An Exploratory Study of Intra-firm Process Innovations Transfer in Asia

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Abstract
This paper examines how seven process innovations have been shared and adopted (or not adopted) between four factories of a multinational company located in Asia. In contrast to most previous studies in this area, these process innovation diffusions happened in a bottom-up manner in which the decision to share and to adopt is made by the individuals at the sites involved rather than by top management either at a local or corporate level. We observe that the factors enabling or discouraging the adoption of process innovation are highly dynamic. When work priorities shift over time, motivating factors once perceived as primary may become secondary, leading to non-adoption of the innovations. As the engineers face an increasing load of other tasks which also demand time and effort, the decision to adopt the innovation or not seems to depend more on the effort required to adapt the innovation for local use than other factors. Innovations which are highly embedded in the original settings face slimmer chance of adoption by other sites as they are likely to require more effort in adapting them for local use. In contrast, innovations which are less embedded in original settings are more likely to be adopted due to the low adaptation effort needed.
I. INTRODUCTION

As organizations grow larger and become truly global in outlook, the danger of ‘re-inventing the wheel’ due to poor communication and lack of understanding between divisions increases. Teece [22, p.55] observes that “the context in which knowledge assets are created and exploited is today truly global”. Knowledge accumulated from operations, be it know-what, know-how or know-why, is a critical source of core competence for multinational companies [5]. Despite the many publications in organizational learning and more recently, knowledge management, managers are still struggling with the task of avoiding “re-inventing the wheel” [13]. In a recent survey, Ruggles [21] reports that only 13% of the respondents think they are good at transferring existing knowledge into other parts of the organization, compared to 46% who believe they are good at generating new knowledge.

This paper describes a research project conducted with the aim to understand how knowledge – in the form of process innovation - is shared and adopted (or not adopted) between different factories in the same company. How does intra-firm process innovation diffusion happen? What are the factors affecting the adoption of process innovation? These are the two major research questions that the project tries to address.

The paper begins with a literature review in the areas relevant to innovation diffusion. The next section describes the research design and implementation, followed by the research findings and analysis. The paper ends by discussing the implications for practice and future research.
II. LITERATURE REVIEW

Researchers have long been intrigued by the ways in which innovations are diffused through different channels over time among the members of a social system. Rogers [20] provides an excellent review of this subject. According to Rogers [20], there are two types of innovation diffusion: centralized or decentralized. In centralized diffusions, innovations are created by technical subject matter experts in R&D centers and diffused through central administrators, who decide which innovation to diffuse and to whom. In contrast, in decentralized diffusions, the innovations are created by non-experts who are often users themselves. Since users are not dedicated R&D members, the innovation is likely to be incremental rather than radical, gained through learning on the job in a trial and error fashion. Unlike the top-down decision making in centralized diffusion, decentralized diffusions happen through peer-to-peer networks where the adoption decision is made by the receivers based on their own evaluations, i.e. in a bottom-up manner. Most research on innovation diffusions have been of centralized diffusions. Ahire and Ravichandran’s [2] study on TQM implementation, Kostova’s [12] study on transfer of quality management from US parent company to subsidiaries overseas and Gallivan’s [7] study on IT system adoption are some of the more recent examples of centralized diffusion studies. In contrast, decentralized diffusions within multinational companies have received a relatively little attention from researchers. This is surprising as much organization knowledge is distributed among individuals, groups, organizations and at a network level [17, 9]. As has been pointed out by Tsoukas [23], in an organization, there never exists a single mind to “specify fully in advance what kind of practical knowledge is going to be relevant, when and where” [23, p.11]. Given this characteristic, "the key
to achieving coordinated action does not so much depend on those 'higher up'
collecting more and more knowledge, as on those 'lower down' finding more and
more ways of getting connected and interrelating the knowledge one has"  [23, p.22].
In this light, understanding how decentralized innovation diffusion happens and
would enable companies to minimize the “re-invention of the wheel”.

A) Intra-firm Innovation Diffusion and Adoption Process

In studying innovation diffusion and adoption, researchers have been primarily
interested in two questions: a) how is innovation diffused and adopted by users, and
b) what are the determinants affecting the speed and success of innovation diffusion
and adoption. Among other findings, the first question has led to the conclusion that
innovation diffusions occur in stages (e.g. [2], [4], [18], [25]). Although different
authors have conceptualized different models, there is a general pattern of innovation
diffusion [25]. A decision-making unit first becomes aware of an innovation's
existence, which is then matched to a problem or opportunity. The innovation's cost
and benefits are appraised together with the sources of support and/or opposition
attempt to influence the process. A decision is made either to adopt or to reject the
innovation. If the innovation is adopted, the innovation becomes accepted as a routine
and the innovation is infused, i.e. is applied to its fullest potential. The succession of
stages seems moderately clear for simple innovations that are borrowed with little
changes, but for organizational innovations that are complex or unproven, the staging
sequence will overlap [18, 8].
B) Determinants of Intra-firm Innovation Adoption

The second common research theme is the identification and ranking of determinants to innovation adoption (e.g. [10], [1]). In a recent review of previous studies, Frambach and Schillewaert [6] group determinants affecting innovation adoption decision into five categories: 1.) perceived innovation characteristics (relative advantage, compatibility, complexity, trialability, observability, uncertainty), 2.) adopter characteristics (size, organization structure, innovativeness), 3.) social network (interconnectedness), 4.) supplier marketing activity (targeting/marketing, risk reduction) and 5.) environmental influences (network externalities, competitive environment). Their paper shows that most of the studies found similar relationships between the various determinants and innovation adoption, despite studying different types of innovation.

The bulk of the research has been of a deductive hypothesis testing nature attempting to identify, rank, and test the causal relationships between the antecedents and adoption decision. While these studies have enhanced our knowledge about the importance and relationships between different factors to knowledge sharing, there is a lack of understanding of how these factors interact [6]. This research aims to fill the research gap by studying how the various determinant factors interact, thus providing a richer understanding of the issues.

