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Internal or External Knowledge: Which is More Important for the Performance of National Laboratories in Technology Latecomer Countries?

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Internal or External Knowledge: Which is More Important for the Performance of National Laboratories in Technology Latecomer Countries?

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Abstract—**The national laboratories in countries that are latecomers to advanced technological development are considered a significant source of scientific knowledge and technology for local industries that the national government deems strategic and for developing the country's infrastructure. This knowledge comes from both inside and outside the national laboratories. We investigate the relative impact of internal and external sources of knowledge on the performance of the national laboratories of a rapidly developing country, whose stated missions are 1) satisfying the needs of targeted local technology users; 2) commercialization of technology; and 3) developing a long-term R&D capability for the country. We conduct a survey-based study, which covers 208 recently completed R&D projects that span three industries: biotechnology; electronics and computers; materials and nano-materials. Our study finds that, regardless of mission, knowledge from external sources impacts performance more significantly than internal knowledge does. The impact on performance is greatest when knowledge from internal and external sources is used in conjunction. We consequently make the case for an open innovation policy for the national laboratories in technology latecomer countries and for implementing practices that enhance the capacity to absorb knowledge that flows into the national laboratories from external sources.**

I. INTRODUCTION

In most countries, the national laboratories are considered a significant source of scientific knowledge and technology for targeted local industries that the national government deems strategic and for local public agencies that are engaged in developing the country's infrastructure [1], [2]. In countries that are technological latecomers, [1] the national laboratories tend to lack the experience, expertise and financial resources to perform fundamental research, conduct and applied research and develop advanced technologies [3]-[5]. They consequently depend on external sources of knowledge much more than their counterparts in developed countries do [2], [6]-[12]. Knowledge from external sources has to be combined with knowledge that resides within the national laboratories for the national laboratories to perform the missions for which they were established. This mandate raises the following question of interest: Which is more important for the performance of national laboratories in technology latecomer countries—internal or external knowledge?

[1] According to Fagerberg and colleagues [3], technological latecomer countries such as Thailand, Indonesia, Chile and Pakistan are making efforts to advance both technologically and economically, but still lag behind countries such as South Korea, Taiwan and Singapore, which are approaching advanced stages of development.

II. BACKGROUND

The national laboratories in technology latecomer countries tend to pursue the following three missions that the government of these countries considers critical: 1) adopt and adapt technology for benefits local industry and public agencies that develop national infrastructure, *i.e.*, organizational entities that will henceforth be referred to as local technology users or LTUs [1], [2], [6]-[12]; 2) commercialize technology for financial benefit of the organizations within the national laboratories themselves [13]; and 3) retain and sustain technological capability to generate an experience base for the demands of the future of the country [2], [7]. To succeed at these three missions, the national laboratories need to deliver many successful R&D projects; engage with external sources of knowledge for acquiring new knowledge; as well as establish and strengthen internal R&D units or project groups as a source of internal knowledge that builds up team's capacity to absorb knowledge from outside the project group [14].

Knowledge that resides within the project group can be developed through deliberate project-internal learning activities *(PILAs)* [15]-[21] while the project is ongoing. Alternatively internal knowledge can be acquired by engaging in internal and external learning before the project begins. Such knowledge can be about the core technology to be developed in the project or about subject matter related to the context of the project [21]. Knowledge can also be brought into the project group by hiring [22] technical personnel that has extensive work experience pertaining to subject matter that is relevant to the project. Such experienced personnel can be "grafted" [22] from other R&D units *(ORDUs)* or project groups within the national laboratories, from local technology users or from foreign-owned firms.

Knowledge can flow into a project group within the national laboratories directly, if the project group engages in external learning (e.g., [23]) with a variety of sources. These include ORDUs from inside the national laboratories [23]; LTUs [25]; local universities [26]; and international sources of knowledge such as foreign-owned firms and foreign universities [26]. External learning activities come in one of two flavors: contextual or vicarious [23]. Contextual Learning Activities *(CLAs)* consist of scanning the environment for information and ideas about competitors, customers and technological trends [23]-[28]. They enable group members to enhance their awareness of current events that are taking place outside their organization. By contrast, Vicarious Learning Activities *(VLAs)* consist of group learning through which an organization acquires second-hand experience about its ongoing project from experienced outsiders [20], [23], [28]-[31].

