological and human aspects of innovation (e.g., DeTienne, Koberg 2002; Ebadi, Utterback 1984), between innovation's technological aspects and project performance (e.g., Davies, Hobday 2005; Kazanjian *et al.* 2000), or between innovation's human aspects and project performance (e.g., Calamel *et al.* 2012; Sundström, Zika-Viktorsson 2009; Oke, Idiagbon-Oke 2010).

Furthermore, most published studies primarily focus on NPD and R&D projects (e.g., Danneels 2002; Sundström, Zika-Viktorsson 2009) – despite the fact that capital projects contribute significant growth to the economy (Chen 2011; Mallick, Mahalik 2010). As a result, there appears to be a lack of research that models and quantifies the triangular relationships between innovation factors (technological aspects and human aspects) and the performance of capital projects, providing management a total picture of how innovation affects project performance.

2. Hypotheses

The preceding section critiques existing studies of innovation and project performance. Now the question is: *How does project innovation affect the performance of capital projects?*

To answer this question, we first examine the relationships between innovation factors and the performance of capital projects. Then, we model and quantify the effects of innovation factors on the performance of capital projects.

To investigate the relationships between innovation factors and the performance of capital projects, we need to develop a series of test hypotheses. A review of literature on innovation suggests that both technological and human aspects affect organizational innovation (e.g., Adams *et al.* 2006; Jassawalla, Sashittal 2002; Prajogo, Ahmed 2006; Tang *et al.* 2012). We posit that technological and human issues should not be examined in isolation when modeling the effects of innovation performance on the performance of capital projects. We define the technological factors of innovation performance as innovation capacity concerning the accumulation of knowledge and the creativity and experience of existing and emerging technologies. The human factors of innovation performance that we define as innovation stimulants concern leadership, team-building, communication management, and productive culture.

To articulate the triangular relationships between innovation factors (stimulants and capacity) and the performance of capital projects, we propose three hypotheses:

- H1:** Stimulant factors of project innovation positively affect the innovation capacity of capital projects.
- H2:** Stimulant factors of project innovation positively affect the performance of capital projects.
- H3:** Project innovation capacity positively affects the performance of capital projects.

3. Research methods

3.1. Participants and procedures

Of the 500 members of Taiwan's Chinese National Association of General Contractors (CNAGC) that we randomly selected and invited to participate in this research, 121 companies participated – a 24.2% response rate (CNAGC has over 1,000 members). Of the 121 firms, 24 have less than US\$5 million in revenue; 30 have US\$5 million–US\$15 million in revenue; 37 have US\$15 million–US\$25 million; and 30 have more than US\$25 million in revenue.

Each of the 121 companies in the sample had a project manager who had just completed a capital project. The 121 capital projects fall into three categories: buildings (69 projects), transportation facilities (22 projects), and industrial facilities (30 projects). Project managers average between one and 26 years of experience; 30 participants had fewer than five years of experience; 51 had between five and 10 years; 33 had between 10 and 20 years; and seven participants had over 20 years of experience.

Surveys collected the data. Prior to the data collection, several experienced researchers and a panel of experts from CNAGC critiqued the questionnaire for structure, readability, clarity, and completeness. These researchers and experts also appraised the extent to which the indicators sufficiently addressed the subject area (Dillman 1978). Based on the feedback from these researchers and experts, the survey instrument was then modified to strengthen its validity.

The final version of the survey questionnaire comprises two sections. The first section, composed of open-ended questions, gathers detailed background information such as annual revenue; project type; project cost, including contract price, budget, contract price for project changes, and actual cost; as well as the project schedule including the contract schedule, scheduled time, contract schedule for project change, and actual schedule.

The second section gathers data for the project innovation variables and measures that data using scales based on a synthesis of literature from the project management, innovation management, group effectiveness, and organizational theory fields. Section two consists of multiple-choice questions in which respondents indicate on a 10-point scale the extent to which certain project variables likely affect the innovation and project performance. Because of space limitations, complete survey questionnaires are available from the authors on request.

