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Identifying the Barriers in Government Infrastructure through Assessing Quantitative Impact of Taiwan's PIE

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Introduction

Utilization of evaluation results in further policy making has long been underscored regarding formatively improvement of STI programs where the iterative information generated through the interactions among multiple domain users can navigate the uncharted waters of technology trajectory (Scheirer, 2012; Glasgow et al., 2014; Howell & Yemane, 2006; Jordan, 2015). However, it poses daunting challenge to evaluation designs which takes into account of available evaluation results and data to assure the causal attribution and managerial utilization. With the logic model, the evaluability assessment employed by many STI funding agencies (e.g., NIH, DOE, etc.) can assure the readiness of summative impact assessment and the alignment of the monitoring indicators with the managerial needs with logic model to guarantee the utilization of evaluation results before designing the impact evaluation. In this study, we first utilized the logic model to conduct the evaluability assessment to inform the evaluation design. The summative impact assessment cannot inform the further policy making regarding programs improvement without preceding formative impact evaluation addressing the descriptive model (change model) and formative process evaluations addressing prescriptive model (implementation model) (Trevisan & Walser, 2015). Against the context of PIE, the absence of adequate ex-ante assessment to inform the program planning and project selection identifying the needs of STI policy interventions requires the qualitative process evaluation and quantitative assessment of project addtionality through survey on PIE's participant firms. Furthermore, the reported quantitative performance data (e.g., royalty revenue, licensing revenue, etc.) by the PIE's participant firms cannot substantiate the counterfactual impact of PIE; instead, combining the summative impact assessment and qualitative process evaluation, the reported quantitative performance data can be the evidence of "goal displacement" effect of the existing monitoring indicators of PIE.

Secondly, we utilized the generic logic model developed by DOE to inform the design of our process evaluation.

Combining “Idea Innovation Network Theory” (Hague & Hollingsworth, 2000) underlying the supply-side model components (e.g., six kinds of researches, and agenda setting, and so forth) (Jordan, 2010), and Rogers’ diffusion theory underlying the demand-side model components (e.g., business infrastructure, information infrastructure, and government infrastructure shaping the policies or programs) (Jordan, 2010), DOE’s high-level generic logic model enables us to identify the bottlenecks in the government infrastructure shaping the emerging technology trajectory. The qualitative process evaluation can be informed by assessing how the feedback loop of formative program evaluation might be systematically obstructed by the institutional context of Taiwan’s STI policy formation even with formative evaluation results. Therefore, the pressing institutional issues such as insufficient utilization of reported quantitative performance data and evaluation results in program planning and management due to funding agencies’ inadequate evaluation capacities and managerial capabilities need to be addressed. By doing so, the misleading “goal displacement” effect of PIE’s existing monitoring indicators can be identified and formatively addressed.

This evaluation research is designed to first identify the discrepancy between the available reported outcome data regarding the PIE (e.g., new products and new processes, technology license royalties, etc.) and the assessment results regarding output additionality through triangulation. Besides, we positively measure the behavioral additionality and project additionality by means of econometric methods, and then explore the institutional causes embedded in funding agencies’ program planning /implementation /evaluation practices.

To evaluate the necessity of the PIE’s program interventions based on market-failure and system-failure policy rationale, we summatively measured the input additionality, output additionality, and behavioural additionality (including the project additionality).

The targeted Program of Intelligent Electronics program is a technology extension program comprising R&D subsidization, technology services, and personnel training. Instead of taking the science-based linear innovation policy intervention rationales, governmental interventions increasingly emphasize facilitating the non-linear and endogenous impact such as enabling the firms to create network linkages, new technology adoption and diffusion through the intertwined program activities such as R&D, training, and technology services. Given that organizational innovation, information, and human capital can give rise to firms’ absorptive abilities in terms of technology diffusion theories (Arvanitis et al., 2002; Tasse, 1997), OECD countries try to focus on the program activities such as training and guidance to facilitate the technology diffusion. Accordingly, in addition to the product innovation and process innovation, the organizational innovation and marketing innovation are emphasized in science metrics as well (OECD, 2005; Georghiou, 1998). Some researches which measure the intermediate impact such as new technology adoption, production cost reduction, and additional benefits of the technology extension program in addition to the measurement of firms’ output (Oldsman, 1996; Jarmin & Jensen, 2011). Likewise, BETA method measured the technology effect, commercial effect, organization and method effect, and capability and training effect comprising impact on organization and network linkage, firm capability (e.g.: human capital), production cost, etc (Bach et al., 2003).