While internal and external learning have been studied extensively and discussed in the academic literature (*e.g.*, [14]-[23], [28]-[31]), these phenomena have not been sufficiently investigated in the national laboratories of technology latecomer countries. Yet, it is in settings such as these that external and internal learning can have enormous practical impact because they directly influence national policy. In particular, policy makers in latecomer countries would want to know whether they should invest more in developing internal sources of knowledge or whether they should encourage engagement and new investment in external sources of knowledge to increase the performance of the national laboratories. This paper consequently addresses the following research question: What is the relative impact of internal and external knowledge on the performance of national laboratories in technology latecomer countries?

III. DESCRIPTION OF RESEARCH

To answer the research question from above, we performed an empirical study of external and internal learning in the national laboratories of a particular technology latecomer country, henceforth referred to as NLTLC. We chose NLTLC as a setting for this study because internal and external learning are observable at NLTLC and because achieving missions 1, 2 and 3 from above is stated policy at NLTLC. We conducted a survey of 128 R&D projects managers with the intent of identifying key factors related to external and internal knowledge and its impact on the performance of R&D projects. Thus, R&D projects within NLTLC are the unit of analysis of our study. Our total sample size was 208 R&D projects, which were completed in NLTLC less than two years before the survey was conducted. The survey covers three industries: biotechnology; electronics and computers; and materials and nano-materials. It was administered directly to project managers in a questionnaire. Due to strong support from the director of NLTLC and his executive team, we received a 100% response rate.

The survey contained questions and statements regarding input variables (IVs) and moderating variables (MVs). Input variables address knowledge inflows, whereas moderating variables pertain to knowledge that resides in or is generated within project groups. The project managers responded to questions regarding these variables on a 6-point Likert scale. Questions and statements pertaining to general information about NLTLC and output variables that assess the performance of projects were also included in the survey. They are detailed in tables in Appendix A.1 and Appendix A.2, respectively.

The output variable for mission 1 (OV1) measures the likelihood of doing another project with project group under study on a 6-point Likert scale. The lower sample size of 194 projects for OV1 results from respondents not being able to answer all questions in the survey. The output variable for mission 2 (OV2) is measured by the probability of commercializing a technology from a particular project. The output pertaining to mission 3, long-term R&D capability, is measured by using three criteria: 1) the probability of generating at least one publication from a particular project (OV3.1); 2) the probability of generating one item of intellectual property (patent or copyright) from the project (OV3.2); and 3) the versatility of technology developed as part of a project as measured by numbers of industry applications of that technology that the respondents could identify on a list (OV3.3) (see Appendix B).[2]

Appendixes A.3 and A.4 illustrate how the constructs under investigation relate to the codes for the input variables that were measured and the questions in the questionnaire to which they correspond. The table in Appendix A.3 details the constructs, the names of input variables and questions pertaining to contextual learning about other R&D units within the NLTLC; local universities; international sources of knowledge; and local technology users. Appendix A.4 details constructs, variables and questions pertaining to vicarious learning with the same entities.

Appendixes A.5, A.6 and A.7 illustrate how the constructs under investigation relate to the codes for the moderating variables that were measured and the questions in the questionnaire to which they correspond. The table in Appendix A.5 details the constructs, the names of moderating variables and questions pertaining to prior knowledge [22], i.e. knowledge that resided within the project group before the project began. The table in Appendix A.6 does likewise for project-internal learning activities (PILAs). Appendix A.7 covers the prior educational experience of team members, which could have been accumulated at foreign or domestic universities, as well as prior work experience [21], which could have been accrued abroad, at local technology users or at other R&D units within NLTLC.

Data analysis consisted of a factor analysis[3] followed by five multiple regression models[4] for each output variable. The factor analysis identified factors that pertained to NLTLC's

[2] Appendix B describes 25 potential choices of industry applications for OV3.3. The number of strategic programs in which the output of the project can be applied is translated into an ordinal scale that consists of the following six classes: 1 means the output could not be applied in any strategic program; 2 means the output could be applied in one strategic program; 3 means the output could be applied in two strategic programs, 4 means the output could be applied in three strategic programs, 5 means the output could be applied in 4 strategic programs, and 6 means the output could be applied in more than four strategic programs.

[3] Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser normalization.

[4] Stepwise backward was used for building regression models, because that approach "runs lower risk of missing a predictor that predicts the outcome than the forward method" ([32], pp. 160-161), and it works when there are many predictors in the model.

internal and external sources of knowledge. The five regression models assessed the relative impact of the factors on the performance of the national laboratories. Model 1, the knowledge inflow baseline, includes factors from outside the project group, only. Model 2.1, the project group baseline, contains factors from inside the project group, only. Model 2.2, the intra-organization baseline, includes factors from inside the national laboratories, i.e., project internal factors and factors pertaining to external learning from other R&D project groups. Model 3, the integrated model, covers all factors from model 1 and 2.1. Model 4, the interaction model, includes almost[5] all factors from model 1 and model 2, as well as their interactions.