III. METHODOLOGY

The desire to understand the process of innovation adoption and the dynamics between various considerations call for a case study approach [26], as it allows the development of events under examination to be observed and traced in their natural
settings. In addition, the flexibility and use of multiple data sources allows rich and in
depth data related to the events under examination to be collected. Indeed, Van de
Ven and Rogers [24] believe that the interpretive approach holds considerable
promise for providing useful understandings in researching innovation diffusions. In
addition, a case study approach is also more likely to generate insights which are
practice relevant. As McCutcheon and Meredith [13, p.252] have pointed out,
“embracing a field investigation technique such as case study is bound to make the
individual research, and the field in general, richer and better prepared to solve real
operations management problems”.

We approached Alpha Asia (not a real name), part of the manufacturing operation of
Alpha Inc’s semiconductor business group, and were given permission and full
support by the Vice President of manufacturing to conduct the case studies in its four
factories in Asia. These plants are located in: Hong Kong (established 1967),
Malaysia (established 1972), Japan (established 1991) and China (established 1993).
These manufacturing plants assemble and test integrated circuits using largely similar
production processes, and in some instances, produce similar products. This similarity
in production technology and in products manufactured means that process innovation
created in one plant is likely to be relevant to other plants, thus increasing the need for
it to be shared and be reused.

The case studies were conducted in the following manner. The Factory Synergies
manager, who has the responsibility of fostering knowledge sharing in Alpha Asia,
was approached for key contacts in the respective four plants. These key contacts
(typically engineering managers in their respective plants), together with the Factory
Synergies manager, were asked for a list of recently adopted process innovations, including both those originated from other Alpha sites and those created internally, which had also been adopted by other Alpha operations. This inquiry generated a list of process innovations as potential case study materials. Selection of innovations to study was made based on the availability of data. Projects which involved plants that were no longer part of Alpha Asia as well as those with insufficient data had to be excluded (either due to lack of documentation or the engineers involved have left the company). Subsequently, field visits were made in the course of which interviews were conducted with the originators, the receivers as well as the key informants in order to glean information on the details of the transfer\(^1\). Semi-structured interviews were used as the primary data collection approach. The interviews were structured around the following questions:

**On Diffusion Process:**

- How did the receiver first come to know the innovation?
- How did the innovation get transferred to the receiver?
- What did the receiver(s) do to prove the relevance/usefulness of the innovation of their organization?
- What changes were made to suit the receiver’s circumstance? Why?

**On adoption consideration:**

- What was the innovation?

\(^1\) All the receivers (i.e. engineers adopting the innovation) were interviewed. Not all originators were interviewed as some engineers have left the company. Interviews with originators for innovations originated from Taiwan (Case Ib, and Case VII) were not possible because the plant had been sold in mid 1999. In these instances, the data was primarily from project documents. Key informants were plant R&D managers or immediate superiors to the engineers involved in adopting the innovations.
• Was the innovation adopted? Why?
• What are the factors that motivated the receiver to initiate the transfer and attempt to adopt the innovation?

In addition, project documents and copies of email correspondence conducted during the project were also obtained to supplement and to triangulate the data. Interviews, where permission was given, were taped and transcribed. Using this information, a case summary was written for each of the seven innovations studied. The factors affecting process innovation adoption and how these factors interact were examined in detail. The categories and patterns generated from each case were then compared and contrasted with the other cases. The similarities and differences between the cases were noted. The following table shows an overview of the seven process innovations studied. Except Case V and VII which were shared and adopted by only one other site, the other five innovations were shared with more than one site with mixed adoption outcome. Among these sites, Alpha Japan has not received any innovation, while there is no innovation originated from Alpha China. The reason for Alpha Japan not receiving any innovation may due to its superior manufacturing knowledge as compare to other sites. After all, it is commonly viewed that Alpha Inc established Alpha Japan in 1991 in order to access advance Japanese manufacturing technologies. The lack of innovation originating from Alpha China may due to its relative low level of semiconductor manufacturing expertise, as it was only established in 1993. In contrast, Alpha plants in Hong Kong (established in 1967) and Malaysia (established in 1972) have achieved a high level of manufacturing expertise over a long period of time.

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IV. RESULTS AND ANALYSIS

The results from the case studies are presented in two sections. The first section looks at the process in which the innovations were diffused. The second section looks at the factors which affect the decision of process innovation adoption.

Table 2 presents a summary of key activities happened during the diffusion of innovation using a four-stage process model. The process model largely follows previous studies by [6], [18] and [25]. However, the uniqueness of intra-firm innovation diffusions, as witnessed in the case studies conducted, suggests several changes to previous models in order to provide a more accurate tracking of major developments of the adoption process as well as for capturing the details of major activities. This resulted in a model comprising awareness, transfer, adaptation, and integration stages.

Awareness

This is the first stage of the process where the eventual-receiver comes to know the existence of relevant innovation which can help in solving a specific problem faced or in improving performance, either through formal (management hierarchy) or informal (peer-to-peer) channels. One informal channel often cited during interviews was the periodic meetings among engineers in the same manufacturing process from different Alpha plants. During these meetings, engineers meet and share information regarding new technology, quality and productivity achievements in their respective operations. Through these, “communities-of-practice” were formed, allowing the flow of
information through a peer-to-peer network. Informal channels seem to be a more effective channel in intra-firm innovation sharing than formal channels. Of the 13 adoption decisions, 8 had come to know about the innovation through the informal networks that exist between peers, typically through ‘word-of-mouth’. Although this is not surprising in cases where the originator and the receiver are located in the same factory (between Malaysia-A and Malaysia-B as in Case III.a, Case IV.a), informal networks seem to be also effective between factories located in different countries (i.e. Case III.b, Case III.c, Case IV.b and Case VII). The role of boundary spanner (the factory synergies manager in Alpha), acting in a semi-formal fashion, also helped in raising the awareness of existence of innovation among possible receivers. This form of communication constituted 31% (4 out of 13) in the case studies that were conducted. Comparatively, only one out of the 13 cases was a direct consequence of formal communication along the management hierarchy.