3.2. Measures and analysis

Cost, time, and performance are the typical measures of project success (Kloppenborg, Opfer 2002). In other words, a project is often considered successful if it finishes within its budget estimate, finishes within its scheduled time frame, and performs as designed (Scott-Young, Samson 2008). Whilst the research literature in project management engages in a fruitful debate over the nature of project performance (Dvir *et al.* 1998), project performance criteria have become multifaceted.

For example, Shenhar *et al.* (2001) use project efficiency, customer benefit, organizational success, and potential benefit to the organization to assess project performance. Yu *et al.* (2005) develop a value-centered model based on net project execution cost and net project operation value to evaluate project performance. The Project Management Institute (2008) assesses project success with cost, time, quality, and stakeholder satisfaction.

Thus, this study chooses project time, cost, profitability, and customer satisfaction as the criteria for capital project performance. The rationales are straightforward: delays in completion time may turn a promising investment opportunity into an expensive failure (Scott-Young, Samson 2008), cost overrun directly encroaches on profit (Teerajetgul *et al.* 2009), and project profitability and customer satisfaction ensure business growth and development (Chen 2011).

Further, based on an extensive review of the interdisciplinary literature and in an effort to generate a more parsimonious measurement, we choose widely accepted constructs and their respective key measures of organizational innovation to gauge project innovation stimulants and capacity. Constructs measuring project innovation stimulants that concern project leadership, project team-building, project communication, and culture are *Leadership (Lead)* and *People Management (PM)*. Those measuring project innovation capacity that relate to the accumulation of project knowledge and project creativity as well as the experience of existing and emerging project technologies are *Knowledge Management (KM)*, *Creativity Management (CM)*, *Research and Development (R&D)*, and *Technology Management (TM)*. Table 1 lists the taxonomy of measures of these constructs, the means and standard deviations of their respective measures, and the constructs' corresponding Cronbach's α values for the reliability analysis for the 121 sample projects. If not otherwise indicated, all measures use a scale in which 1 is "strongly disagree" and 10 is "strongly agree". High scores suggest good performance; low scores indicate poor performance.

Lead ($\alpha = .92$) is measured according to a four-item scale (see the respective Variable, Measure, Mean, Standard Deviation, and Cronbach's α columns in Table 1) based on Bart (2002), Linton and Walsh (2004), O'Neil *et al.* (1998), Prajogo and Ahmed (2006), and Prajogo and Sohal (2006). *PM* ($\alpha = .97$) is measured according to a five-item scale (see Table 1) based on Abbey and Dickson (1983), Amabile and Conti (1999), Prajogo and Ahmed (2006), Prajogo and Sohal (2006), and Shalley *et al.* (2000). *KM* ($\alpha = .96$) is measured according to a four-item scale (Table 1) based on Herrera *et al.* (2010), Miller *et al.* (2007), Prajogo and Ahmed (2006), Subramaniam and Youndt (2005), Wu *et al.* (2008), and Youndt *et al.* (2004).

CM ($\alpha = .96$) is measured according to a seven-item scale based on Amabile and Conti (1999), Dulaimi *et al.* (2005), Kratzer *et al.* (2006), Prajogo and Ahmed (2006), Shalley *et al.* (2000). *TM* ($\alpha = .95$) is measured according to a four-item scale (Table 1) based on Hayes and Wheelwright (1984), Prajogo and Ahmed (2006), Urban and von Hippel (1988). *R&D* ($\alpha = .96$) is measured according to a five-item scale (Table 1) based on Adams *et al.* (2006), Bessant and Francis (1997), Prajogo and Ahmed (2006), Prajogo and Sohal (2006).