The relative impact of internal knowledge and external knowledge on project performance was assessed by benchmarking the model's predictive power and the total variance that the different regression models explained. Benchmarking criteria include R^2, Adjusted R^2, and F-ratio for multiple regressions pertaining to OV1 and OV3.3. Logistic multiple regressions had to be run for OV2, OV3.1 and OV3.2, because these output variables were derived from binary data. The Cox & Snell R^2, the Nagelkerke's R^2, the Chi-Square and the percentage correct are used for benchmarking the variance explained by and the prediction power of these regressions.

IV. RESULTS

The factor analysis has identified 17 factors, which include all input variables and moderating variables under study (see Appendix C and Appendix D). (The label FIV is assigned to factors composed of input variables; the label MIV is assigned to factors composed of moderating variables.) The factors are orthogonal, so multi-collinearity problems (described in [32]) did not occur in the regressions that were subsequently performed. Cumulatively, the 17 factors explain 90% of the variance. The constructs of the first 11 factors are reliable, with Cronbach's alpha always being greater than 0.7. The last six factors report no Cronbach's alpha since they are individual variables.

The factor analysis could not identify a truly dominant factor or small group of factors that explain most of the variation. PILA is the most significant factor; the next five factors pertain to vicarious learning activity. The vicarious learning factors are followed by a group of five factors that are either associated with contextual learning or prior knowledge about the subject matter. The list of factors is closed out by six single variables that are either associated with prior experience of various kinds or prior knowledge about the core technology that is under development.

Table 1 displays the results of the regression exercise. It shows that the five output variables have different predictive power and explanatory power, and that the regression models that include knowledge inflows tend to have greater explanatory power than the ones that do not. Output variable OV3.2—the probability of generating at least one patent from a project—clearly has the lowest predictive power of all five output variables. The Cox & Snell R^2 and the Nagelkerke's R^2 are below 0.2 for models 1 through 4, meaning that these models cannot explain 20% of the variance. In model 1, the Chi-Square is not significant at the level of $p<0.05$. The remaining output variables -- OV1, OV2, OV3.1 and OV3.3 -- have a relatively high explanatory power for models that involve knowledge inflow. However, models 2.1 and 2.2, which exclude all factors that are exogenous to the national laboratories, have a significantly lower explanatory power. When compared to model 1, models 2.1 and 2.2 are particularly weak indicators of user satisfaction, probability of commercialization and probability of publication.

Not surprisingly, the explanatory power of the regression models increases as more variables are added. However, the differences in explanatory powers vary significantly from model to model. Model 3, the integrated model, has a much greater explanatory power than models 1, 2.1 and 2.2; model 4, the interaction model, has a slightly greater explanatory power than model 3. It should also be noted that for output variables OV1, OV2, OV3.1 and OV3.3, model 2.2, the intra-organization baseline, does not show much of an improvement over model 2.1, the project group baseline. Evidently, including knowledge inflows from other R&D project groups in a regression model does not significantly increase the explanatory power of the model.

V. CONCLUSIONS AND DISCUSSION

The empirical study that has been described in this paper finds that, regardless of mission, knowledge from external sources impacts performance more significantly than internal knowledge does. The impact on performance is greatest when knowledge from internal and external sources is used in conjunction. We consequently try to make the case for an open innovation policy [15] for the national laboratories in technology latecomer countries and for implementing practices that enhance the capacity to absorb knowledge [14] that flows into the national laboratories from external sources. We find that our study has normative implications for management practice, which are denoted below.

Firstly, the factor analysis shows that, regardless of knowledge source, vicarious learning activities explain more of the observed variance than contextual learning activities. This implies that the national laboratories could benefit from implementing programs that enhance the ability of individual R&D project groups to learn vicariously, i.e., to engage in face-to-face meetings and develop personal relationships with personnel outside the group.

[5] The interaction model does not cover FIV8, contextual learning about other R&D project groups within the national laboratories; FMV6, prior education at local universities; and FMV7, prior education at foreign universities.

TABLE 1. SUMMARY OF PREDICTIVE POWER OF MODELS 1, 2.1, 2.2, 3 AND 4.