The objective of this study is to summatively investigate the empirical evidence of the impact of program intervention on firm-centric input additionality, output additionality (employment, productivity, and firm’s profit growth) and intermediate behavioural additionality. And then, we compared the results of output additionality with the reported quantitative data of PIE through triangulation.

Therefore, this study first simultaneously assessed the output additionality combining the DID regression and Matching Method to exclude the non-program influence stemming from the observed and unobserved variable to determine whether the program treatment

significantly contribute to the output additionality of the participant firms. Given that the patent output has less to do with firm's profit and added values (Lohmann, 2014), our study chose to measure the output additionality of PIE utilizing the indicators including "Net revenue", "Employee size", "Net profit", and "Productivity", taking into account of the practices of several researches (Oldsman, 1996; Jarmin & Jensen, 2011; Link & Scott, 2012; Link & Scott, 2013).

Secondly, regarding the impact assessment of intermediate impact on participant firms, this study chose to measure those behavioural additionality including "Creating inter-organizational linkages", "Improving quality or sale of products and processes", "Enhancing R&D or innovation capacities", "Enhancing capability of commercializing technologies", "Enhancing technological expertise of employees", "Increasing employment of high-quality personnel", "Reducing R&D/production/operation cost", "Broadening the scope of R&D", and "Facilitating technology adoption" through retrospectively surveying the participant firms of three kinds of program activities simultaneously by the Likert scale as Arvanitis et. al. (2002) did, instead of objectively measuring the program treatment intensity (Oldsman, 1996; Jarmin & Jensen, 2011).

Thirdly, with respect to the R&D subsidization, since the intervention must be justified by the underinvestment of R&D investment due to appropriability problem and time horizon (Gomper & Lerner, 1999), the impact measurement should enable the participant firms to define and address the market-failure or system-failure of status quo, re-orienting the program towards more promising impact (Link & Scott, 2013). Therefore, the input additionality and project additionality measurement in this study are aimed at assessing whether or not the R&D subsidy increase the R&D activities and investment (Georghiou, 2004, Lohmann, 2014). Besides, the R&D subsidy program can be justified by the behavioural additionality such as "acceleration additionality", and "scale and scope additionality" (Lohmann, 2014). Accordingly, we separately assess the impact of PIE on subsidized firms in terms of input additionality (increased R&D intensity), project additionality, scope additionality, and acceleration additionality.

Finally, we tried to interpret the policy implications of results yielded by our econometric impact assessment against the backdrop of Taiwan's institutional context concerning the STI program planning processes.

Methods

This study combined the quantitative impact assessment with qualitative process evaluations concerning the program planning and project selection processes. Concerning the output additionality data, we use the secondary data maintained by the private survey company. With respect to the measurement of behavioural additionality, we collected the behavioural additionalities including capacity and capability enhancement, linkages creation, R&D acceleration, scope additionality, project additionality (would not have conducted the R&D project absent PIE's R&D subsidies), etc.

When assessing the output additionality of PIE, we combined the DID with Matching Method (exact matching) to exclude the specific firm characteristic variables (related to selection bias) and unobserved variables (Caliendo & Kopeinig, 2008; DIDE-CUMSPH, 2013). We employ the DID regression method to examine the causal relationship (Dimick & Ryan, 2014; DIDE-CUMSPH, 2013) and use semi-parametric DID to determine the average effect of program intervention on the treated firms (Houngbedji, 2015).

We surveyed 75 funded firms and 75 matching non-treated firms in pre- and post-time periods by questionnaires including output additionality (characteristics, Table 1) and intermediate behavioural additionality (the stimulus in training, outreach service, and R&D activity, Table 3 & 4). Due to business confidentiality concerns or other factors, some firms

did not reveal their net profits, total assets, and productivity indexes. The missing data were fulfilled by imputation. The DID estimations of these three characteristics were performed by incomplete data (N<75 in the treated group of the pre-time period) and imputed complete data (N=75 in each group of each time period).