Table 1. Taxonomy, means, standard deviations, and reliabilities

Variable	Measure	Research Reference	Mean N = 121	Standard Deviation	Cronbach's α
Leadership (Lead)	Project leaders share similar beliefs	O'Neil <i>et al.</i> 1998; Prajogo, Ahmed 2006; Miller <i>et al.</i> 2007	7.28	1.65	0.92
	Project leaders encourage learning and improvement	Linton, Walsh 2004; Prajogo, Ahmed 2006	7.33	1.44	
	Project leaders encourage change and sharing	Prajogo, Ahmed 2006	5.71	1.82	
	Unity of purpose	Bart 2002; Prajogo, Ahmed 2006; Prajogo, Sohal 2006	5.80	1.58	
People management (PM)	Team member training and development exists	Prajogo, Ahmed 2006; Prajogo, Sohal 2006	6.74	1.68	0.97
	Project maintains team member communication	Prajogo, Ahmed 2006	6.21	1.67	
	Team member satisfaction regularly measured	Prajogo, Ahmed 2006; Prajogo, Sohal 2006	6.55	1.49	
	Team member training and multi-skilling used	Prajogo, Ahmed 2006; Prajogo, Sohal 2006	6.59	1.72	
	Project's work environment is positive	Abbey, Dickson 1983; Amabile, Conti 1999; Prajogo, Ahmed 2006; Prajogo, Sohal 2006; Shalley <i>et al.</i> 2000	6.64	1.53	
Knowledge management (KM)	Project intellectual capital build-up is important	Prajogo, Ahmed 2006; Subramaniam, Youndt 2005; Youndt <i>et al.</i> 2004	6.82	1.47	0.96
	Regular upgrades in project-related knowledge and skills	Herrera <i>et al.</i> 2010; Prajogo, Ahmed 2006	6.86	1.62	
	Company shares and disseminates project-related information and knowledge	Miller <i>et al.</i> 2007; Prajogo, Ahmed 2006	6.62	1.65	
	Project-related intellectual assets managed well	Prajogo, Ahmed 2006; Wu <i>et al.</i> 2008	6.88	1.54	

Continue of Table 1

Variable	Measure	Research Reference	Mean N = 121	Standard Deviation	Cronbach's α
Creativity management (CM)	Top management support for innovative ideas/solutions is high	Amabile, Conti 1999; Dulaimi <i>et al.</i> 2005; Shalley <i>et al.</i> 2000	6.41	1.82	0.96
	Project manager decision authority is high	Amabile, Conti 1999; Dulaimi <i>et al.</i> 2005; Shalley <i>et al.</i> 2000	6.55	1.72	
	Time and resources provided for generating innovative ideas/solutions	Amabile, Conti 1999; Prajogo, Ahmed 2006	6.75	1.67	
	Groups have diverse skills and communicate openly	Prajogo, Ahmed 2006	6.47	1.57	
	Cognitive conflicts moderately high	Kratzer <i>et al.</i> 2006	6.45	1.56	
	Manager has bottom-up problem-solving style	Dulaimi <i>et al.</i> 2005	6.64	1.71	
	Creativity is rewarded and recognized	Amabile, Conti 1999; Prajogo, Ahmed 2006	6.52	1.72	
Technology management (TM)	At the leading edge of project practices/technologies	Urban, von Hippel 1988	6.63	1.76	0.95
	Evaluating potential of using new project technologies/practices	Hayes, Wheelwright 1984; Prajogo, Ahmed 2006	6.66	1.49	
	Acquire project technological capabilities in advance of needs	Hayes, Wheelwright 1984; Prajogo, Ahmed 2006	6.89	1.51	
	Continuously thinking of next-generation technology	Prajogo, Ahmed 2006	6.71	1.63	
Research and development (R&D)	Team education and confidence are high	Kessler, Chakrabarti 1996	6.58	1.63	0.96
	Physical resources adequate	Adams <i>et al.</i> 2006	6.69	1.75	
	Financial resources adequate	Adams <i>et al.</i> 2006	6.38	1.70	
	Tools and systems adequate	Bessant, Francis 1997	7.29	1.33	