Criteria	Model 1. Knowledge Inflow Baseline	Model 2.1. Project Group Baseline	Model 2.2. Intra-Organization Baseline	Model 3. Integrated Model	Model 4. Interaction Model
Mission-1: User Satisfaction					
R^2	.469	.069	.069	.571	.703
R^2 adjust	.458	.059	.059	.550	.665
F	41.705***	7.042**	7.042**	27.175***	18.385***
No.	193	193	193	193	193
?R^2 adjust (based on model '2.1')	-	-	0.000	0.491	0.606
Mission-2: Probability of Commercializing a Technology					
Cox & Snell R^2	0.384	0.102	.133	0.485	.604
Nagelkerke's R^2	0.512	0.136	.177	0.648	.807
Chi-square	100.728***	22.419***	29.568***	138.714***	192.909***
Percentage correct	80.3	66.3	69.7	86.1	92.3
No.	208	208	208	208	208
?Cox & Snell R^2 (based on model '2.1')	-	-	0.031	0.383	0.502
?Nagelkerke ^{2} (based on model '2.1')	-	-	0.041	0.512	0.671
Mission-3.1: Probability of Generating a Publication					
Cox & Snell R^2	0.236	0.115	.141	0.338	0.447
Nagelkerke's R^2	0.329	0.161	.197	0.472	0.625
Chi-square	55.922***	25.390***	31.553***	85.665***	123.321***
Percentage correct	78.8	73.1	74	81.3	86.1
No.	208	208	208	208	208
?Cox & Snell R^2 (based on model '2.1')	-	-	0.026	0.223	0.332
?Nagelkerke ^{2} (based on model '2.1')	-	-	0.036	0.311	0.464
Mission-3.2: Probability of Generating a Patent					
Cox & Snell R^2	.015	.048	.061	.075	0.237
Nagelkerke's R^2	.020	.065	.083	.102	0.323
Chi-square	3.041	10.199**	13.044**	16.167**	56.182***
Percentage correct	62.5	65.9	63.9	63.9	72.1
No.	208	208	208	208	208
?Cox & Snell R^2 (based on model '2.1')	-	-	0.013	0.027	0.189
?Nagelkerke ^{2} (based on model '2.1')	-	-	0.018	0.037	0.258
Mission-3.3: Versatility of Technology					
R^2	.091	.058	.102	.149	0.311
R^2 adjust	.073	.048	.085	.123	0.25
F	5.099**	6.256**	5.777***	5.857***	5.056***
No.	207	207	207	207	207
?R^2 adjust (based on model '2.1')	-	-	0.037	0.075	0.202

*** Significant at the $p<0.001$ level (2-tailed).
** Significant at the $p<0.01$ level (2-tailed).
* Significant at the $p<0.05$ level (2-tailed).
Please note that '?R^2 adjust', '?Cox & Snell R^2' and '?Nagelkerke R^2' respectively denote the differences between models 4, 3 and 2.2, on the one hand and model 2.1, on the other hand, for the parameters 'R^2 adjust', 'Cox & Snell R^2' and 'Nagelkerke R^2'.

Secondly, our study has shown that the probability of generating a patent (OV3.2) lacks explanatory power, which suggests that patenting is not a strong function of knowledge inflows. Other factors (perhaps economic incentives) drive the generation of a patent. These factors need to be identified and harnessed, if the national laboratories want to make the ability to generate patents a key component of the experience base that responds to the demands of the future of the country.

More importantly, our study finds that the differential in explanatory power between knowledge inflow baseline (model 1) and the project group baseline (model 2.1) was much greater than the one that was observed between the intra-organization baseline (model 2.2) and the project group baseline. This observation suggests that performance (as measured by user satisfaction, success at commercialization, the propensity for publication and versatility of technology) depends significantly more on knowledge inflow into the national laboratories [15], [26] than on knowledge exchanges between project groups within the national laboratories [24], [28]-[31]. This implies that the impact of collaborative efforts between R&D project groups within the national laboratories on the performance of these groups is limited. The national laboratories under study must manage inflows from exogenous sources of knowledge to achieve significant improvements in performance.

It should be noted that the above differential in explanatory power was observed with statistical significance in all three industries under study. This suggests that the results from above may be generalizable across many industries.

Finally, the large differential between the integrated model and the interaction model on the one hand, and the baseline models on the other hand imply synergy between knowledge inflows and internal knowledge. As theory would predict [14], [33], related internal knowledge increases the capacity to absorb knowledge from the outside. The project groups within the national laboratories are thus well advised to accumulate relevant knowledge prior to the beginning of a project [21], hire ("graft") personnel with relevant knowledge [22], and engage in organizational learning activities within the project group [15]-[19].