A difference-in-differences estimations with regression model

Relationship between policy intervention and subsequent firm performance is evaluated by pre-post designs, in which the firms' ex-post output is compared with the ex-ante one. The difference-in-differences (DID) estimates were conducted to rule out unobserved effects, selection bias, and other intervening factors of measured outputs by a valid comparison group (Dimick & Ryan, 2014; Rigby & Ramlogan, 2013). The non-treated firms not funded by PIE were sampled by the exact matching method in terms of critical firm characteristics such as size, industry, and established time period (Bondonio et al., 2014; Caliendo & Kopeinig, 2008). The non-treated group holds a constant trend over time, which is of similar trend with treated group. The DID estimates are extracted from regression models and the following linear regression model (DIDE-CUMSPH, 2013; Dimick & Ryan, 2014) was conducted:

$$Y = \beta_0 + \beta_1 * \text{Group} + \beta_2 * \text{Time} + \beta_3 * \text{Group} * \text{Time} + \varepsilon$$

where Y is outcome variables as firm characteristics. The Group, Time, and the interaction term (Group*Time) denote as dummy variables. The DID estimation (β_3) is the differential change over time in the PIE group compared to the change over time in the non-treated group.

In the following chart, the intervention impact is measured by the differences between observed and unobserved counterfactual outcomes after intervention in treated group (Chart 1). If absent the PIE, the treated group's outcome trend could be parallel to that of the non-treated group. DID can rule out the unobserved and observed characteristics between the treated group and comparison group, thereby identifying the intervention effect.