End of Table 1

Variable	Measure	Research Reference	Mean N = 121	Standard Deviation	Cronbach's α
Profitability	R&D strategically important	Prajogo, Ahmed 2006; Prajogo, Sohal 2006	6.69	1.69	
	Revised profit performance = (revised contract price – actual cost)/actual cost	Hartley, Watt 1981	5.50	2.94	
Cost	Revised cost performance = revised estimated cost/actual cost	Anbari 2004	5.60	2.87	
Time	Revised time performance = revised estimated duration/actual duration	Anbari 2004	5.60	2.89	
Customer satisfaction (CS)	Meets customer budget estimate	Tohumcu, Karasakal 2010	6.89	1.67	0.97
	Meets customer scheduled time frame	Tohumcu, Karasakal 2010	7.17	1.58	
	Low defect rate	Tohumcu, Karasakal 2010	7.02	1.65	
	Resolves defects quickly and effectively	Ling <i>et al.</i> 2009	7.40	1.28	
	Customer complaints low	Luu <i>et al.</i> 2008	7.12	1.44	
	Responsiveness to customer requests/complaints	Qureshi <i>et al.</i> 2009; Tohumcu, Karasakal 2010	7.43	1.33	
	Conforms to contract requirements	Ling <i>et al.</i> 2009	7.15	1.52	
	Courtesy of staff	Ling <i>et al.</i> 2009	7.02	1.54	
	Understanding of customer's company and industry	Bettencourt <i>et al.</i> 2001	7.08	1.43	
Communication with the customer is effective	Chen 2011; Ling <i>et al.</i> 2009	7.55	1.32		

Finally, *Project Performance (PP)* is measured on a four-item scale that includes *Profitability*, *Cost*, *Time*, and *Customer Satisfaction (CS)*. *Profitability* is measured on a one-item scale (see Table 1) based on Hartley and Watt (1981). *Cost* and *Time* are both measured according to one-item scale (see Table 1) based on Anbari (2004). *CS* (α =

.97) is measured according to a 10-item scale based on Bettencourt *et al.* (2001), Chen (2011), Ling *et al.* (2009), Luu *et al.* (2008), Qureshi *et al.* (2009), and Tohumcu and Karasakal (2010).

Principal component analysis reveals that all the factor loadings of the measurement items of *Lead*, *PM*, *KM*, *CM*, *TM*, and *R&D* are all 0.63 or greater and thus exceed the threshold value of 0.50 (Hair *et al.* 1998). We therefore include the variables in the innovation performance-measurement model. Principal component analysis also shows that the factor loadings of *PP*'s *Time*, *Cost*, *Profitability*, and *CS* are 0.57, 0.74, 0.28, and 0.71, respectively. (For comparison purpose, percentile ranks categorize time performance on a 10-point scale based on the computed values of *Time* from the 121 sample projects using the revised estimated duration/actual duration equation in Table 1. The same technique also applies the *Cost* and *Profitability* equations in Table 1.) We therefore delete the *Profitability* measurement item. *PP* ($\alpha = .73$) is measured by *Time*, *Cost*, and *CS*.

The methodology to analyze the relationships between innovation factors and performance of capital projects and to quantify the impact of innovation on the performance of capital projects is threefold. First, to test the hypotheses, this study uses the absolute values of the kurtosis indexes to verify normality, followed by maximum likelihood (ML) and asymptotically distribution-free (ADF) estimation methods of structural equation modeling (SEM), respectively, when the data is normally and abnormally distributed.

Second, based on the test results of the hypotheses, this study conducts a hierarchical robust regression analysis using a maximum R-square improvement procedure to obtain the optimum subset of regressor variables. Use of robust regression analysis not only dampens the influence of outlying observations, but also ensures that the forecasts and the model estimation are unbiased when the normality of the residuals is violated (Neter *et al.* 1996).

Though this study already applies a maximum R-square improvement procedure, which is a very popular method for combating the multicollinearity (Freund, Wilson 1998) that may impair the usefulness of a model's estimated parameters, there is a need to examine if multicollinearity still exists. This study uses incomplete principal-component analysis (Littell, Freund 2000) to detect and rectify the problem of multicollinearity.