Prior knowledge is an internal factor that tends to impact the relationship between knowledge inflows and organizational performance ([14], [34]-[38]). Prior knowledge includes "basic skills, a shared language, and knowledge of the most recent scientific or technological developments in a given field" ([14], p. 131). Grafting on new members is a process through which an organization can rapidly gain new knowledge that has not been previously available within the organization. It primarily consists of moving people with relevant knowledge, experience and expertise from one organization or project group to another and integrating them into the project group [22]. These people could come from abroad [39]-[43], from inside the country but outside the organization [22] or from within the organization but outside the project group [44]. Project internal learning activities help project group members learn from experience as they execute their own projects [23], [45], [46]. The activities typically include "asking questions, seeking feedback, sharing information, experimenting, and talking about errors" [23, p. 82]. PILAs also play an important role for project members to absorb external knowledge that they have gained from technology gatekeepers. These employees interact extensively with individuals and organizations outside their own [47], [48]. They consequently bring technology into an organization from the outside.

The study that has been described in this paper is subject to a few limitations that can be overcome by follow-on research. Firstly, the study investigated the relative impact of knowledge inflows and internal knowledge as a whole on the performance of R&D project groups. It differentiates between the various sources of knowledge, but it does not determine how knowledge from particular sources affects the different criteria that have been established in this study. This limitation can be overcome extracting more data from the five regression models that have been run for this study. Secondly, this study is limited by the fact that it was conducted at the national laboratories of only one country, a latecomer to advanced technology. If the study were repeated in the national laboratories of other technology latecomer countries with similar results, then the results of this study may be generalizable to the national laboratories of other countries at similar levels of development. The study's generalizability could be enhanced even further, if the study were repeated at corporate laboratories and in the national laboratories of a variety of countries at different levels of technological development.

Conducting the follow-on research described in the previous paragraph may lead to significant contributions to theory. First and foremost, performing the recommended follow-on studies would characterize the impact of different forms of internal knowledge on the capacity to absorptive external knowledge from a variety of sources, which would contribute to an improved theoretical understanding of the absorptive capacity phenomenon. The follow-on research from above could also produce empirically grounded theory of how knowledge flows through national innovation systems and enhance the theoretical understanding of the role that the national laboratories play within their national innovation systems.

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APPENDIXES

Appendix A.1: General information about projects in the national laboratories

	Code	N	Questions' order in questionnaire
Project ID	Project ID		
Basic research	Basic_stg.	208	Q.1 R&D strategy: Please classify the project by stage of technological development by using the definitions from below.
Applied research	App_stg.	208	
Development and demonstration	DD_stg.	208	
Bio technology	Bio_tech.	208	Q.2 Please classify the project by technology type.
Material and Nano technology	MN_tech.	208	
Embedded and software technology	ES_tech.	208	
Number of project group members	NO_mem	208	Q.4 Number of full-time members working on this project
Number of PhD in project group	NO_PhD	208	Q.5 Number of full-time members working on this project with Ph.D. as the highest degree
Number of MSc in project group	NO_MSc	208	Q.6 Number of full-time members working on this project with Masters as the highest degree

Appendix A.2: Questions Pertaining to Output Variables

	Code	N	Questions' order in questionnaire
Mission 1: User Satisfaction	OV1_Sat_LTUs	194	Q.39 Based on the results of this project, do you think that the targeted customers of this project will have another collaborative project with your project group in the near future?
Mission 2: Probability of Commercialization of Technology	OV2_Prob_Rev	208	Q.40 Is there any income (in kind and in cash) expected to result from this project? Please estimate expected income of this project.
Mission 3.1: Probability of Generating Publication	OV3_1Prob_JrPub	208	Q.41 Are there any publications expected to result from this project? Please estimate the number of publications 41.1 Publications in journals with impact factor higher than 10 41.2 Publications in journals with impact factor higher than 2 41.3 Publications in journals with citation index 41.4 Proceeding in international conference 41.5 Proceeding in domestic conference 41.6 Book 41.7 Other, please identify ....
Mission 3.2: Probability of Generating Intellectual Property	OV3_2Prob_Patent	208	Q.42 Are there any patents expected to result from this project? Please estimate the number of patents that is expected to result
Mission 3.3: Versatility of Technololgy	OV3_3Ver_Tech	208	Q.3 Please identify as much as possible the strategic programs of NLTLC in which the output of this project can be applied.

