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Technology upgrading of Small-and-Medium-sized Enterprises (SMEs) through a manpower secondment strategy – A mixed-methods study of Singapore's T-Up program

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ABSTRACT

This paper outlines a scheme that uses manpower from public research institutes to assist the technology upgrading of Small-and-Medium-sized Enterprises (SMEs). The Growing Enterprises through Technology Upgrading (GET-Up) initiative has been successfully implemented in Singapore since 2003. The key program in the initiative is a manpower secondment scheme (i.e. a temporary placement of manpower in a different organization) known as T-Up. We propose that T-Up represents a new approach to technology transfer which additionally maximizes the industrial impact of public sector research. Instead of traditional technology transfer modes which are transactions-based, T-Up utilizes skills and human resource transfer through secondment of public sector researchers. Findings from two surveys conducted in 2005 and 2012 show that the T-Up secondment program had positive impact on the technological capabilities, innovation performance and growth of participating companies. Additionally, case studies highlight that this approach addresses a wide range of challenges faced by local SMEs and is flexible enough to cater to specific needs and requirements.

1. Introduction

One key challenge faced by Newly Industrialized Economies (NIEs) is the evolution of an appropriate strategy to sustain long-term economic growth. Singapore's economic prosperity in the last four decades is attributed to her success in transitioning from a growth strategy reliant on sourcing technology from foreign Multi-National Companies (MNCs) to one that is more balanced with increasing emphasis on indigenous innovation capability (Wong and Singh, 2008). In January 2003, the Singapore government launched a multi-agency initiative named "Growing Enterprises with Technology Upgrade" or in short "GET-Up", to stimulate technology transfer from public to private sector, so as to nurture indigenous innovations in local industry. Concerted effort was from four government agencies, i.e. Agency for Science, Technology And Research (A*STAR), Economic Development Board (EDB), Standards, Productivity & Innovation Board Singapore (SPRING) and International Enterprise (IE) Singapore. The initiative is a new integrated approach that utilizes skills and human resource transfer, supplemented by a practical technology roadmapping programme, and provision of technical advisors when needed to assist the technology upgrading of small and medium enterprises.

As a provider of information, government disseminates an array of scientific knowledge through government owned laboratories, technical publications, journals and computer based services (Spann et al., 1995). Following the US government in taking a cooperative technology paradigm, many governments made legislative changes so that universities and government laboratories can play a stronger role in developing technology for use in the private sector (Bozeman, 2000). Technology transfer offices were established in most research offices and universities (Siegel and Phan, 2005). The last decade witnessed an increased number of studies pertaining to university-industry technology transfer (see Bozeman (2000) and Teixeiria and Mota (2012)). But there is scarce literature about technology transfer between public research institutes and private sector. Although public research institutes and universities share important features, the two differ on various perspectives. For example, public research institutes are closer to industrial technology development and have lesser focus on basic research unlike universities. Moreover, interdisciplinary

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research is more prolific in public research institutes than in universities. Thus, technology transfer from research institutes could be less constraining than that from universities, which warrants careful examination and our study addresses this important gap. Second, most of the studies on technology transfer focus on established firms (incumbents or R&D intensive firms). Even the majority of the Open Innovation (OI) literature that examines how firms use both internal and external ideas to advance their technology have focused primarily on MNCs (e.g. Mortara and Minshall, 2011). It is only recently that OI researchers began to study open innovation activities in SMEs (Van de Vrande et al., 2009; Lee, et al., 2010; Minshall et al., 2013). Our study on GET-Up has a special focus on how SMEs source technology from public research institutes, which is an important addition to not only the technology transfer literature, but also the open innovation literature.

As GET-Up's primary focus is movement of scientists and engineers, the centrepiece of the scheme is T-Up – a researcher secondment program through which SMEs can access the sizeable pool of high-quality and experienced researchers at the well-established public research institutes. Secondment here refers to the research staff of a public research institute being “loaned” to work on a full-time basis in an SME for up to two years; the secondee's salary will be paid mainly by a government grant and only partially by the SME; on completion, the secondee will return to the public research institute unless he/she is retained by the SME on mutual agreement. In this paper, we present a mixed-methods study of T-Up as an innovative approach to transfer public sector knowledge and intellectual properties to industry, and we also show that it is an effective mode for SMEs to source technologies from external parties (Chesbrough et al., 2006; Bozeman, 2000). Based on both survey data collected in 2005 and 2012 and qualitative data collected from selected participating SMEs, we present quantitative and qualitative evidence of how T-Up has benefited the participating firms and achieved the policy objectives of upgrading technological capabilities in local enterprises. Insights from the study could help policy makers understand the significance of the Singaporean workforce for indigenous innovation development, more so for SMEs as they lack the necessary absorptive capacity (Cohen and Levinthal, 1990) in order to benefit from other modes of transfer. The findings should guide policy makers in making investment decisions on programs that encourage talent mobility.

The paper is organized as follows. In the next section, we briefly describe the scope and process of T-Up. In the first part of our mixed methods approach, we assess the impact of T-Up by presenting findings from two survey studies. Then, these findings are reinforced by case studies presenting qualitative evidence obtained through interviews with selected policy-makers and T-Up recipients. Finally, we discuss the findings from several theoretical perspectives and present practical implications for policy-makers and industry practitioners.