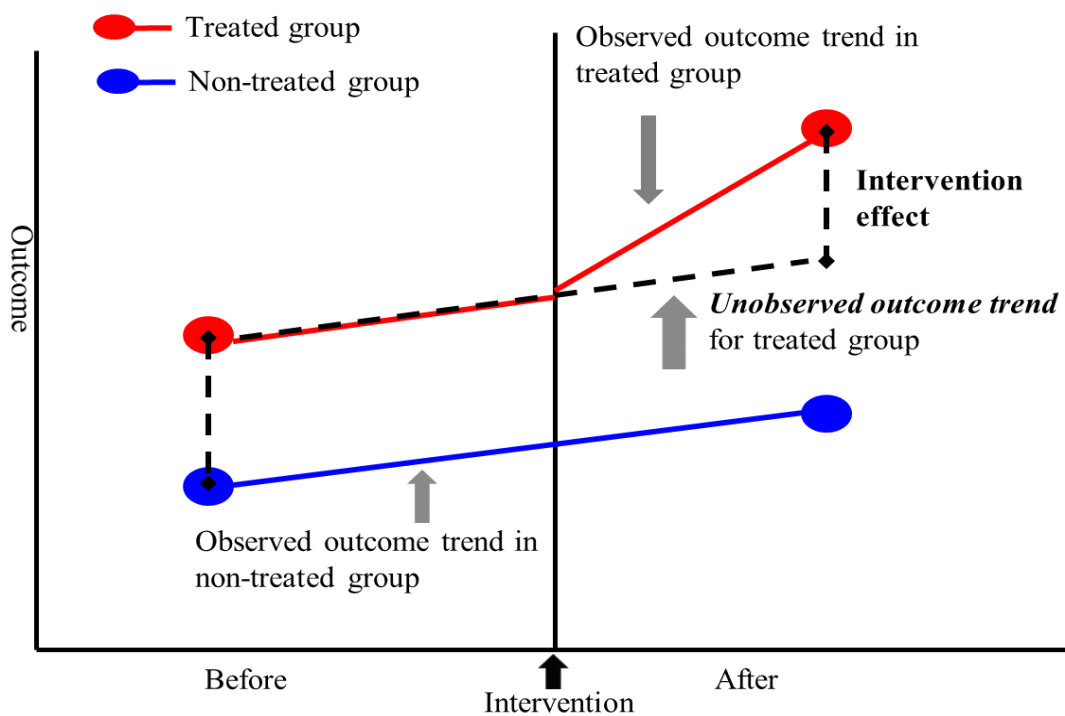


Chart 1 Illustration of the Rationale of DID

A semiparametric DID approach

The differences in observed firm characteristics may not hold the constant trends over time between treated and non-treated groups. To consolidate the conclusion, we also adopted the semiparametric DID approach to make the parallel trend assumption more reliable (Abadie, 2005; Hounghbedji, 2015). According to DID estimations, the p-values of imputed complete data were smaller than those of incomplete data sets (Table 1). Hence, we used imputed complete data to compute semiparametric DID estimates (Table 2) and test if the conclusions of semiparametric DID approaches are in line with those of DID's.

Spearman's rank correlation coefficients

Taking account of some assumptions such as linear relationship and normal distribution that need to be held when conducting Pearson's coefficients (Göktas & Isçi, 2011), we adopted Spearman's rank correlation coefficients instead of Pearson's. The results of Spearman's coefficients are more robust with outliers (Mukaka 2012) and the outcomes of Pearson's coefficients can be incorrect if one of the assumptions is not fulfilled.

With respect to the subsidized firms, we performed Spearman's correlations with Bonferroni multiple comparison corrections between the certain Program activity and 7 final output additionality ($r=0.309$, $p<0.0071$; Table 3) and 9 intermediate behavioural additionality ($r=0.316$, $p<0.0056$; Table 4) in the treated group.

A binomial test

The subsidized firms with R&D acceleration were denoted as success, otherwise as failure. The 54 firms reported that they would do program activities without public support. Significance of acceleration in program activities at the group level was evaluated by a binomial test (one-tailed $p = 0.038$ 34/54 firms; that is, at least 34 of the 54 firms had acceleration of time). For a success probability of 0.5 (acceleration in program activities exists or not) in the binomial distribution with 54 trials, 34 is the minimal number of successes so that the critical number of 34 or more successes was selected.

Results of firm-centric and econometric impact assessment

Firm-centric output additionality

Comparing the output of the participant firms of three program activities of PIE with that of non-treated firms using DID estimations with regression models (Table 1) and semi-DID approaches (Table 2) ($p > 0.05$), our results showed that PIE has no significant impact on participant firms' employment, productivity, net revenue, and net profit)

Intermediate behavioural additionality

In addition to the distribution of PIE's behavioural additionality on the survey participant firms, our analysis using the Spearman's coefficients with Bonferroni corrections showed that PIE's treatment intensity in R&D activity have positive correlation with the company's net profit (Table 3). PIE's treatment intensity in R&D activity were positively correlated to a lot of intermediate behavioural additionality ("Creating inter-organizational linkages", "Improving quality or sale of products and processes", "Enhancing capability of commercializing technologies", "Enhancing technological expertise of employees", "Enhancing R&D or innovation capacities", "Broadening the scope of R&D", and "Facilitating new technology adoption", Table 4).

Input additionality and behavioural Additionality on the subsidized firms of PIE's R&D subsidy

We employ the DID and semiparametric DID approach to assess the input additionality of the R&D-subsidized firms. There were no significant impact on R&D intensity between treated and non-treated groups by DID estimations ($p=0.506$) and semiparametric DID ($p=0.328$) (Table 6).

Concerning the project additionality, 14.29% (9 out of 63) of survey subsidized firms have project additionality by the PIE (would not have conducted the R&D project without PIE's R&D subsidization).

With respect to the behavioural additionality, our study revealed that 34 out of 54 firms (64.15%) showed acceleration of time in program activities. The 54 and 34 firms demonstrated that the acceleration of years averaged at 1.07 and 1.71 years, respectively (Table 5). Overall, a binomial test revealed that significance of acceleration of years exists (one-tailed $p=0.038$), that is, PIE's R&D subsidies accelerated the R&D, or outreach service, or training activity in the funded firms.

Regarding the qualitative process evaluation, we conducted the interviews on the managers of PIE's funding agencies and the document analysis to review the program planning and project selection processes and mechanisms.