Transfer

The next stage is the transfer stage where the receivers learn more about the innovation (e.g. how it works) before proceeding to the evaluation state. The primary knowledge transfer method was the transfer of evaluation reports from the originator to the receiver, which were sent through emails. Receivers were most interested in how the innovation worked in the originator’s setting so that they were able to conduct similar experiments to test and adapt the innovation. Face-to-face meetings only took place when the originator and the receiver were located on the same site (Case I.a, Case III.a and Case IV.a). This approach was taken because of the easy accessibility rather than because of the complexity of the knowledge. However, in Case VI.a, the receiver did not meet the originator (for the purpose of this transfer) or
visit the equipment, even though it was located in the same building albeit on different floors as the receivers were able to understand the innovation and how it worked simply by listening to the idea behind the innovation. A tele-conference was only held in Case VI.b as the receiver needed to clarify the problem encountered by the originator, which led to the process innovation. The extensive use of email and relatively scarcity of face-to-face meeting in these knowledge sharing cases suggest that cost is a strong key consideration in the decision of the transfer medium. This is not surprising because of the inherent difficulty in measuring the potential improvements these innovations might provide.

It is worth noting that while the basic ideas behind these innovations seem simple, the implementations require a high level of expertise. Hence, it is the receiver’s capability and skills that make the transfer seem relatively easy. In other words, the complexity involved is relative to the capability of the receiver. This point is illustrated clearly in Case I.a where the technician of the receiving operation (i.e. PQFP) understood the situation simply by mere descriptions made by the originator without having to refer to technical drawings or to see the equipment itself.

**Evaluation**

Once the transfer has been carried out, evaluation and adaptation activities can begin. The evaluation stage is when the greatest effort is needed. At this stage, the receiver conducts experiments or trial runs to confirm the applicability of the innovation, to assess the cost, and at the same time to adjust the parameters to suit the local environment. The case studies reveal that many factors motivate a need for thorough evaluation. The differences in equipment (in all cases), product (in all cases) and in
the material used (in all cases) in the particular manufacturing process as well as downstream (Case III, V) of the manufacturing process affected by the innovations were all taken into account. This ‘ultra-cautious’ mentality was a result of the high emphasis on quality in Alpha.

**Adaptation**

Adaptation is the stage in which the receiver customizes and implements the necessary changes for the innovation to work under the local conditions. Common activities include the change of process parameters (in all cases), sourcing material locally for cost and consistency supply reasons (as in Case VII) and incorporating changes into the relevant procedures or specifications. Although in general an adaptation takes place after the evaluation, adoption is closely linked to the evaluation stage, as can be seen in the case-studies. As many of these innovations were incremental in nature, the necessary degree of adaptation tended to be small.

Four factors have emerged from the case studies, i.e. perceived benefits, management influence, urgency of need and the resources needed. Table 3 shows a summary of these factors in each of the cases. The emphasis here is not on finding an exhaustive list of factors but to gain insight on how these factors interact during the knowledge sharing process.

**Perceived Benefits**

The receivers initiated the transfer process on the assumption that the innovation that was to be adopted would benefit their operations, based on what the originator had
managed to achieve. These benefits were, to the receivers, ‘tentative’ because the innovation might not bring the same level of benefits due to the differences between the originators’ and the receivers’ environment. These benefits could either be an improvement in the product quality, a reduction of production cost, the shortening of the manufacturing cycle time, or the fulfillment of new manufacturing requirements which have to be met because of the introduction of a new product. Many of these innovations brought simultaneous benefits in terms of quality, cost and cycle time. The perceived benefits can be ‘high’ when the innovation was likely to bring significant benefits to the receiver such as resolving a customer complaint, by reducing production costs or production lead time significantly or enabling the production of a new product. An example of high benefit was the solving of a customer complaint in Alpha China when they adopted ejector pins of a larger radius, an innovation originated from Alpha Taiwan (Case I.b). A similar case was the use of “vanishing oil” (an oil-based lubricant which evaporates quickly in room condition) Alpha Malaysia-A, which was adopted from Alpha Hong Kong (Case V) which has reduced the built up of excessive tin at the trim and form operations. Without these process innovations, the departments involved would continue to experience reliability-related customer complaints from major customers. In Case III.a, III.b, and III.c, the innovation - the use of X4 wire in wirebonding operation - had enabled the production of fine pitch products at the receiving sites, thus avoiding possible delay in new product introduction and low production yield. Sometimes the innovation might only bring marginal benefits where the adoption of the innovation would improve current manufacturing performance marginally. In Case II.b, the receiving site experienced a small degree of delamination problem compared to the originator (Japan) which the innovation has successfully resolved. In addition, the root cause of
the delamination was believed to be not from the leadframes that were being used (which was the root cause in Japan’s case). In Case VI.b, the receiving site, Alpha Hong Kong, believed the causes to their product defect were different from those of Alpha Malaysia-A (the originator) even though the defects were of similar type. Thus, the solution to Malaysia-A’s problem was not likely to solve the problem faced by Hong Kong.

**Urgency of Needs**

The second motivating factor is the urgency of need to adopt the new process innovation. The urgency to adopt the process innovation varies for the receivers. In very urgent cases, the innovation is perceived to be able to solve an immediate problem such as a customer complaint (Case Ia, Ib, V, and VIa) or the launch of a new product (Case IIIa, IIIb and IIIc). In Alpha, customer complaints are major issues for top management. This is due to the fact that many of their products are sold to large multinational companies where a few customers dominate their sales. In this context, even a small number of customer complaints on product defects may result in serious loss of business as these customers buy a large volume of products. Some of the products are used in automobiles which can involve safety issues such as in Case V and VI.a. Innovations which enable the smooth launching of a new product are also urgently required by receivers. These include case IIIa, IIIb, IIIc where the use of the new wire at the wirebonding process has enabled the launching of a new product.