2. Background and description of the program

As Singapore transforms itself into a knowledge-based economy, the promotion of R&D has become a key strategy for driving economic growth. To support this growth strategy, there has been concerted effort to promote indigenous technological development in two spheres: the public sector comprising the universities and public research institutes; and the local industry comprising SMEs, larger local enterprises, and MNCs. To create a strong base of science and technology capability, the Singapore government has invested heavily in public sector research. Public research institutes with focus on key industrial clusters were established under the umbrella of the Agency for Science, Technology and Research (A*STAR). These public research institutes have created substantial intellectual properties, and developed a large number of competent research scientists and engineers.

At the same time, policy-makers recognized that the business paradigm under which the Singaporean companies had operated for many years was undergoing rapid change and these companies had to make major adjustments. Before the early 2000s, Singaporean companies could depend on the MNCs which readily transferred the latest technologies to their key supporting industry partners anywhere in the world. This traditional source of technology transfer started to diminish rapidly in many high-tech sectors as the time-to-market and product life-cycles became shorter and shorter. The global manufacturing outsourcing practice in recent years has also resulted in much reduced in-house manufacturing expertise in many MNCs. Therefore, as the supporting companies of these MNCs, many Singaporean companies that have indigenous technology and manufacturing know-how could become the preferred global partners of MNCs, be it in the global market place or even in the home countries of the MNCs. In other words, innovation and intellectual property creation have become critical success factors for the Singaporean companies to survive and thrive (Hang, 2007). This is especially important and urgent for firms in the manufacturing sector as they face keen competition from neighboring countries where the cost of labour is lower. In addition to creating strong local companies to support the MNCs, another industry strategy was to help more local SMEs create indigenous technologies and products/services that would enable them to compete in the global markets. If they continued to grow, some of these local companies could eventually establish themselves as MNCs with their roots and bases in Singapore.

However, Singapore's SMEs faced many challenges that limited their ability to develop sophisticated and high-level technological capabilities. While there were generous assistance schemes to ease the financial burden of investing in R&D or technology in-sourcing, a main challenge was the shortage of R&D expertise. Many local SMEs had difficulties hiring degree holders due to their size and lack of reputation, let alone Ph.Ds or experienced researchers. A large proportion of the graduates from the local universities and researchers from the public research institutes chose to join MNCs, government, or the financial sector. Some of them left the country. Another major challenge was that some SMEs depended on the success of their previous subcontractor or OEM business and operated in a maintenance mode due to organizational inertia. The business owners of these SMEs simply did not have the ambition or foresight to upgrade their business. As a result, the R&D capabilities of the local SMEs remained poor – they lacked the absorptive capacity (Cohen and Levinthal, 1990) to work with other technology providers and were unable to generate indigenous innovation.

To address these issues, Singapore launched a multi-agency initiative called GETUp in 2003. GET-Up is targeted at promising local enterprises in the manufacturing sector which see themselves as “global enterprises in the making”. The suite of programs under GET-Up comprises: (i) TRM, a Technology Roadmapping program; (ii) T-Up, a manpower secondment scheme; and (iii) TA, a scheme to provide expert Technical Advisory services. This paper is focused on the T-Up scheme. The promising Singaporean enterprises in the manufacturing sector are mainly in the Electronics, Engineering, InfoComm and Chemicals clusters. These are also the same industrial clusters in which the Science and Engineering Research Council of A*STAR has built seven public research institutes with over 1500 Research Scientists and Engineers (researchers) and substantial intellectual properties to share. The enterprises targeted for assistance have been shortlisted by Economic Development Board (EDB), Standards, Productivity and Innovation Board (SPRING) and International Enterprise (IE)

Singapore based on their technology upgrading needs and potential. Over 400 enterprises were covered in the first year of operation of GET-Up, and another 100–200 companies have been visited annually after the first year.

T-Up (or in full, Technology for enterprise capability Upgrading) is the centrepiece among the three programs in GET-Up, involving the deepest levels of commitment from both public and private sector participants. The T-Up secondment programme aims to upgrade the technological capability of enterprises by: i) helping to identify critical technologies; ii) building in-house R&D capabilities; iii) forging collaborations between PRIs and enterprises to effect technology transfer; iv) building a culture of innovation and creation; and v) providing access to human capital and expertise.

Under the T-Up program, experienced researchers could be seconded from public research institutes to work in the SMEs for a period of up to two years to help upgrade the SMEs' R&D capabilities and create leading-edge technologies with commercial value. The secondment arrangement is typically structured around a specific innovation project jointly determined by the SME and the research institute. Therefore T-Up acts as a "brain loan" program through which SMEs have access to the sizable pool of high-quality and experienced researchers at the well-established A*STAR public research institutes. In addition, an existing financing scheme has been used to co-fund the salaries of the seconded researchers for up to two years. The SMEs were also encouraged to use the two years to court and recruit these researchers afterwards. With mutual agreement, the researchers could be retained by the SMEs after the secondment period, and the public research institutes would then recruit fresh researchers to start a new cycle of manpower training. Alternatively, the researchers could return to the public research institutes and continue to do research there with their newly gained industrial experience. One important feature of the scheme is the simple and clear-cut treatment of Intellectual Properties (IPs). If there are new IPs developed by the T-Up seconded staff during their attachment period in the SMEs, the IPs would belong to the SMEs.