Appendix A.3: Questions Pertaining to Contextual Learning Activities [22] (Input Variables)

	Code	N	Questions' order in questionnaire
Contextual learning with other R&D units 1	IV1_ORDU_CLA1	208	Q.11 At least some members of our project group looked for technical ideas in internal reports inside NLTLC.
Contextual learning with local universities 1	IV2_LocUniv_CLA1	208	Q.12 At least some members of our project group looked for technical ideas in papers, reports and websites published by universities inside the country.
Contextual learning with inter sources 1	IV3_InatSrc_CLA1	208	Q.13 At least some members of our project group looked for technical ideas in papers, reports and websites that were published by foreign universities and foreign-owned companies.
Contextual learning with technology users 1	IV4_LTUs_CLA1	208	Q.14 To understand the needs of our targeted customers, at least some members of our project group looked for technical requirements in industry newsletters, bulletins, websites and trade
Contextual learning with other R&D units 2	IV5_ORDU_CLA2	208	Q.15 At least some members of our project group looked for data on what other teams inside NLTLC were doing on similar or complementary projects.
Contextual learning with local universities 2	IV6_LocUniv_CLA2	208	Q.16 At least some members of our project group looked for data on what other teams at universities inside the country were doing on similar or complementary projects.
Contextual learning with inter sources 2	IV7_InatSrc_CLA2	208	Q.17 At least some members of our project group looked for data on what other teams at foreign universities and foreign-owned companies were doing on similar or complementary projects.
Contextual learning with technology users 2	IV8_LTUs_CLA2	208	Q.18 At least some members of our project group looked for data on what our targeted customers were doing on similar or complementary projects.

Appendix A.4: Questions Pertaining to Vicarious Learning Activities [22] (Input Variables)

	Code	N	Questions' order in questionnaire
Vicarious learning with other R&D units 1	IV9_ORDU_VLA1	208	Q.19 Experts within NLTLC talked to our project group about the lessons learned from their past experiences.
Vicarious learning with local universities 1	IV10_LocUniv_VLA1	208	Q.20 Experts from universities inside the country talked to our project group about the lessons learned from their past
Vicarious learning with inter sources 1	IV11_InatSrc_VLA1	208	Q.21 Experts from foreign universities and foreign-owned companies talked to our project group about the lessons learned from their past experiences.
Vicarious learning with production units 1	IV12_LTUsPU_VLA1	208	Q.22 Our targeted customers who have production units talked to our project group about how to develop technology that is suitable for their requirements.
Vicarious learning within end users 1	IV13_LTUsEU_VLA1	208	Q.23 Our targeted customers who are end users talked to our project group about how to develop technology that is suitable for their requirements.
Vicarious learning with other R&D units 2	IV14_ORDU_VLA2	208	Q.24 At least some members of our project group talked to experts within NLTLC about lessons learned from our past experiences.
Vicarious learning with local universities 2	IV15_LocUniv_VLA2	208	Q.25 At least some members of our project group talked to experts within universities inside the country about lessons learned from our past experiences.
Vicarious learning with inter sources 2	IV16_InatSrc_VLA2	208	Q.26 At least some members of our project group talked to experts from foreign universities and foreign-owned companies about lessons learned from our past experiences.
Vicarious learning with production units 2	IV17_LTUsPU_VLA2	208	Q.27 At least some members of our project group talked to our targeted customers who have production units to determine ways to improve our project.
Vicarious learning with end users 2	IV18_LTUsEU_VLA2	208	Q.28 At least some members of our project group talked to our targeted customers who are end users to determine ways to

Please note that we observed two forms of vicarious learning with local technology users. One form involved LTUs that owned production units (PUs). The other form of LTU consisted of end users (EUs) without production units.

Appendix A.5: Questions Pertaining to Prior Knowledge [21] (Moderating Variables)

	Code	N	Questions' order in questionnaire
Prior knowledge in core technology	MV1_PreKn_Core	208	Q.7 How long was your group developing technology that is directly relevant or useful to this project?
Prior knowledge in journal publications	MV2_PreKn_Jr	208	Q.8 How many journal publications that were directly relevant or useful to this project did your project group generate before this
Prior knowledge in patents	MV4_PreKn_Pat	208	Q.10 How many patents that were directly relevant or useful to this project did your project group generate before this project began?
Prior knowledge level of project group	MV14_PreKn_Lev	208	Q.38 Prior to the start of our project, our project group generated a lot of patents and publications that are relevant to this project.