In other cases, the urgency of adopting the innovation is less - particularly when the innovations are perceived to be one of the many continuous improvement activities to reduce cost and improve quality (case II.a, IVa, IVb, VII) or were only experiencing a
very low incidence of the same problem which the innovation was trying to solve (case II.b. VI.b).

Management Influence

The case studies also revealed that the ways in which the receivers came to know about the innovation also affected the willingness to try out the innovation. Receivers often perceived a strong management preference if they were made aware of the innovations by direct or indirect managers. Management influence was often implicitly assumed by the receivers rather than by an explicit instruction from the management. This point was obvious in Case II.b and in Case VI.a where the receivers commented that since they were informed about the innovation by the factory synergies manager, a senior and well regarded technical manager in Alpha Asia, they saw it as ‘preference’ by the management to adopt the innovation. The Hong Kong engineer in Case II.b, said:

“Even though we didn’t have a major delamination problem, some colleagues said we should try it too, especially when the information came from Kumar (the Factory Synergies Manager)”.  

William, the engineer involved in the Case VI.a, echoed:

“Because the information came from Kumar, we tried it. It was obvious. The message was top-down”.

Sometimes management exercised the influence fully where receivers were forced to accept the new innovation, as demonstrated in Case VI.a and VI.b. Although Hong Kong did not adopt the innovation on existing tools because of the high modification
cost, Kumar, the factory synergies manager, decided that all new tools in Alpha Asia must incorporate the innovation because he believed that the new design was technically superior. Correspondingly, if the innovation was made aware by a peer, the perceived management influenced is generally considered to be low.

Despite the high management influence, Case VI.b was not adopted because the evaluation showed that there was no possible way of incorporating the innovation because of limited space in the forming tool. In Case II.b, the priority of adopting the innovation from Japan had been relegated because of more urgent tasks. The latter suggests that management influence is not static, but changes over time.

**Effort Needed**

To adopt and apply knowledge created elsewhere requires efforts from the receivers to contact the knowledge holder, to retrieve, evaluate and adapt the innovation. These efforts require resources such as the engineer’s and production time to conduct experiments, collect and analyze the data, resources such as raw materials as well as production capacity as the experiments or trial runs were typically conducted on production machines. Much effort was spent on evaluating the innovation in order to confirm the applicability and at the same time on optimizing the innovation to suit the local environment. These efforts included conducting experiments, modifying equipment, communicating and discussing with the originator of the innovation, and contacting suppliers for local material sourcing. Some of the changes were undertaken by the suppliers involved (Case II, Case VI), reducing the demand for resources on Alpha. The case studies suggest that a high level of effort needed to receive, evaluate and adapt the innovation act as a barrier to innovation adoption.
It is difficult to categorize the degree of effort needed because each plant has different manufacturing resources. For instance, Alpha Malaysia was perceived to have more engineering and manufacturing human resources than Alpha Hong Kong, i.e. there were more engineers and operators per product manufactured in Malaysia than in Hong Kong. One possible reason is the lower labor (skilled and unskilled) cost in Malaysia.

V. DISCUSSION

The case studies suggest that the decision to transfer and evaluate is motivated by a combination of different factors, which include potential benefits, the influence of management authority and the urgency of needs (as drivers) as well as the effort needed (as a barrier). Once the receiver finds a justification, not necessarily in a conscious and explicit manner (more so when these factors are constantly changing), he or she will proceed to evaluate the applicability of the innovation in the local environment. As the seven cases have shown, compared to other stages of knowledge sharing, the evaluation consumed much of the effort. The effort requires resources such as time (for communication, analyzing results) and equipment capacity (for experiments and trial run) which are also demanded by other manufacturing activities (e.g. new product introduction and equipment maintenance). Thus, the whole adoption decision process is constantly under review (often in an intuitive manner) and compared to other activities that may bring higher benefits.

This dynamic nature is demonstrated clearly in Case III Japan – Hong Kong. Despite the low perceived benefits of the new innovation (there is not much of a problem of delamination in Hong Kong, which the innovation is supposed to improve), the Hong
Kong engineer decided to proceed because of the high management influence she perceived. However, a major process standardization initiative, which demanded more time and effort from the Hong Kong engineer, shifted the work priorities. The management influence became insignificant in the face of this more important task. As a result, the transfer attempt was halted. The demand for resources was also one of the reasons why the innovations generally took a long time (usually more than three months) to put in place.

As can be seen in all the case studies (except for Case II Japan – Hong Kong which did not proceed to the evaluation stage), much of the decision to adopt (or reject) the innovation (i.e. accepting the knowledge) hinges on the outcome of the evaluation. Even in Case VI PQFP – Hong Kong, the manager involved believed that if it had not been for the space limitation on the forming tool, they would have adopted the innovation even though they were facing a different problem from the originator (hence the solution was not relevant in Hong Kong). He notes:

“If there has been space in the die set, we would have adopted it. Even though we don’t have the problem at the moment, it doesn’t mean we will not have it in the future. The Malaysia design is a better design than our current design ...”.