Discussion

With respect to the output additionality, our study reveals no significant impacts on funded firms' performance comparing treated and non-treated groups. In addition to improper planning or implementation of PIE, the impact assessment results run against the positive monitoring indicators reported by the PIE regarding technology commercialization. By contrary, the program's impact on the intermediate behavioural additionality is significant using the Spearman's coefficients with Bonferroni corrections. It is revealed that PIE's treatment intensity in R&D activity was positive correlated with the company's net profit (Table 3). PIE's treatment intensity in R&D activity were positively correlated to a lot of intermediate behavioural additionality ("Creating inter-organizational linkages", "Improving quality or sale of products and processes", "Enhancing capability of commercializing technologies", "Enhancing technological expertise of employees", "Enhancing R&D or innovation capacities", "Broadening the scope of R&D", and "Facilitating new technology adoption")

The DID and semiparametric DID analysis reveal no significant impact on the R&D intensity of subsidized firm. Likewise, only 14% of subsidized firms show the project additionality and the primary impact of PIE's R&D subsidization rests on R&D acceleration, R&D scope broadening, etc. Since Hsu's measurement of project additionality of Taiwan similar R&D programs (Hsu, 2009) have similar findings (only 7% of project additionality), the inadequate ex-ante evaluation of R&D underinvestment problem might have misled the program to target those R&D activities without underinvestment. This assessment results revealed the striking problem regarding the "government infrastructure" of STI program planning regarding the agenda setting in the generic logic model.

The performance of Taiwan's STI program implemented by S&T agencies are usually evaluated in terms of annually reported technology license royalty, new products and processes, etc. Conducting the qualitative assessment on the program planning and project selection processes embedded in the government infrastructure through document analysis and interviews, we found that the PIE's funding agency delegate the program planning to the research institute executing and do not have adequate capacities and practices to conduct the project selections. Accordingly, combining the accountability pressure by key monitoring indicators (e.g., new products, new process, license revenues, etc.) and the absence of

evaluation capacities and relevant project selection galvanized the funding agency to conservatively select those projects which were already in the R&D agenda of the participant firms.

In other words, the monitoring indicators of PIE could have misled the S&T agency to conservatively target those commercially feasible R&D activities or select those firms with better capabilities. The same institutional factors might have made the DID analysis of output additionality of PIE reveal no significant difference between treated and non-treated firms excluding the selection bias embedded in the project selection processes. These possible institutional explanation of the insignificant output additionality, input additionality, and project additionality of PIE require further evidences of positive researches.

Conclusions

In terms of market-failure rationales, our study demonstrated that there was no output additionality of PIE's program interventions on the participant firms' employment, productivity, profit, and net revenue. Likewise, the PIE's R&D subsidization yielded no significant impact on subsidized firms' input additionality (R&D intensity) and project additionality (14 % similar to 7% of Hsu's study) in contrast to the positive reported monitoring indicators regarding the technology commercialization in PIE.

The primary impact of PIE rests on the intermediate behavioural additionality on participant firms by which PIE's interventions can be justified by the system-failure rationales.

The absence of output additionality, input additionality, and project additionality might have something to with the institutional factors influencing the program planning, project selection, and monitoring processes due to improper ex-ante evaluation, and improper ex-post performance evaluation practices which were revealed in our qualitative impact assessment. The results of our mixed (quantitative and qualitative) impact assessments demonstrated the urgent needs to establish and modify the government infrastructure of Taiwan's STI program planning. The program interventions and targeted clients listed in the program proposals should be based on evidence-based market-failure assessment of status quo baseline and intervention rationales instead of merely the monitoring indicators.

Furthermore, with the logic model (evaluability assessment) and generic logic model, the available collected data, the preceding evaluation results can be better consolidated in the assessment framework to inform the evaluation design. By reflexively assessing the institutional structure shaping the program planning and project selection practices by means of mixed methods and logic model, we hope Taiwan's STI program's government infrastructure regarding the impact assessment and monitoring indicators system management can be restructured to avoid the pitfall of performance evaluation of STI programs.