3. Research methodology

3.1. Quantitative survey data

In order to assess the impact of T-Up on firms, A*STAR commissioned two surveys at two different points in time – namely 2005 and 2012. The survey analysis addressed the question of whether T-Up has enhanced the technological capabilities of firms in terms of improved skills, attitudes and awareness. The assessment of T-Up's impact in these areas is based on the perceptions of the recipients, as reported in their survey responses.

The first survey was conducted at the end of 2005, three years after the launch of T-Up. The primary aim of the survey was to examine the impact of the T-Up scheme as measured by respondents' perceptions of how the scheme has changed or influenced their organizations. A total of 55 enterprises were successfully surveyed via email or telephone, representing an overall response rate of 95% from a total of 58 program recipients. The 55 respondents comprise companies that had either completed at least one project with a seconded researcher or were still hosting seconded researchers at the time of the survey. A follow-up survey to assess the impact of T-Up was conducted in 2012, ten years after the program's initial launch in 2003. Conducted using a self-administered online questionnaire, the survey targeted all 144 companies that had completed at least one project with a seconded researcher. A total of 56 firms responded to the 2012 survey, representing a 39% response rate.

3.2. Matching sample of non-T-Up companies

To further examine the impact of T-Up, we compared the innovation and growth performance of T-Up recipients against the performance of equivalent companies that have not received T-Up support. For both the 2012 and 2005 surveys, each responding T-Up recipient was matched to a control company with comparable characteristics. In the 2005 study, the control companies were drawn from a random stratified sample of companies obtained from Singapore's business registry. In the 2012 study, the control companies were drawn from a list of firms that had been invited by the GET-Up administrators to participate in the T-Up program but had declined participation. Both control groups were constructed by selecting companies matched to the T-Up recipients using three measures: industrial sector, size (in terms of sales or employment), and age. The matched-pair design eliminated potential bias and allowed for comparative evaluation of the T-Up program for recipients versus non-recipients. The companies in the control groups were surveyed to obtain information on their innovation activities and growth performance. A screener question was asked to ensure that the non-recipients had engaged in technological activities in the last 3 years.

3.3. Interviews with T-Up recipients

We also conducted interviews with 15 companies which had received T-Up assistance, and present the qualitative findings as case studies. The cases were selected based on the quantitative findings collected from the quantitative study in order to assist in the clarification of the latter (e.g. Sammons et al., 2005). Each case is different and unique but the two cases presented in this paper are good representatives of the other cases. The qualitative study offered much richer information than the survey results, as we solicited the views of the seconded researchers, the senior management of the SMEs and research institutes, and the GETUp team (Eisenhardt and Graebner, 2007), and therefore it yielded a more detailed and complete picture of the effect of T-Up on various participants. The qualitative data provided a subjective account of the technology transfer process, which was compared with the 'objective' evidence from the quantitative data, offering triangulation for the results. Subsequently, our case histories were shared with and checked by the informants before being incorporated into the paper.

4. Impact of GET-Up: findings from the surveys

4.1. Perceived impact of GET-Up

The T-Up secondment program aims to strengthen the capacity of local enterprises for technological innovation through the assignment of research scientists and engineers (researchers) from the public research institutes under the umbrella of A*STAR. Among the 55 survey respondents who had received T-Up assistance as at end 2005 and the 56 survey respondents who had completed at least one T-Up project as at early 2012, the perception of the program was generally positive. As seen in Table 1, around half the respondents in the 2005 survey agreed or strongly agreed that T-Up had been beneficial in terms of enhancing their technological learning and enterprise innovation, and very few respondents expressed disagreement. Around half of respondents also indicated that their technological capabilities had improved substantially due to T-Up. The respondents to the 2012 survey were less positive, with a higher proportion expressing disagreement compared to the 2005 survey. Nonetheless, the dissenting proportion is outnumbered by the proportion who agreed that

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Table 1
Perceived impact of T-Up secondment.

	2005 Survey			2012 Survey		
	% Disagree	**% Agree**	***t*-test**[a]	**% Disagree**	**% Agree**	***t*-test**[a]
A) Improve technology learning[b]						
Learn to execute R&D projects	3.6	45.5	5.41**	26	36	0.40
Learn to exchange skills, know-how or technologies	3.6	47.3	6.42**	15.7	35.3	2.10*
Gain new techniques, competencies or technologies	3.6	52.8	6.45**	20.4	55.5	3.07*
Develop new ideas or skills	3.6	34.5	4.45**	14.8	57.4	4.46**
B) Enhance enterprise innovation:						
T-Up helped introduce product innovation	1.9	50.0	6.89**	17.3	46.1	3.13*
T-Up helped introduce process innovation	0	57.4	7.73**	20.4	32.7	1.65
	2005 Survey			**2012 Survey**		
	% Little or Not At All	**% A lot**	***t*-test**[a]	**% Little or Not At All**	**% A lot**	***t*-test**[a]
C) Improve technology capabilities[c]						
Improve product design	1.8	49.1	7.07**	5.7	56.6	5.92**
Improve process design	5.5	49.1	5.68**	12	40	2.91*
Improve product quality	3.6	47.3	5.84**	na	na	na
Reduce lead time	5.5	52.7	4.95**	24.5	28.6	0.16
Reduce manufacturing costs	7.3	52.7	5.52**	23.5	23.5	0.15
	2005 Survey			**2012 Survey**		
	Aggregate mean	***t*-test**[a]		**Aggregate mean**	***t*-test**[a]	
Improve technology learning	3.48	11.5**		3.33	3.18*	
Enhance enterprise innovation	3.54	9.59**		3.36	2.92*	
Improve technology capabilities	3.49	11.1**		3.28	2.98*	

* Significant at 5%,
** Significant at 1%.
[a] We conducted *T*-tests for the means against the median of the scale, and reported the *t* values here.
[b] Measured on a five point scale, where 1 = Strongly disagree and 5 = Strongly agree. Ratings of 1 or 2 are classified as "Disagree". Ratings of 4 or 5 are classified as "Agree".
[c] Measured on a five point scale, where 1 = Not at all and 5 = A great deal. Ratings of 1 or 2 are classified as "Little or not at all". Ratings of 4 or 5 are classified as "A lot".