In summary, although factors such as perceived benefits, management influence, urgency and the required effort will influence a receiver’s decision to transfer and evaluate the new knowledge, the decision to reuse depends on the outcome of the evaluation. Given that this whole process occurs in a dynamic environment - where different manufacturing activities are competing for the limited engineering and
production resources – the influence of these factors (i.e. perceived benefits, management influence, urgency and effort needed) are changing in the face of other priorities. The decision to evaluate or not the adoption is contingent upon the resources available at the moment of transfer and evaluation. Thus, the less resource required to evaluate the innovation, the more likely that the innovation will be adopted. If the trends found in Alpha can be generalized, then companies may achieve better decentralized innovation diffusion by reducing the differences between originator and receivers. The case studies at Alpha show that a lot of resources were needed to confirm and adapt the innovation for local use because of the differences between equipment, processes and raw material, even though in some cases, the plants were producing the same products. The significance of similarity between originators and receivers for intra-firm sharing can be seen from the following point pointed out by an experienced engineering manager in Hong Kong:

“... personally I think most of the time we want to fan in ideas but because equipment, package, lead count, positions are different, purpose is different, so it is very difficult to adopt fan in successfully”

Indeed the differences between plants seemingly producing similar products can be very high. Subtle differences in raw materials, type of equipment, process parameters, may hinder the swift sharing and adoption of process innovation from other similar plants in the same companies because of the huge amount of effort required to adopt them. The high demand to quality and product yield in semiconductor manufacturing means engineers take a very cautious approach, requiring thorough evaluation on the

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2 ‘Fan in’ is a jargon used in the Alpha to describe the adoption of an innovation from elsewhere. In contrast, ‘fan out’ is a term to describe the adoption of innovation created locally by another Alpha factory.
in-coming innovation before it can adopted locally. In addition, contrarily to common assumption, the manufacturing knowledge of hi-tech products like semiconductors, may not be well understood [3]. This inevitably means the process innovation – created and proven effective to solve a problem in a particular factory – is embedded in the innovator’s settings. The case studies reveal two groups of factors which contributed to this embeddedness of the innovation: factory location related factors and production technology related factors.

Firstly, the location of the factory can cause embeddedness because the supply of raw material and/or the supplier of technological capability can be location-specific. The increasingly close relationship between suppliers and customers means that some organizational knowledge which underpins the process innovation can be dependent on the supplier and the relationship between them. Thus, any attempt to transfer and reuse this process innovation has to take into account the availability of similar supplier capabilities of the recipient site. This is evident in the case of Case I.b, the Chinese engineer (the receiver) had to resort to alternative material because the raw material used in Alpha Taiwan (the originator) was too expensive (making the cost reduction improvement meaningless) if sourced from Japan, as Alpha Taiwan did. In contrast, the knowledge of X4 as a suitable wire for fine pitch bonding could be transferred and reused by Alpha Hong Kong (Case III.b) and Alpha China (Case III.c) because the wire supplier was able to supply to these two factories.

The second group of factors which contributes to embeddedness is the type of production technology. This factor is apparent in all the seven cases studies where the receivers had to spend a great deal of effort to confirm the relevance of the innovation
as well as adapting it for local use, as the innovations were embedded in the type of equipment and technology used by the innovator. The choice of manufacturing technology of a factory is often a direct consequence of management actions, underpinned by their strategic beliefs. Before early 1999, Alpha Inc., believing that time-to-market is the most important competitive advantage, delegated decisions related to manufacturing activities (e.g. equipment, production processes, materials) to individual business group (which is organized by product) and to factory management. It was believed that, by doing so, the manufacturing operations will be highly responsive as each factory was free to make the decisions deemed most appropriate to them. However, this approach resulted in high disparities in terms of the equipment, processes, and materials used between among Alpha factories as each sought a best decision based on cost, previous experience, relationship with local suppliers and other considerations. For example, Alpha Japan would use Japanese-made equipment because of the good local support, ease of maintenance, and high mean-time-between stops (MTBS) while Alpha Malaysia would prefer equipment of lower capital cost and high throughput. Consequently, the result was that knowledge created in one factory has a high embeddedness, impeding swift reuse in a sister factory despite the fact that these factories were manufacturing the same products.

The first group of factors – location related, may be minimized by ensuring factories – despite in different location – source from the same supplier. Indeed some companies brought along their suppliers when they started up a new manufacturing site abroad. Yet, this can only be done to a limited degree as not all suppliers are capable of supplying globally. Such an approach would also mean potentially higher cost and longer delivery time. This can be seen in Case VII where the receiver, Alpha China,
had to find a local supplier for the trim/form punches as importing them from Japan would be too expensive and take a long time. Indeed, this approach of attempting to source from a single supplier (especially if from home country) goes against one of the reasons of investing abroad – sourcing cheaper supply of materials than those in the home country.

The second group of factors – product technology related, can be overcome by ensuring strict standardization among factories producing similar products, thus lowering the possible effort require to re-evaluate and adapt an innovation by the receivers. An example of this approach is Intel’s Copy Exactly [11, 15, 16]. Copy Exactly is a methodology for replicating the equipment, processes and supporting system across all wafer fabrication sites which produces similar products. Once this is achieved, manufacturing of a product can be transferred from one factory to the other, and achieved the same yield and quality as in previous factories with relative ease. As Mlynarczyk [16] has identified, this approach minimizes the risk of achieving low start-up yields in new production sites as well as reducing the time required to transfer new processes.

Nonetheless, not every company may adopt a Copy Exactly strategy. Intel’s strategy is partially made possible by the ‘globality’ of the products (semiconductor chips). Not only is the end product, i.e. the chips, the same throughout the world, but the raw materials used in the manufacturing process are also well-specified and often similar. This allows a high level of standardization of manufacturing processes, irrespective of product market or manufacturing locations. By using a standardized manufacturing technology, knowledge created in one factory can be transferred and reused in a
different factory quickly as they do not have to be re-evaluated again, given that these factories are similar. The amount of communication between the sender and the receiver can be reduced to a low level as the receiver shares a similar context with the sender. This similarity in context also means that information communication tools such as emails are adequate to transfer the knowledge.