Third, this study validates its optimal models using an out-of-sample test. Specifically, this study develops a hypothesis to test whether a significant discrepancy exists in the mean value of the differences between estimated and actual project performance for both the estimation data and the out-of-sample data. To examine the hypothesis, this study uses the Kolmogorov-Smirnov test to verify normality, followed by T-tests and Mann-Whitney tests, respectively, when the data is normally and abnormally distributed. We first use all 121 sample capital projects to test our hypotheses. We then split the sample into two subsamples: the estimation data and the out-of-sample validation data. The estimation data, composed of 61 projects randomly selected from 121 capital projects, are used for model-building. We use the out-of-sample validation data – the remaining 60 projects – to validate the model.

4. Results

4.1. Results of hypothesis tests

Figure 1 provides the analysis results of SEM's ML estimation for innovation's effects on the performance of capital projects. This study uses the ML estimation method because the absolute values of the kurtosis indexes are all smaller than 1.24, indicating that the data are normally distributed. The structural model provides an adequate fit to the data, where the model chi-square (χ^2) = 27.36, the degree of freedom (df) = 22, $\chi^2/df = 1.24$, the root mean square error of approximation (RMSEA) = 0.05, the comparative fit index (CFI) = 0.94, and the Tucker-Lewis index (TLI) = 0.90.

As seen in Figure 1, the path coefficients support all but the second hypothesis. Specifically, project stimulant factors positively affect the innovation capacity of capital projects (Hypothesis 1), and project innovation capacity positively affects the performance of capital projects (Hypothesis 3). On the other hand, the rejection of Hypothesis 2 suggests that stimulant factors of project innovation insignificantly affect the performance of capital projects. The test results suggest that project innovation capacity serves as a mediator between innovation stimulants and the performance of capital projects.

To confirm our findings, we compare the fit of our hypothesized model to the alternate model, where the direct path between innovation stimulant and project performance is deleted. The rationale behind this test is straightforward: the alternate model would result in a poorer fit to the data if stimulant factors have a direct impact on project performance.

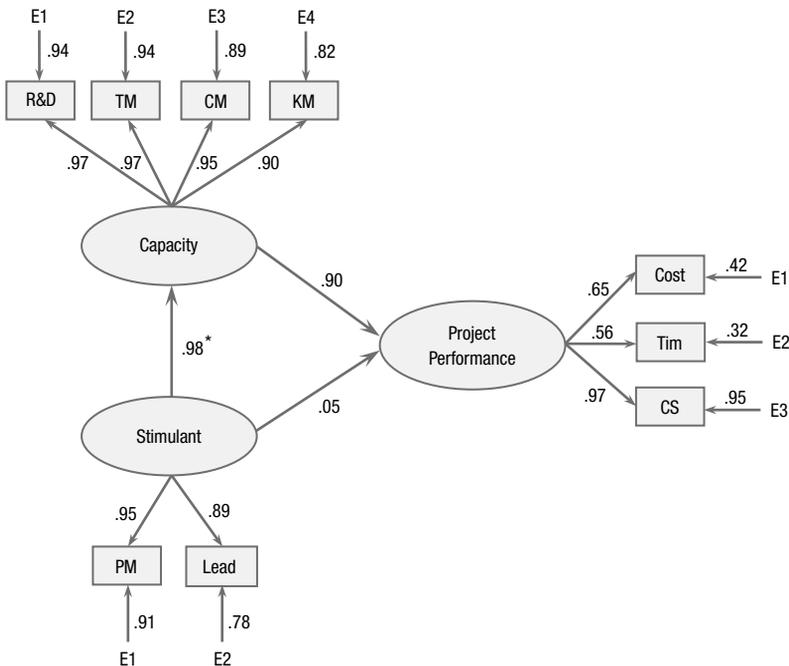


Fig. 1. Innovation's effects on the performance of capital projects

The alternate model exhibits an almost identical fit to the data, with $\chi^2 = 27.4$, $df = 23$, $\chi^2/df = 1.19$, RMSEA = 0.04, CFI = 0.95, and TLI = 0.92. This result suggests that deleting the path between stimulant and performance does not make our hypothesized model inferior and therefore verifies that innovation capacity mediates innovation stimulants and the performance of capital projects.