T-Up has been beneficial. In addition, our *t*-test results show that on average the respondents agree that T-Up has helped them to improve learning and technology capabilities and enhance their innovation.

Additionally, one of the most important deliverables of the T-Up secondment program is the degree of knowledge transfer from the seconded researchers to the enterprise. As seen in Table 2, the majority of respondents in the 2005 survey found that the seconded researchers had transferred some knowledge to the company, with only a handful of respondents indicating low knowledge transfer.

In the 2012 survey, the degree of knowledge transfer was rated

Table 2
Perceived degree of knowledge transfer under T-Up secondment.

	2005 Survey				2012 Survey			
	% low	**% medium**	**% high**	***t*-Test**[a]	**% low**	**% medium**	**% high**	***t*-Test**[a]
Degree of knowledge transfer from seconded researcher to company[b]								
Process technology	3.6	43.6	52.8	6.69**	21.7	37	41.3	1.93^
Product technology	1.8	43.6	54.6	7.20**	21.1	26.9	51.9	2.84*
Product design	3.6	47.3	49.1	6.55**	21.5	37.3	41.2	1.45
Components design	3.6	41.8	54.6	6.91**	na	na	na	na
R&D project management	7.3	47.3	45.4	4.44**	28.6	44.9	26.5	−0.28
	2005 Survey				**2012 Survey**			
	Aggregate mean	***t*-test**[a]			**Aggregate mean**	***t*-test**[a]		
Overall Knowledge Transfer[c]	3.51	13.76**			3.23	2.20*		

^ Significant at 10%.
* Significant at 5%.
** Significant at 1%.
[a] We conducted *T*-tests for the means against the median of the scale, and reported the t values here.
[b] Measured on a five point scale where 1 = Low and 5 = High. Ratings of 1 or 2 are classified as "Low". Ratings of 3 are classified as "Medium". Ratings of 4 or 5 are classified as "High".
[c] Derived as average of knowledge transfer areas listed in preceding lines of this table.

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slightly lower compared to the 2005 survey, with around one fifth of respondents reporting low degree of knowledge transfer. Nonetheless, it is observed that over 40% found that a high degree of knowledge transfer had taken place in the areas related to product, process and design. The *t*-test results for the overall knowledge transfer also show that the average responses are positive. More detailed analysis of the 2012 data revealed that the SMEs who reported high knowledge transfer were substantially younger (median age =9 years) than the SMEs which reported low knowledge transfer (median age =14 years). Further analysis shows that the recency of projects was not a factor. While we lack the data to verify the cause of this discrepancy, this finding might be explained by cultural factors in that more established older enterprises tend to have more entrenched attitudes and are less willing to accept new ideas.

One measure of effective technology transfer is the market impact of the transferred innovation (Bozeman, 2000). We examine the success of T-UP as a technology transfer mechanism by studying the outcomes of the innovation projects undertaken by researchers during their period of T-Up secondment at the participating SMEs. In particular, we consider two outcomes related to market impact; firstly, the creation of tangible IP assets and secondly, successful commercialization, which is achieved when the innovation generates revenues for the firm. As seen in Table 3, in the 2005 survey, only a small proportion of the SMEs created new IP from the T-Up supported projects. Less than 10% had successfully commercialized the inventions developed under the T-Up program. This is understandable as the survey was conducted when the program was still quite new. Encouragingly, a much larger proportion of enterprises surveyed in 2012 (41%) indicated that the T-Up project outcomes have been successfully commercialized. The rate of in-house IP creation had also increased substantially, from 11.8% in the 2005 sample to 57.1% in the 2012 survey.

These differing results from the two surveys show that T-Up participation did not immediately yield commercialization outcomes in the early stages of the program but the impact has become more apparent with the passing of time. This is not unexpected as it could take several years to push the innovation results to the market. Some of these commercialization activities might have taken place after the completion of the T-Up secondment period. Nonetheless, the findings from the 2012 survey attest to the effectiveness of T-Up secondment to transfer technology and know-how that generate commercially-viable innovations for SMEs.

4.2. *Impact of T-Up secondment on firm performance: comparisons between the T-Up recipients and control group of non-recipients*

The second set of findings relates to T-Up's impact on the performance and aspirations of recipient firms. We used the performance data of T-Up recipients in the two surveys to compare with those from the control groups of companies which did not participate in the program. To ascertain if participation in the T-Up scheme has measurably benefited companies, we used more objective measures of performance like R&D spending intensity, product innovation intensity (i.e. the share of new product sales in total sales) and firm growth, measured as firms' average annual growth in sales revenues in the last three years. We also investigated how T-Up boosted the companies' aspiration in terms of projected sales, which is measured by self-reported expectations for future sales growth.