Table 1. Output additionality assessment of PIE using DID regression

Mean of characteristic (SE)	2010		2015		DID estimation (β_3)	P-value
	Non-treated group, N=75	PIE group, N=75	Non-treated group, N=75	PIE group, N=75		
Net revenue	32949697200 (16643068669)	8317270260 (3361898916)	34904384253 (18993311479)	7231774200 (2325430465)	$-3.04 \cdot 10^9$	0.91
Employee Size	1157 (317)	1052 (288)	1176 (317)	1260 (392)	189.69	0.77
Net profit	1441917040 (489692349)	1714784169 ^a (5400586266)	395523152 (534696920)	683092773 (306672506)	$1.47 \cdot 10^7$ ^b	0.99
Productivity index	1514513 (343994)	719862 ^d (901167)	8233255 (6964938)	502729 (119144)	-6953730 ^b	0.35
					-6467827 ^c	0.26

SE: standard error; PIE: National Program for Intelligent Electronics; DID: difference-in-differences; R&D: research and development. ^a Having missing value, N=59. ^b Incomplete data. ^c Imputed complete data. ^d Having missing value, N=59.

Table 2. Output additionality assessment of differences of firm characteristics before and after PIE in the treated and non-treated groups using semiparametric DID approach.

Differential (Diff.) characteristic	Coefficient of semiparametric DID	Standard error	P-value
Diff. net revenue	$-2.13 \cdot 10^9$	$3.43 \cdot 10^9$	0.53
Diff. size	184.39	126.15	0.14
Diff. net profit ^a	$-6.57 \cdot 10^8$	$8.19 \cdot 10^8$	0.42
Diff. productivity index ^a	-7250419	6794927	0.29

PIE: National Program for Intelligent Electronics; DID: difference-in-differences; R&D: research and development. ^a Imputed complete data.

Table 3. Association between program treatment intensity and output additionality in the treated firms

		Final output additionality (firm characteristic)			
		Net revenue	Size	Net profit	Productivity index
Program activity					
Overall	3 facets	0.185	0.232*	0.266*	0.210
Training		0.065	0.052	0.138	0.141
Outreach service		0.104	0.124	0.089	0.020
R&D activity		0.223	0.244*	0.317***	0.200

Note: * means $p < .05$. ** means $p < .01$. *** means $p < .0071$ ($=0.05/7$, Bonferroni multiple comparison corrections).

Table 4. Association between program treatment intensity and intermediate behavioral additionality in the treated firms

Program activity	Intermediate behavioral additionality								
	Creating inter-organizational linkages	Improving quality or sale of products and processes	Enhancing R&D or innovation capacities	Enhancing capability of commercializing technologies	Enhancing technological expertise of employees	Increasing employment of high-quality personnel	Broadening the scope of R&D	Reducing R&D/production/operation cost	Facilitating technology adoption
Overall 3 facets	0.482***	0.430***	0.344***	0.396***	0.483***	0.261*	0.314**	0.361***	0.410***
Training	0.191	0.233*	0.08	0.143	0.221	0.147	0.225	0.236*	0.281*
Outreach service	0.380***	0.350***	0.223	0.213	0.373**	0.135	0.124	0.12	0.214
R&D activity	0.378***	0.322***	0.443***	0.486***	0.448***	0.269*	0.295*	0.426***	0.376***

Note: * means $p < .05$. ** means $p < .01$. *** means $p < .0056$ ($=0.05/9$, Bonferroni multiple comparison corrections).

Table 5. R&D acceleration for subsidized firms (N=54, mean= 1.07 years).

	No acceleration	Acceleration (mean=1.71 years)				
Accelerated years	no response	0.5	1	1.5	2	3
Number of firms (%)	20 (37.04)	1 (1.85)	12 (22.22)	3 (5.56)	13 (24.07)	5 (9.26)

Table 6 Assessment of input additionality (increased R&D intensity) by DID and semiparametric DID approaches

	2010		2015		DID estimation (β_3)	p-value	Coefficient of semiparametric DID	p-value
	Non-treated group, N=62	PIE group, N=62	Non-treated group, N=62	PIE group, N=62				
Mean of R&D intensity	0.0309	0.1732	0.0291	0.1322	-0.0391	0.506	-0.0389	0.328
Standard error	0.0082	0.0524	0.0059	0.0245				

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