4.2. Model-building

As suggested, project innovation capacity (composed of *TM*, *KM*, *CM*, and *R&M*) significantly affects the performance of capital projects. Based on the results, this study conducts a series of hierarchical robust regression analyses using a maximum R-squared improvement procedure to develop optimal innovation-effect models from the estimation data of the 61 projects. Table 2 reports the model-building results.

As seen in the table, the optimal innovation-effect model at step 1 (Model 1) includes the *TM* variable and explains 31.78% of the variation in the *PP* data. At step 2, the optimal innovation effect model (Model 2) is composed of *TM* and *KM*, capable of explaining 33.91% of the variation in the *PP* data, which is 2.13% more than that of Model 1. The optimal models at steps 3 and 4 (Models 3 and 4) are composed of *TM*,

Table 2. Optimal innovation effect models created with robust regression analysis using a maximum R-squared improvement

Dependent variable: <i>PP</i>								
Variables	Model 1		Model 2		Model 3		Model 4	
	Coefficient	Chi-Square	Coefficient	Chi-Square	Coefficient	Chi-Square	Coefficient	Chi-Square
Step 1								
Intercept	0.46	0.22	0.36	0.14	0.35	0.12	0.37	0.71
<i>TM</i>	0.80	28.35 *	0.43	2.00	0.38	1.02	0.34	0.39
Step 2								
<i>KM</i>			0.38	1.80	0.37	1.65	0.26	0.48
Step 3								
<i>CM</i>					0.06	0.06	0.01	0.99
Step 4								
R&D							0.20	0.66
R^2 (%)	31.78		33.91		33.91		34.42	
Changes of R^2 (%)			2.13		0.00		0.51	
The White test	2.10		5.12		9.56		11.23	

Notes: * p < 0.05; ** p < .01; *** p < .001.

KM, and CM, and TM, KM, CM, and R&D, respectively. The corresponding R-squares of Models 3 and 4 are 33.91% and 34.42%, suggesting that Model 4 is the optimum model among Models 1 to 4.

The bottom of Table 2 shows the chi-square values of the White test (White 1980) for Models 1 to 4. The White test establishes whether the residual variance of a variable in a regression model is constant (homoscedasticity) or not (heteroskedasticity). Diagnostics for heteroskedasticity in regression models are essential because heteroskedasticity leads to inefficient parameter and covariance-matrix estimates. As seen in the table, the chi-square value for the White test of Model 4 is 11.23, and the associated *p*-value is larger than 0.05, suggesting the acceptance of the null hypothesis of no heteroskedasticity in the residuals at the 0.05 level.

Further, multicollinearity, in which two or more independent variables in a multivariate regression model are highly correlated, may impair the usefulness of the model's estimated parameters by inflating their variances (Freund, Wilson 1998). Hence, this study uses the eigenvalues (Freund, Wilson 1998), the variance of principal-component regression analysis, to determine if the effects of multicollinearity are present in the model.

The multicollinearity diagnostics of Model 4 are in the left-hand side Table 3, where the "Condition Number" column, the square root of the ratio of the largest to smallest eigenvalue, indicates the degree of near-linear dependencies. Eigenvalues have condition numbers larger than 30, and variables with variation proportions greater than 0.5 for each of these eigenvalues are involved in the near-linear dependency (Belsley *et al.* 1980). As seen in the table, although the KM and R&D variables of the fourth eigenvalue have respective variation proportions of 0.70 and 0.84, the fourth eigenvalue has a condition number of 7.33 – smaller than 30. Consequently, multicollinearity does not exist in the model.