We used hierarchical OLS regression to see if SMEs in the T-Up scheme reported higher levels of innovation activity and stronger growth compared to the control group. The dependent variable in the regression equation was alternated to represent the various outcome measures of interest. The key predictor was the dummy variable *T-Up Participation* which took the value 1 if the company was a T-Up recipient and 0 if the company was from the control group of non-recipients.

As shown in Table 4, T-Up secondment has significantly benefited SMEs in terms of product innovation intensity (β=3.21, $p<0.05$) and recent sales growth performance (β=14.22, $p<0.05$) in the 2012 survey. T-Up firms report significantly higher level of sales derived from new products/ services as well as higher recent sales growth, compared to their counterparts that had not participated in T-Up. However, there is no significant difference between T-Up firms and the control group in terms of projected sales growth.

On the other hand, the results for the 2005 data reveal less significant impact of the T-Up program. The *T-Up Participation* variable is only significant in the case of sales growth in the last three years (β=2.07), and only at the 10% level of significance. It seems that at the early stage of the T-Up program, T-Up recipients did not achieve significantly better innovation performance than firms that did not participate in the scheme. It is possible that an initial gestation period was needed for firms to fully reap the

Table 3
Outcomes of T-Up innovation projects.

	2005 Survey	2012 Survey
T-Up project led to the creation of in-house IP	11.8%	57.1%
Innovation from T-Up project successfully commercialized	7.6%	41.1%

Table 4
Regression results examining impact of T-Up on firms' innovative activity and growth performance – comparisons between T-Up recipients and non-recipients.

	Product innovation intensity (% of sales derived from new products)		Growth in sales in Last 3 years	
	2005	2012	2005	2012
Constant	21.25**	1.55	16.67**	8.17
Sector control[a]				
Chemical	−6.19	4.64*	4.18ˆ	−1.06
Electronics	2.73	1.14	−2.66	8.55
General Manufacturing	1.94		0.11	
Transport	15.35ˆ		3.96	
ICT		4.24*		1.73
Age	0.19	−.01	−0.05	−0.53
Size (Sales in 2005)[b]	−0.15		−0.72	
Size (Employment in 2012)[b]		0.00		0.00
R&D Spending Intensity[c]	2.27**	2.27**	1.51	2.83
T-Up Participation	−2.22	3.21*	2.07ˆ	14.22*
Adjusted R sq	0.33	0.45	0.03	0.17
F stat	7.14	9.35	1.42	2.37
Sig. of F	0.00	0.00	0.20	0.04

* Significant at 5%.
** Significant at 1%.
ˆ Significant at 10%.
[a] Different sectors for 2005 and 2012 are due to composition of final samples.
[b] Size is measured by sales in 2005 and by employment in 2012. Employment information was not collected in the 2005 survey. Contemporaneous sales data was incomplete in the 2012 survey.
[c] R&D Spending Intensity is measured as R&D expenditure as a percentage of sales revenue in the reference year.

potential benefits of participating in the program. It is also possible that the T-Up program has evolved and improved over the years with feedback from the SME recipients and as the T-Up team gained more experience. For example, with better understanding of recipients' needs, the public research institutes could provide more suitable secondee candidates for the SMEs. Hence the 2012 survey participants showed better outcomes than the earlier batch in 2005. Overall, the difference in the two regression results could also suggest that the awareness of R&D among the SMEs has been raised over the years.

5. Case studies of T-Up recipients

A good example of T-Up secondment is Advanpack Solutions Pte. Ltd. (APS). APS received the assistance of a researcher – Mr. Raymond Lim – from Institute of Micro-Electronics (IME) to develop Molded Interconnect System (MIS) and Thermo Compression Bonding (TCB) in 2007. Mr. Lim has a masters' degree in mechanical engineering and had been a junior engineer in IME for two years by then. When APS approached IME for a possible secondee, he was selected and joined the T-Up scheme as "*it was a good opportunity to know what was going on in real practice*".

Before Mr. Lim joined, APS focused only on the packaging assembling technologies (i.e. copper pillar bump) and processes, which were difficult to commercialize in the market as no customer had the capacity to integrate these innovations. Hence APS decided to develop its own fully integrated packaging solution to solve this problem and needed expertise with the upstream and downstream technology know-how. With his background in packaging design and testing analysis, Mr. Lim joined the R&D team and worked under the supervision of the project leader Mr. C.K. Ong. APS expected Mr. Lim to help develop the paper lead-frame technology for IC packaging and to be the liaison person with the research institute to access the facilities and expertise. It took Mr. Lim half a year to understand what Mr. Ong's team was doing, navigate different directions with the team, and fully integrate into the company. Within the following one and half years, using his modelling and simulation capabilities, he helped to conduct thermal mechanical stress analysis in the flip-chip design. Knowing the advanced material testing and analysis equipment in IME, he also helped to identify the failures more effectively in the later stage of the packaging design process and hence speeded up the entire R&D progress. After two years, in 2009 the R&D team successfully developed a new packaging solution which has been awarded one patent with another six patents pending. The solution has generated tremendous interest and demand and has been licensed to two major clients in the industry. This has supported the company's expansion overseas. Mr. Lim also helped to push R&D in a process innovation which not only assisted the manufacturing of the packaging solution but also generated extra revenue through other applications in the industry.