In contrast, companies with products which are less “global” may have to resort to a ‘idea sharing’ strategy, i.e. sharing the basic concepts where ‘copy exact’ is not possible because of the differences between production technology used in different plants due to the nature of product and company strategy. For instance, although cements having quite similar properties around the world, it is difficult for a cement manufacturer to implement a high level of standardization between different cement works as the main raw material (lime stone) used to manufacture cement has different material properties according to its location. This necessitates optimizations at individual plants in order to achieve maximum performance, resulting in variances in equipment and process. Nonetheless, the manufacturing processes at these works share similar underlying principles. As such, companies can pursue strategies which allow effective sharing of ideas and concepts behind local innovations but letting the respective works decide how these innovations should be adopted and implemented. This entails creating a knowledge sharing system which allows members from different factories can be made aware of each other’s innovations (such as annual factory manager meetings) which allows the receivers to identify and transfer the knowledge from the innovating sites through means such as benchmarking visit and secondment.
VI. LIMITATIONS OF STUDY AND FUTURE RESEARCH

The small number of cases and from a single company (albeit different plants) inevitably limit the generalizability and validity of the findings. Several uniqueness of Alpha warrants special attention when trying to generalize the findings. Firstly, the role of Synergies Manager in Alpha may have a direct impact on the level of innovation diffusion. Although it is not uncommon to have managers playing the role of boundary spanners in other multinational companies, the high level of seniority of Alpha’s Synergies Manager (of a vice-president level and the first Six Sigma black belt winner in Alpha from Asia Pacific) suggest that sharing of innovation within Alpha is of high management priority. Secondly, sharing of innovation is one of the performance measurements in Alpha’s various technical awards as well as senior staff promotion. The fact that there are established jargons such as fan-in (adopting an innovation originated outside the organization/site) and fan-out (transferring an innovation to other organization/site) suggests that sharing of innovation (and hence the knowledge underpinning the it) within the company has long been emphasized. Although companies are beginning to emphasize and reward knowledge sharing [19], the depth and spread of such emphasis in Alpha suggest it may take a few years before companies can see real improvement in intra-firm knowledge sharing.

To overcome these limitations, future studies need to examine decentralized innovation diffusion in a larger number of companies by using case study methodology or conducting a large scale questionnaire survey. In addition, factors such as organization culture and structure, information communication technologies (ICT) – which are likely to influence the speed and spread of innovation adoption – are not apparent in this single-company study. All the Alpha plants studied, despite
their different locations, share similar organization culture and use similar information communication technologies. By conducting studies in multiple companies, the effect of these factors on decentralized innovation diffusion may be identified.

VII. CONCLUSION
As manufacturing companies globalize, the opportunity to share and reuse knowledge multiply offering significant benefits in terms of improved efficiency, speed of response and consistency of quality. The research reported in this paper is based on detailed case studies of seven decentralized innovation diffusions. This complements earlier research which has concentrated mainly on centralized innovation diffusion which used a deductive hypothesis testing approach. The findings have two main theoretical implications. Firstly, in the context of bottom-up diffusion, the decision to adopt (or not adopt) an innovation appears to be a dynamic and long process where the significance of factors such as perceived benefits and effort needed may change over time, particularly when face with urgent or more important activities such as customer audit. Thus an initial decision to adopt an innovation may not necessary lead to eventual adoption, and vice versa. Most previous studies often assume that the adoption decision as one-off, as is implied by their antecedents-outcome models (e.g. [1], [6]). The latter do not take into account the changing significance of various factors over the often long period of time between the moment when the adopter becomes aware of the innovation for the first time to the transferring, evaluating, adapting, and eventually the adoption (or rejection) of the innovation. Secondly, external influence such as work priority appears to have a great impact on eventual adoption decision, particularly in deciding allocating resources for innovation adoption. Previous studies often concentrate on internal factors such as benefits and
complexity of the innovation, not accommodating adequately external factors during the innovation adoption process. For instance, in Frambach and Schillewaert [6]’s summary of antecedents of innovation adoption, the influence of environment is only measured in terms of network externalities and competitive environment at the industry level.

The intention to examine bottom up sharing of process innovation in detail meant that only a small sample size can be used. This inevitably limits the statistical validity and generalizibility of the study. Nevertheless some new insights have been gained which may contribute to the understanding of knowledge sharing and reuse. In particular:

- For decentralized innovation adoption, the decision to adopt an innovation is highly dependent on the effort needed to prove and adapt the innovation for local use
- This effort needed to prove and adapt the innovation for local use is related to the innovation “embeddedness”, which is caused by the plant location and the choice of manufacturing technology
- Multinational companies may adopt either an Intel’s style Copy Exactly to “ideal sharing”, depending on the nature of the product and process. It is important for companies to individually adopt strategies which are appropriate rather than “one approach fits all”.

References


<table>
<thead>
<tr>
<th>Case</th>
<th>Brief Description of Process Innovation</th>
<th>Originating Site</th>
<th>Receiving Site*</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Increase ejector pin radius of die bond equipment to avoid die crack</td>
<td>Malaysia-A, Taiwan</td>
<td>a) Malaysia-B, b) China</td>
</tr>
<tr>
<td>II</td>
<td>Add acid rinse process at leadframe manufacturing to reduce delamination of package</td>
<td>Japan</td>
<td>a) Malaysia-A, b) Hong Kong, c) China</td>
</tr>
<tr>
<td>III</td>
<td>Use of new wire - X4 in fine pitch devices in wire bonding</td>
<td>Malaysia-B</td>
<td>a) Malaysia-A, b) Hong Kong, c) China</td>
</tr>
<tr>
<td>IV</td>
<td>New mold cleaning method using NCS sheet to improve cleaning quality and reduce production cost</td>
<td>Malaysia-A</td>
<td>a) Malaysia-B, b) Hong Kong</td>
</tr>
<tr>
<td>V</td>
<td>Installation of vanishing oil spraying at trim/form to reduce sliver</td>
<td>Hong Kong</td>
<td>Malaysia-A</td>
</tr>
<tr>
<td>VI</td>
<td>Change of reset pin design to reduce patchback</td>
<td>Malaysia-B</td>
<td>a) Malaysia-A, b) Hong Kong</td>
</tr>
<tr>
<td>VII</td>
<td>New trim/form punches which reduces cost and improves quality of cutting</td>
<td>Taiwan</td>
<td>China</td>
</tr>
</tbody>
</table>