Appendix A.6: Questions Pertaining to Project-Internal Learning Activities [14]-[18] (Moderating Variables)

	Code	N	Questions' order in questionnaire
Project-internal learning activity 1	MV5_PILA1	208	Q.29 Our project group took time to figure out ways to improve our work process.
Project-internal learning activity 2	MV6_PILA2	208	Q.30 Our project group took time to monitor our project's work progress.
Project-internal learning activity 3	MV7_PILA3	208	Q.31 Individuals within our project group spoke up to challenge technical assumptions concerning issues that were under discussion among members of our project group.
Project-internal learning activity 4	MV8_PILA4	208	Q.32 The project group implemented suggestions made by team members.

Appendix A.7: Questions Pertaining to Prior Experience [20] (Moderating Variables)

	Code	N	Questions' order in questionnaire
Prior experience in education from international sources of knowledge	MV9_PrExp_ Ed_InatSrc	208	Q.33 At least one of our project group members has had very extensive educational experience at a foreign university on subject matter that is relevant to this project.
Prior experience in education from local sources of knowledge	MV10_PrExp_ Ed_ LocUniv	208	Q.34 At least one of our project group members had very extensive educational experience at a domestic university on subject matter that is relevant to this project.
Prior experience in working from international sources of knowledge	MV11_PrExp_ Wk_ InatSrc	208	Q.35 At least one of our project group members had very extensive working experience abroad on subject matter that relevant to this
Prior experience in working with local technology users	MV12_PrExp_ Wk_ LTUs	208	Q.36 At least one of our project group members had very extensive working experience with our targeted customers on subject matter that is relevant to this project.
Prior experience in working with other R&D units	MV13_PrExp_ Wk_ ORDU	208	Q.37 At least one of our project group members had very extensive working experience with other projects within NLTLC on subject matter that is relevant to this project.

Appendix B: Versatility of Technology

Question Q3 asks the following of the responding project manager: "To which of the following government-supported programs could the technology that is under development in your project group be applied?"

a. The Rice Program
b. The Tapioca Program
c. The Rubber Program
d. The Seed Program
e. The Plants for the Future Program
f. The Animal Production and Animal Health Program
g. The Food Innovation Program

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h. The Newly Emerging Disease - Re-emerging Disease Program
i. Preventive, predictive and personalized medicine
j. Healthcare practice and medical devices
k. The Genotype Technology Program
l. Assistive Devices and Technologies for People with Disabilities and The Elderly Program

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m. The Sustainable Environment Program
n. The Resource and Energy Efficiency Program
o. The Renewable Energy and New Technology Research Program
p. The Technology for Rural Development Program
q. The Bio-resources Program

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r. The Hard Disk Drive Industry Research Program
s. The Air-conditioning and Refrigerator Industry Program
t. The Automotive and Automotive Parts Industry Program

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u. Digital engineering
v. Sensor and intelligent system
w. Functional materials
x. Service research and innovation
y. Other (please identify) …………………………………………………