Besides R&D, Mr. Lim participated in patent application and IP (intellectual property) management. Due to his previous patent filing experience in IME, Mr. Lim was asked to take up the patent filing jobs. In 2009 when the company's IP consultant left, Mr. Lim took over the IP management job. He also helped to link the resources from National University of Singapore and the company's needs in the area of IP. This was essential to the company's transition from the traditional manufacturing business model to the new IP licensing (technology transfer) business model. "*His work has helped APS to develop its new business model as an IP creation and licensing company*", said Mr. Jimmy Chew, the CEO of APS.

When asked about Mr. Lim's contribution to APS, Ms. K. M. Lee, the Finance & Administration manager of APS said, "*We are very pleased with Raymond's performance and the ideas he has contributed to our projects. He surpassed our expectations. On top of that, he has excellent work attitude and has adapted very well into our work environment.*" After two years in the T-Up program, Mr. Lim found that his expertise and interests had expanded so much that he was drawn much more to the job in APS than his previous job at IME. At the same time, the leaders of APS found Mr. Lim to be irreplaceable in the company and hence offered a premium package to retain him. Mr. Lim became the first seconded engineer from IME who stayed on in the SME, one of the few T-Up researchers to have done so. Today he is the Director of Technology & IP management in APS, leading two other newly-hired IP experts in strengthening and protecting APS's core competency. The packaging solution he helped to develop has been granted 11 patents and licensed to ten companies.

The case of APS shows how the T-Up secondment scheme benefited both the SME and the seconded engineer. While the seconded engineer helped the SME to develop new products, establish new competitive advantage, increase its revenue and employment, and strengthen its ties with the public research institute and university, the SME also helped the seconded engineer to expand his knowledge pool and skill set, re-identified his career goal, and nurtured his personal development in the industry.

Another example is Addvalue Communications Pte Ltd., which also "T-Uped" with IME (Institute of Microelectronics). The researcher – Mr. Zhao Bing from IME – assisted to convert a FPGA baseband to an ASIC design for its INMARSAT satellite communication system in design simulation and timing analysis for netlist, enhancement of chip architecture (modular interface), and improvement of interface with external chips, such as SRAM and micro-controllers. These new capabilities gained by Addvalue enabled the company to design new ASIC-based basebands for future products. With the new ASIC design, Addvalue projected a conservative estimated savings of US$240K per year, based on US$60 per terminal and a sales projection of 4000 terminals a year. During our interview, the vice president of the company Mr Kevin Peng said: "*Zhao Bin has been instrumental in assisting Addvalue in the synthesis and static timing analysis closure for the ASIC … Addvalue would like to express a sincere and heartfelt gratitude to IME for the ASIC GET-Up assistance and the upgrading of technological expertise of Addvalue in the ASIC domain.*"

These two cases well-illustrate the results from our qualitative analyses. In the case of APS, the seconded researcher helped the SME to gain new R&D capabilities, develop new products (i.e. paper lead-frame for IC packaging), improve the processes, and successfully commercialize the IPs. In the case of Addvalue, the T-Up secondee helped the SME to literally upgrade its R&D with new technologies and develop new capabilities by converting to ASIC design for various applications in commercialization.

In addition, our case studies revealed one positive outcome of the T-Up program which was not captured in the quantitative results, i.e. the increase in joint R&D projects between the SMEs and the public research institutes after T-Up. This is because during the T-Up period, regular interactions with industry have helped the public research institutes and the seconded researchers to better appreciate the needs and practices of the industry and hence became better prepared to work with them. An example is Singapore Asahi Chemicals and Solders Industries Pte Ltd. Graduating from being a T-Up participant and beneficiary, the company continued to carry out a number of R&D projects on lead-free solder materials development with the help of one public research institute – SIMTech. It benefited from having ready access to sophisticated R&D equipment and expertise in structural analysis and materials characterization in SIMTech, and hence achieved a breakthrough in a new lead-free solder which was fully compatible with the existing manufacturing process and which was qualified for production use by a number of MNC customers such

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as Matsushita and Sony.

The case studies presented illustrate how companies have benefited from the T-Up scheme in different ways. From the perspective of policy-makers, the success of T-Up contributes to a broader national objective. Commenting on the achievements of the T-Up scheme, Prof. C.C. Hang, the former executive deputy chairman of A*STAR and the chairman of the GET-Up steering committee in 2003, said: "*The public research institutes were set up by the Singapore Government to attract and nurture local and foreign R&D talent needed to support its knowledge-based economy development, especially the MNC operations in Singapore. The T-Up has enabled public research institutes to help in upgrading Singapore's SMEs which in turn support the innovative operations of MNCs. All these benefits and positive experiences have finally led to increased R&D collaborations between public research institutes and the upgraded SMEs, which once again has reassured the public funding agency the strategic importance of public research institutes in the growing knowledge-based economy.*"

6. Discussion

In this paper, we have outlined a unique scheme of using secondment of researchers from public research institutes to assist in the technology upgrading of SMEs which has been successfully implemented in Singapore since 2003. Findings from the surveys show that the scheme has generated positive impact on the technological capabilities, innovation performance and growth of participating companies. Additionally, selected case studies highlight that this approach addressed a wide range of challenges faced by local SMEs and inspired further R&D collaboration between the SMEs and public research institutes. The results imply that the public research institutes have found a more effective way to fulfil their mission of technology transfer to local industries and as a result they have developed better understanding of the industry needs which will improve their future R&D planning and efforts.