Table 1 Overview of process innovations studied

* Receiving sites refer to sites which were made aware and attempted to adopt the particular process innovation. Not all innovations were adopted eventually.
<table>
<thead>
<tr>
<th>Case</th>
<th>Originator</th>
<th>Receiver(s)</th>
<th>Awareness</th>
<th>Transfer</th>
<th>Evaluation</th>
<th>Adaptation</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>Malaysia-A</td>
<td>a) Malaysia – B</td>
<td>Informal, peer-to-peer network</td>
<td>Evaluation report from originator, sample parts Communication through phone, face-to-face, email</td>
<td>Ran experiments to confirm and optimize parameters (pin height)</td>
<td>Optimized process parameters, changed process and equipment maintenance procedure Replaced parts</td>
<td>Adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) China</td>
<td>Formal, management communication</td>
<td>Evaluation report from boundary spanner (through email) only</td>
<td>Duplicated originator’s experiment to re-confirm and optimize parameters (pin height)</td>
<td>Optimized process parameters Replaced parts</td>
<td>Adopted</td>
</tr>
<tr>
<td>II</td>
<td>Japan</td>
<td>a) Malaysia-A</td>
<td>Semi-formal, informed by boundary spanner</td>
<td>Evaluation report from boundary spanner (through email) Emails with originator Face-to-face (informal) to confirm evaluation data reported</td>
<td>Conducted experiment with new material (leadframe) together with existing material</td>
<td>Replaced old material with new material No change in process parameters or procedure</td>
<td>Adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Hong Kong</td>
<td>Semi-formal, informed by boundary spanner</td>
<td>Evaluation report from gate keeper</td>
<td>Assessed the potential benefits, discussed with supplier involved</td>
<td>No changes (Not adopted)</td>
<td>Not adopted</td>
</tr>
<tr>
<td>III</td>
<td>Malaysia-B</td>
<td>a) Malaysia –A</td>
<td>Informal, peer-to-peer network</td>
<td>Evaluation report from Intranet Informal face-to-face</td>
<td>Ran experiments to confirm validity of the new material (X4 wire)</td>
<td>Optimized process parameters. Bill of Material (BOM) updated.</td>
<td>Adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Hong Kong</td>
<td>Informal, peer-to-peer network</td>
<td>Evaluation report (email) from originator</td>
<td>Conducted pilot run (being new product) using new wire</td>
<td>Optimized process parameters. Bill of material (BOM) updated.</td>
<td>Adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) China</td>
<td>Informal</td>
<td>Evaluation report (through email) from originator Discussions using emails with originator</td>
<td>Conducted experiments to test and to optimize process parameters</td>
<td>New wire added to BOM and process parameters optimized.</td>
<td>Adopted</td>
</tr>
</tbody>
</table>

Table 2 Summary of case studies based on a 4-stage process model
Case | Originator | Receiver(s) | Awareness | Transfer | Evaluation | Adaptation | Outcome |
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>IV</td>
<td>Malaysia-A</td>
<td>a) Malaysia-B</td>
<td>Informal, peer-to-peer network</td>
<td>Evaluation report</td>
<td>Conducted experiments to test and optimize process parameters</td>
<td>No change (Not adopted)</td>
<td>Not adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Line visits and discussions with originator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Hong Kong</td>
<td>Informal, peer-to-peer network</td>
<td>Evaluation report (through email) from originator</td>
<td>Conducted experiments to test and optimize process parameters</td>
<td>No change (Not adopted)</td>
<td>Not adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Informal face-to-face meeting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Hong Kong</td>
<td>Malaysia-A</td>
<td>Informal, multiple sources from supplier, line visit</td>
<td>Emails to Alpha Hong Kong</td>
<td>Ran experiments to optimize settings and confirm validity</td>
<td>Changed location of kit</td>
<td>Adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Discussions with supplier (Hong Kong)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Equipment Kit from Hong Kong</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>Malaysia-B</td>
<td>a) Malaysia-A</td>
<td>Semi-formal, strong influence from boundary spanner</td>
<td>Evaluation report (through email) from originator</td>
<td>Modified tools to incorporate design</td>
<td>Machine drawing updated. Frequency of maintenance changed.</td>
<td>Adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Face-to-face discussion</td>
<td>Ran modified tool to valid ‘applicability’</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Hong Kong</td>
<td>Semi-formal, strong influence from boundary spanner</td>
<td>Evaluation report (through email) from originator</td>
<td>Discussions but existing tool design did not allow modification as in originator’s case</td>
<td>No change (because innovation was not adopted)</td>
<td>Not adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tele-conference with originator, boundary spanner</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>Taiwan</td>
<td>China</td>
<td>Informal, peer-to-peer</td>
<td>Evaluation report (hardcopy)</td>
<td>Source material locally Conducted experiments to compare different materials and identify best material</td>
<td>Frequency of maintenance (regrind) changed.</td>
<td>Adopted</td>
</tr>
</tbody>
</table>