Appendix C: Factor Analysis and Cumulative Variance Explained

Factor Analysis and Total Variance Explained

Factor #	Initial Eigenvalues: % of Variance	Initial Eigenvalues: Cumula-tive %	Rotation Sums of Squared Loadings: % of Variance	Rotation Sums of Squared Loadings: Cumula-tive %	Factors of moderating variables (FMV)/ Factors of independent variables (FIV)	Description	Cronbach's Alpha
1	16.212	16.212	10.383	10.383	[FMV1_PILAs]	FMV1: Project internal learning activities	(α = .887)
2	14.298	30.510	7.005	17.389	[FIV1_LTUsPU_VLAs]	FIV1: Engage with LTUsPU via VLAs	(α = .946)
3	11.461	41.972	6.678	24.067	[FIV2_InatSrc_VLAs]	FIV2: Engage with InatSrc via VLAs	(α = .859)
4	7.003	48.975	6.525	30.592	[FIV3_LocUniv_VLAs]	FIV3: Engage with LocUniv via VLAs	(α = .891)
5	6.306	55.281	6.445	37.037	[FIV4_LTUsEU_VLAs]	FIV4: Engage with LTUsEU via VLAs	(α = .916)
6	5.325	60.605	6.435	43.473	[FIV5_ORDU_VLAs]	FIV5: Engagement with ORDU via VLAs	(α = .867)
7	4.535	65.140	5.827	49.299	[FIV6_InatSrc_CLAs]	FIV6: Engage with InatSrc via CLAs	(α = .816)
8	4.091	69.231	5.743	55.043	[FMV2_PrKn_PJ]	FMV2: Prior knowledge about the subject matter pertaining to the project	(α = .773)
9	3.358	72.590	5.295	60.337	[FIV7_LTUs_CLAs]	FIV7: Engage with LTUs CLAs	(α = .769)
10	3.184	75.774	5.215	65.553	[FIV8_ORDU_CLAs]	FIV8: Engagement with ORDU_CLAs	(α = .760)
11	2.866	78.640	5.061	70.613	[FIV9_LocUniv_CLAs]	FIV9: Engage with LocUniv via CLAs	(α = .723)
12	2.336	80.976	3.587	74.200	[FMV3_PrExp_Wk_LTUs]	FMV3: Prior experience in working with local technology users	-
13	2.225	83.201	3.504	77.704	[FMV4_PrExp_Wk_ORDU]	FMV4: Prior experience in working with other R&D units	-
14	1.983	85.184	3.353	81.057	[FMV5_PrKn_Core]	FMV5: Prior knowledge in core technology	-
15	1.832	87.016	3.322	84.379	[FMV6_PrExp_Ed_LocUniv]	FMV6: Prior experience in education from local sources of knowledge	-
16	1.668	88.684	3.287	87.666	[FMV7_PrExp_Ed_InatSrc]	FMV7: Prior experience in education from international sources of knowledge	-
17	1.494	90.178	2.042	89.708	[FMV8_PrExp_Wk_InatSrc]	FMV8: Prior experience in working at international sources of knowledge	-

Appendix D: How Variables Map onto Factors

Factors	FMV1	FIV1	FIV2	FIV3	FIV4	FIV5	FIV6	FMV2	FIV7	FIV8	FIV9	FMV3	FMV4	FMV5	FMV6	FMV7	FMV8
Cronbach's Alpha	0.887	0.946	0.859	0.891	0.916	0.867	0.816	0.773	0.769	0.76	0.723	-	-	-	-	-	-
Descriptive statistics: Min	-2.442	-2.129	-1.680	-1.826	-2.073	-1.736	-3.210	-1.639	-2.762	-2.330	-2.032	-2.096	-2.133	-2.767	-3.720	-2.793	-2.969
Descriptive statistics: Max	2.341	2.386	2.928	3.046	2.488	3.260	2.175	2.393	2.569	3.947	3.939	2.247	2.502	1.697	1.990	1.686	3.082
Variables:																	
MV7_PILA3	.899																
MV8_PILA4	.847																
MV5_PILA1	.805																
MV6_PILA2	.793																
IV12_LTUsPU_VLA1		.909															
IV17_LTUsPU_VLA2		.892															
IV16_InatSrc_VLA2			.884														
IV11_InatSrc_VLA1			.883														
IV10_LocUniv_VLA1				.907													
IV15_LocUniv_VLA2				.906													
IV13_LTUsEU_VLA1					.903												
IV18_LTUsEU_VLA2					.892												
IV14_ORDU_VLA2						.897											
IV9_ORDU_VLA1						.872											
IV3_InatSrc_CLA1							.895										
IV7_InatSrc_CLA2							.846										
MV2_PrKn_Jr								.860									
MV14_PrKn_Lev								.852									
IV4_LTUs_CLA1									.875								
IV8_LTUs_CLA2									.761								
IV1_ORDU_CLA1										.883							
IV5_ORDU_CLA2										.743							
IV2_LocUniv_CLA1											.891						
IV6_LocUniv_CLA2											.740						
MV12_PrExp_ Wk_ LTUs												.852					
MV13_PrExp_ Wk_ ORDU													.905				
MV1_PrKn_Core														.906			
MV10_PrExp_ Ed_ LocUniv															.928		
MV9_PrExp_ Ed_InatSrc																.889	
MV11_PrExp_ Wk_ InatSrc			.439														.503
% of Total Variance	10.383	7.005	6.678	6.525	6.445	6.435	5.827	5.743	5.295	5.215	5.061	3.587	3.504	3.353	3.322	3.287	2.042
Cumulative % of Variance	10.383	17.389	24.067	30.592	37.037	43.473	49.299	55.043	60.337	65.553	70.613	74.200	77.704	81.057	84.379	87.666	89.708
Extraction Method: Principal Component Analysis.					Rotation Method: Varimax with Kaiser Normalization.												