6.1. Theoretical implications

The success of T-Up and our findings have a few implications for the literature. We firstly posit that T-Up represents an alternative to the traditional modes of public-private technology transfer. In the literature, there is a multitude of theoretical models on the inter-organizational technology transfer process, from the early models emphasizing appropriability to the recent models built on the foundation of the Knowledge-Based-View (KBV) (Wahid et al., 2009). While there is great range in theoretical perspectives, the mechanisms of technology transfer in practice, especially from public to private sectors, are still largely confined to traditional modes like joint R&D and licensing (Bozeman, 2000). Amesse and Cohendet (2001) mapped the traditional contexts for technology transfer between organizations: identifying R&D contracting and outsourcing as one context, and buying and selling proven technologies as the other context. In both situations, the traditional modes of transfer, such as contract research and licensing, are typically used. The effectiveness of such traditional technology transfer modes depends on the transferability of the knowledge (i.e. how codified the transferred knowledge is) and the absorptive capacities of the receiving organizations (Chen, 2004; Tsai, 2001; Cohen and Levinthal, 1990).

The T-Up scheme transfers technology via manpower secondment which directly places R&D expertise trained by the public research institutes in the hands of the SMEs, thus mitigating the issues of knowledge transferability. Respondents from both surveys in our study indicated that there was high degree of knowledge transfer from the seconded researchers, especially in the area of product technology. In addition, the seconded researchers would work with the R&D teams in the companies which would nurture the absorptive capacity of the company. Our findings from the survey support these statements. For example, over 50% of the participants in T-Up reported in the survey that they have gained new techniques, competencies or technologies.

Secondly, our study enhances current understanding of researcher mobility as an enabler of knowledge transfer. By presenting the practice and effect of T-Up, we contribute empirical evidence to the unresolved debate of whether mobility of personnel from the public R&D system would have positive impact on firms' innovation and performance (e.g. Kessler et al., 2000; Arvanitis et al., 2008; Edler, 2003; Edler et al., 2011). The survey results show that T-Up researchers from the public research institutions imparted new technologies to the SMEs and also improved their capacity for learning and innovation. Synthesized with the case study evidence, this suggests that T-Up not only provided the SMEs scientific knowledge and frontier technologies (Ahuja et al., 2008; Yli-Renko et al., 2001), but also expertise, inspiration, and capability to overcome the difficulties in the R&D process and create innovative solutions (Herrera et al., 2010). Since our subject firms are all SMEs, our findings complement Herrera et al. (2010) who found a positive impact of public researcher mobility in big firms in the high-tech sector.

The design of T-Up as a researcher mobility mechanism seems to well address the concerns about the cost of technology transfer (Herrera et al., 2010). For example, the cost of defining the content of the knowledge transfer is borne by the knowledge brokers (the T-Up team) from the government who visit the SMEs to understand their needs, discuss with the public research institutes, and bridge the two parties in personnel selection and secondment. In addition, the IP arrangement between the company and the public research institute is clearly defined – i.e. the SMEs are assigned the IP invented by the secondee while he/she works in the SMEs – which eliminates possible transaction costs and disputes over IP. The knowledge transferred via the seconded researchers includes not only the codified knowledge but also the tacit knowledge embedded in these researchers, hence reducing the uncertainty and stickiness during the transfer process (Szulanski, 2000; Arora and Gambardella, 2010).

Thirdly, our study contributes new perspectives to the growing Open Innovation literature. Due to their small size and skill resource constraints, SMEs are unable to conduct extensive internal R&D to generate their own technologies but still need a flow of new technology to be able to compete in increasingly competitive market spaces. As pointed out by Mayer and Blaas (2002), SMEs in recent decades have begun to utilize technology transfer as a strategic means of meeting challenges posed by the globalization of business and markets. This situation has created a new niche-market for technology transfer (Morrissey and Almonacid, 2004). In line with these arguments, open innovation (OI) offers an even broader paradigm of how companies interact with outside parties to exchange knowledge (Chesbrough et al., 2006). Most OI literature focuses on big multinational companies. Recent research in this area has been attracted to the OI activities in SMEs (Van de Vrande et al., 2009; Lee, et al., 2010). However, most of these studies focus on the OI in the technology commercialization process, leaving the front funnel of the OI in SMEs – the technology sourcing process – unexamined. The T-Up program offers a unique way to engage both the SMEs and the research institutes in OI by sourcing technology know-how, expertise, and personnel from the research institutes to the SMEs. Documenting this unique practice, our paper also fills the gap in the OI literature by showing how government can facilitate technology sourcing of SMEs and technology transfer from public research institutes to SMEs (Minshall, et al., 2013; van de Vrande and Vanhaverbeke, 2010).

This paper has also identified future studies that can contribute further to the literature on public-private knowledge transfer, researcher mobility and open innovation in SMEs. With data on control groups, the effectiveness of T-UP's researcher mobility model can be compared against other knowledge transfer mechanisms and other open innovation sources used by SMEs. Future studies should also be devoted to compare the T-Up researchers with other mobile researchers from the public sector and to study the reverse knowledge transfer after the secondment to industry.