Table 3. Multicollinearity diagnostics, Kolmogorov-Smirnov, and Mann-Whitney tests of Model 4^a

Multicollinearity Diagnostics							Kolmogorov-Smirnov and Mann-Whitney Tests					
Principal Component	Eigenvalue	Condition Number	Proportion of Variation				Source	Observation Number	Mean Rank	Kolmogorov-Smirnov	Sum of Ranks	Mann-Whitney U
			TM	KM	CM	R&D						
1	3.59	1.00	0.01	0.01	0.01	0.01	$\mu_{E PP-\hat{P}P}$	61	55.15	0.13*	3364.00	1473.00
2	0.23	3.92	0.01	0.23	0.55	0.01	$\mu_{OS PP-\hat{P}P}$	60	66.95	0.08	4017.00	
3	0.12	5.64	0.96	0.06	0.12	0.14						
4	0.07	7.33	0.027	0.70	0.32	0.84						

^a Model 4 = 0.37 + 0.34TM + 0.26KM + 0.01CM + 0.20R&D, where R² = 34.42%.

Notes: * *p* < 0.05; ** *p* < .01; *** *p* < .001.

4.3. Model validation

This study validates its optimal innovation-effect model (Model 4) using an out-of-sample test. We use Model 4 to estimate the performance of the 60 out-of-sample capital projects, which we then compare to the 60 projects’ actual performance. To determine conclusively whether Model 4 (developed from the estimation data for the 61 capital projects using the proposed estimation method) provides equal estimation power for the out-of-sample data, we form the hypothesis:

$$H_0: \mu_{E|PP-\hat{P}P} = \mu_{OS|PP-\hat{P}P},$$

$$H_a: \mu_{E|PP-\hat{P}P} \neq \mu_{OS|PP-\hat{P}P},$$

where $\mu_{E|PP-\hat{P}P}$ is the absolute average value of the differences between estimated and actual project performance for the 61 estimation projects, and $\mu_{OS|PP-\hat{P}P}$ is the absolute average value of the differences between estimated and actual project performance for the 60 out-of-sample projects.

The hypothesis examines whether a significant discrepancy exists in the mean value of the differences between the estimated and actual project performance of the 61 estimation projects and the 60 out-of-sample projects. If no significant discrepancy exists, we can confidently claim that our optimal innovation-effect model (Model 4) explains 34.42% of the variation in project performance.

The right-hand side of Table 3 shows the results of the Kolmogorov-Smirnov and Mann-Whitney tests. We use the Mann-Whitney test because the significant 0.13 value from the Kolmogorov-Smirnov sets suggests that the data sets of $\mu_{E|PP-\hat{P}P}$ are abnormally distributed. The sample data is also unpaired (there are 61 estimation projects versus 60 out-of-sample projects).

As the right-hand side of Table 3 shows, the Mann-Whitney U is 1473.00 and the associated *p*-value is larger than 0.05, confirming an insignificant discrepancy. We therefore accept the null hypothesis, implying that no significant discrepancy exists in the mean value of the differences between the estimated and actual project performance of the 61

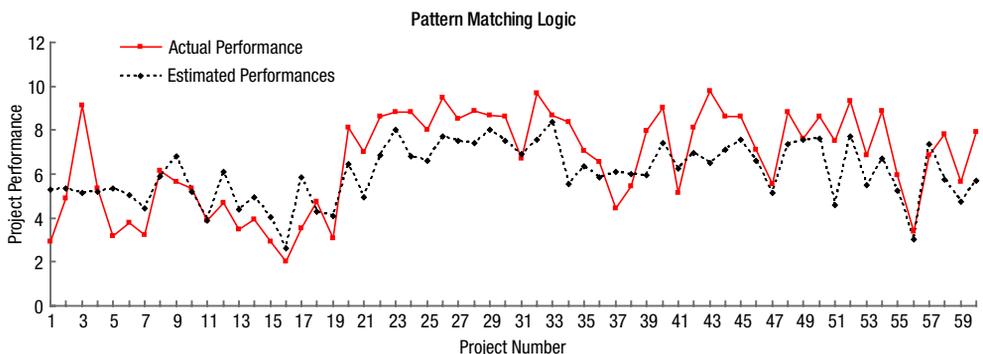


Fig. 2. Plots of the actual versus fitted values of Model 4 for the 60 out-of-sample projects

estimation projects and the 60 out-of-sample projects in the optimal innovation-effect model (Model 4). Figure 2 plots the actual project performance against the estimated project performance for the 60 out-of-sample projects in Model 4.