Table 2 Summary of case studies based on a 4-stage process model (continued)
<table>
<thead>
<tr>
<th>Case</th>
<th>Perceived benefits</th>
<th>Urgency of needs</th>
<th>Management influence</th>
<th>Effort needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.a</td>
<td>High perceived benefits as the innovation is believed to solve customer complaints on die crack</td>
<td>High degree of urgency as the innovation may solve a customer complaint</td>
<td>Low management influence as it was informed by the originator in informal setting. On the receiving department – technician heard about the news from his counterpart while having tea breaks in cafeteria, while the engineer heard about the innovation through “communities of practice” group discussion.</td>
<td>Conducted experiments to adjust optimum pin height for a set of different sticky tapes which hold the die as the receiving site has die produced in different wafer fabs.</td>
</tr>
<tr>
<td>I.b</td>
<td>High perceived benefits as it would solve customer complaints on die crack</td>
<td>High degree of urgency as the innovation may solve customer complaint on reject due to die crack</td>
<td>There is an high implicit management influence as the as the engineer involved as made aware about the innovation by his immediate supervisor</td>
<td>Replicated originator’s evaluation to optimize parameters such as pin high and diameter for different dies.</td>
</tr>
<tr>
<td>II.a</td>
<td>Improve wirebonding quality as measured by stress test albeit at a lesser degree due to the difference in molding compound used</td>
<td>Low urgency as the receiving site did not experience any immediate problem which the innovation addressed, although the innovation will improve the quality of wirebonding process</td>
<td>High management influence as the innovation was made to the engineer involved by the regional manufacturing director</td>
<td>Contacted local supplier to provide samples of leadframes and conducted experiments to compare new and existing material.</td>
</tr>
<tr>
<td>II.b</td>
<td>Low perceived benefits as the receiver only experienced a very low level of problem which the innovation (on leadframes) is addressing, and is believed not to be caused by leadframe</td>
<td>Low urgency of needs as the receiving site only had a low level of delamination problem – which the innovation is supposed to solve</td>
<td>High management influence as the engineer was informed by her manager, who in turn was informed by his supervisor about the innovation</td>
<td>Meetings and discussions with peers as well as the leadframe manufacturer on the relevance of the innovation, but no evaluation was conducted.</td>
</tr>
<tr>
<td>III.a</td>
<td>High perceived benefits as the innovation allows the launch of a new product</td>
<td>The innovation is urgently needed so as not to delay the launch of a new product</td>
<td>The management influence is low as the receiver was made known through informal conversations with the originator</td>
<td>Ran evaluation with new material to confirm validity and optimize wirebonding process parameters.</td>
</tr>
<tr>
<td>III.b</td>
<td>High perceived benefits as the innovation allows the production of a new device</td>
<td>The innovation is urgently needed for the launch of the new device</td>
<td>The innovation was made aware to the receiver by the US product engineers who oversees the launch and the quality of the product. The influence is perceived to be high by the receiver as the innovation was a ‘preference’ from the US product engineer.</td>
<td>Ran evaluation with new material to confirm the validity and to optimize wirebonding parameters</td>
</tr>
<tr>
<td>III.c</td>
<td>The perceived benefits is high as the innovation is believed to improve production yield substantially of a new product</td>
<td>High degree of urgency as the new product was experiencing a low yield problem.</td>
<td>The influence is low as the innovation was informed to the receiver by a US wirebond engineer.</td>
<td>Requested supplier to present the properties of the new wire. Ran evaluation to compare new material (sent from Malaysia) with existing wire as well as to optimize the process parameters.</td>
</tr>
</tbody>
</table>

Table 3 Key consideration factors of innovation adoption decision
<table>
<thead>
<tr>
<th>Case</th>
<th>Perceived benefits</th>
<th>Urgency of needs</th>
<th>Management influence</th>
<th>Effort needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV.a</td>
<td>The perceived benefits are high as the innovation may improve molding process quality and reduce production cost.</td>
<td>The need is moderately urgent as the receiver does not experience particular problem with existing molding process. The innovation is one of the many continuous improvement activities.</td>
<td>The influence is low as the information came from the originator, who is another mold process engineer.</td>
<td>Discussions, line visits and observations at originator site. Further discussions with material supplier, and conducted experiments by varying different mold temperature to test out the new mold cleaning sheet.</td>
</tr>
<tr>
<td>IV.b</td>
<td>The process innovation is perceived to has only marginal benefits as the receiver site already is using a similar but different version of mold cleaning material which the innovation is about.</td>
<td>There is no immediate need to implement the process innovation as the existing molding process has no immediate quality problem.</td>
<td>The receiver heard about the innovation during a meeting of mold process engineers. There is no management directive to try out the process innovation.</td>
<td>Discussion with the material supplier and the originator in Malaysia through emails. Conducted evaluation comparing new and existing material</td>
</tr>
<tr>
<td>V</td>
<td>The process innovation can be high as it is aimed at solving customer complaints on patchback defects at trim and form process.</td>
<td>High urgency of need to try out the innovation to resolve a major customer complaint</td>
<td>The receiver came to know the innovation by their equipment manufacturer who informed them such process innovation was being used in their sister site in Hong Kong.</td>
<td>Emails with originator for information on the performance as well as the modification kit and its supplier. Conducted evaluation to find optimize location of kit and process parameters</td>
</tr>
<tr>
<td>VI.a</td>
<td>The process innovation is perceived to have high benefits as its can overcome the problem of excessive tin build-up at lead forming process. Such problem can cause major product defects.</td>
<td>There is a high degree of urgency as the receiver also experienced customer complaints and yield loss due to excessive tin build-up at forming tool.</td>
<td>There is a strong management influence as the Factory Synergy believed the new innovation is of a superior design than existing method. He has instructed all future forming tool to incorporate the new design for all sites.</td>
<td>Discussions with originator over possible results and material used. Tools were converted to incorporate the new design. Experiments were ran to confirm the benefits and establish new maintenance routine.</td>
</tr>
<tr>
<td>VI.b</td>
<td>Low perceived benefits as the receiver believe the innovation can not solve their tin excess problem which is believed to be caused by a different reason</td>
<td>Low urgency as the problem which the innovation addressed is thought to be not exist in the recipient site due to difference in tooling design</td>
<td>Strong management influence as the Factory Synergy manager was very concerned about tin excess problem at all Asian manufacturing sites</td>
<td>Discussions with originator and equipment manufacturer through conference calls and emails. Attempts to redesign tools but found not feasible due to difference in tool design.</td>
</tr>
<tr>
<td>VII</td>
<td>The innovation has high benefits as it may reduce tooling cost, improve product quality and increase machine up time significantly (by reducing the maintenance frequency).</td>
<td>The urgency to implement the innovation is moderate as it is seen as a continuous improvement activity</td>
<td>The management influence is low as the receiver heard about the innovation from in their annual trim and form process meeting and initiative the transfer.</td>
<td>Sourcing material from local and international suppliers Evaluation to compare different types of material</td>
</tr>
</tbody>
</table>

Table 3 Key consideration factors of innovation adoption decision (continued)