6.2. Managerial implications

The success of T-Up shows that SMEs can upgrade their technology capability by sourcing knowledge from government research labs. From the perspective of SMEs, which typically contend with resources constraints and low absorptive capacity, two features of T-Up are salient: its collaborative structure as a form of open innovation and the researcher mobility approach. To benefit from public sector research and knowhow, SMEs should actively engage with public sector organizations in their knowledge search locus. Our empirical findings in this paper show that a majority of T-Up recipients gained new technologies and knowledge by being open about their technology needs to the government officials (i.e. GETUp team) and accommodating the researchers from the public research institutes into their firms. When compared with the control groups of non-T-Up-recipients, the T-Up recipients had improved innovation rate and sales growth, indicating the effect of open innovation. But this finding also shows that there is a delayed effect of T-Up on the firm's innovation performance. This is consistent with similar findings in Herrera et al. (2010), which suggests that it takes time for the effects of researcher mobility on firm performance to be visible. Hence, both the government and the SMEs should be cognizant that researcher mobility may not provide immediate quantifiable results and should be supported as a longer-term strategy for technology transfer.

Although the majority of the seconded researchers returned to the research institutes after their secondment with the SMEs, our case studies suggest that they may have become more market-oriented and sensitive to the needs of the industry. From the perspective of the research institutes, the T-Up secondment may therefore enhance the researchers' capabilities to do translational R&D, and may also strengthen the relationship between the research institute and SMEs and the industry as a whole. For instance, IME secondee Mr. Lim helped APS become familiar with the facilities and his ex-colleagues in the research institute even after his secondment and facilitated several subsequent research projects between APS and the A*STAR research institutes. While this case study provides one persuasive example, it will be interesting and potentially important for future studies to examine objectively whether and how the T-Up experience has benefited the researchers and research institutes. While it is evident that the program manager for GET-Up has done a very good job in implementing the unique technology transfer scheme, it is timely for the management to consider how the scheme could be further improved in the future, and analysis of the researchers' and research institute's perspectives would inform this process. Nonetheless, the preliminary findings in this paper suggest that research institutes should view government schemes like T-Up more favourably and be more proactive in despatching researchers to SMEs as secondees. Likewise, researchers should view the secondment as an opportunity to gain useful industry and market knowledge which will help them in their future career development.

6.3. Policy implications

One common issue faced in technology transfer from public research institutes is that technology maturity is often not at a market-ready level, thus affecting the transferability of the technologies (Chakrabarti and Rubenstein, 1976). Less mature technologies require further development by the transferee and more engagement with the transferor before they can be commercialized. Difficulties may arise when the inventors from the transferor organization cannot devote sufficient time to these development and translational efforts. The T-Up model of researcher mobility circumvents these concerns by placing the researcher within the SME. This is supported by the survey evidence showing relatively high rate of commercialization of T-UP projects in the long-run.

These findings, along with results on the degree of knowledge transferred, also suggest that transferring R&D personnel is potentially a much more effective way of transferring technology from public research institutes to SMEs, compared to traditional mechanisms such as licensing, While more specific data on control sample groups could be collected in future studies to formally test such hypotheses, this paper nevertheless contributes a new approach of public-private technology transfer. The preliminary findings using over ten years of data show that the T-Up approach has been effective. This suggests that the T-Up model of transferring personnel may be instructive for policy makers in Newly Industrialized Economies (NIEs) who are also trying to commercialize government-funded R&D results and upgrade the capabilities of SMEs.

An important lesson from the T-UP experience is that the researcher mobility brought by T-Up is well-motivated and supported by government, which is the major difference between T-Up and other researcher mobility schemes documented in the literature. T-Up incorporated a design that provides a safety net for the researchers to fall back on – i.e. after finishing the secondment they can choose to go back to the public research institutes. Without being concerned about the opportunity cost to them of secondment, the seconded researchers should have more motivation to transfer knowledge, bridge the public research institutes and SMEs, and create innovative outcomes. If they choose to go back to the public research institutes, they would also bring their industry experience along to help the public research institutes better understand the needs of industry. Additionally, the clearly-defined policy on IP assignment during the T-Up period alleviates concerns about potential IP disputes. When structuring a knowledge transfer program, policy-makers need to consider both the incentives and disincentives to the knowledge provider and knowledge receiver.

7. Conclusion

This paper presented the effects of a unique government initiative to transfer knowledge from the public sector to SMEs with both quantitative and qualitative data. In doing so, we have attempted to contribute to the literature of knowledge/technology transfer from public to private sector by offering an alternative approach of technology transfer, offer new evidence to the ongoing debate about the effectiveness of researcher mobility, and fill a gap in the open innovation literature by providing empirical findings on how SMEs could source technologies from the public sector via open innovation. Our findings suggest that SMEs can benefit from open innovation by incorporating domain experts from the public research institutes. Hence SMEs should openly share about their technology requirements and welcome public sector researchers into their firms. Likewise, public research institutes also can benefit from open innovation by dispatching

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researchers to the SMEs as the returning researchers gain industry and market knowledge and could strengthen the ties between the research institutes and industry. However, both SMEs and policy makers should view knowledge transfer as a long-term strategy and not expect immediate results. For policy makers, our findings show that government can effectively facilitate public-private sector technology transfer and commercialization by transferring researchers from public research institutes to companies for a considerably long period of time. The researcher mobility approach is an effective way to commercialize public R&D, contingent on providing adequate motivation and a safety net to researchers. While our focus on one policy-oriented program may limit its generalizability, the evidence presented in this paper delivers insights to the academic discussion in the management literature and generates practical implications for SMEs and policy-makers in the other NIEs similar to Singapore.

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