6. Discussions

This study examines and models the triangular relationships between innovation factors (stimulants and capacity) and the performance of capital projects. Drawing on the literature in innovation management (e.g., Adams *et al.* 2006; Jassawalla, Sashittal 2002; Prajogo, Ahmed 2006; Prajogo, Sohal 2006), we posit that innovation stimulants and capacity should not be examined in isolation when modeling the effects of innovation performance on the performance of capital projects.

The results of hypothesis tests show that project stimulant factors positively affect the innovation capacity of capital projects, and project innovation capacity positively affects the performance of capital projects. However, stimulant factors of project innovation insignificantly affect the performance of capital projects. In fact, drawing on the structural relationships shown in Figure 1, project innovation capacity serves as a mediator between innovation stimulants and the performance of capital projects. In other words, the stimulant factors do not have a direct impact on capital project performance but rather have an indirect impact realized through project innovation capacity.

Our test results reported here provide a comprehensive framework for analyzing the relationship between project practices and innovation performance. As mentioned, most prior research on project innovation focuses on examining the relationships between innovation capacity and stimulants, between innovation capacity and project performance, or between innovation stimulants and project performance. From a managerial perspective, constraining findings of one or another of these studies might be potentially misleading.

For example, based on the findings of the relationship between innovation capacity and project performance, this study quantifies the effects of innovation performance on project performance using a series of hierarchical robust regression analyses. The optimal innovation-effect model, composed of *TM*, *KM*, *CM*, and *R&D*, explains 34.42% of the variation in project performance. In other words, this model indicates that whilst a capital project may improve innovation by *TM*, *KM*, *CM*, and *R&D*, the innovation also improves the performance of the capital project by 34.42%. This indication may mistakenly suggest that having excellent technology, R&D, knowledge, and creativity management is sufficient for accomplishing high project performance.

In sum, our findings suggest that project innovation capacity positively affects the performance of capital projects, and project stimulant factors are fundamental enablers that affect innovation performance and, by extension, the performance of capital projects. Therefore, in order to create innovative projects, project leaders need to build project environments that foster leadership, team-building, communication, and a productive culture for innovation. Such environments provide momentum that motivates project team members to innovate. More important, such environments allow project-based organizations to leverage their innovative capacity to deliver innovative outcomes and project performance.

Conclusions

Extensive research in the innovation-management field examines and identifies a wide variety of measures that describe innovation outcomes and the inputs that affect those outcomes; however, relatively little research explores innovation from a project perspective. Although several published studies delineate the relationships between innovation and project performance, most studies concentrate on examining the relationships between innovation capacity and stimulants, between innovation capacity and project performance, or between innovation stimulants and project performance. Further, these studies primarily focus on NPD and R&D projects – despite the fact that the capital projects industry also contributes significantly to the growth of economy.

This study develops an innovation performance-measurement model for capital projects by incorporating technological factors (capacity) and human factors (stimulants). The results show that innovation capacity mediates the relationship between innovation stimulants and innovation performance (and thus, by extension, project performance) that is consistent with prior research at the firm level. This study reclassifies creativity and knowledge management into the technological aspect (capacity) and extends the findings to the project level.

This study performs hierarchical robust regression analyses using a maximum R-squared improvement procedure to develop optimal innovation-effect models that are based on capacity variables. Out-of-sample validation demonstrates that our optimal model explains 34.42% of the variation in project performance. This result in turn implies that as the innovation performance of a capital project improves, the project's performance improves by 34.42%.

In conclusion, this study clarifies and explains the relationship between the technological and human aspects of innovation performance at the project level, and it offers managers a practical way to measure the impact of project innovation performance on project performance. As an extension of this research, a study of the longitudinal relationships between project innovation and performance throughout the project-delivery process would benefit decision-making, management, and project control.

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