Facilitating New Product Development with Collaborative E-Commerce System: An Investigation in Semiconductor Industry

Chieh-Min Chou
Department of Information Management, National Central University

Jen-Ming Chen
Institute of Industrial Management, National Central University

Abstract

The trend of vertical disintegration in semiconductor industry promotes more and more collaborative e-commerce applications for interchanging business information and facilitating timely and efficient communication between the specialized firms. While previous literature focused on the operational performance enhancement of e-commerce system (ECS) usage, this study contributed to increase understandings on the performance of using ECS to facilitate new product development (NPD) process through combining qualitative and quantitative methods in a two-phase case study. This study found that the specialized firms mainly leveraged the collaborative e-commerce systems to facilitate the "technical dialogue" between design and process engineers to conquer the technological knowledge integration issues in NPD process. With support by real transactional data, ECS usage has positive impacts on NPD performance and the design-related ECS accounts for the most of performance variance. In general, the integrated device manufacturing and the fabless customers have different effects of using ECS on NPD performance. With respect to the firm's location, the eastern companies obtain better NPD performance than the western companies by using those ECS. This study suggests that a foundry company should develop different ECS services to support various customers in terms of organizational type and geographical location.

Key words: E-commerce, Semiconductor Industry, New Product Development, Collaboration.

以協同電子商務系統促進新產品開發：以半導體產業為例

仇介民
中央大學資訊管理學系

陳振明
中央大學工業管理研究所

摘要

半導體產業的垂直分工趨勢促使愈來愈多的跨企業電子商務系統應用於大量商業資訊交換及溝通平台的建立。相較於過去眾多文獻集中於探討跨組織資訊系統於提升作業效能層次的研究，本文討論跨企業電子商務系統在促進新產品開發的效益。本研究採兩階段個案研究整合定性及定量研究方法。階段一透過深度訪談發現專業設計及製造廠商主要運用電子商務系統促進協同新產品開發過程中設計、工程及後勤階段必要的「技術對話」以克服跨組織知識整合上的劣勢。階段二則以實際企業間交易資料分析使用各種電子商務系統的效果。研究結果顯示，各類電子商務系統的使用均正向相關於新產品開發效能，而以支援設計相關活動系統的使用效果最大。整合元件廠商與積體電路設計公司在電子商務系統使用模式上有顯著差異，而亞洲公司在電子商務系統使用效果上顯著優於歐美公司。本研究建議晶圓代工廠商應針對不同客戶型態及文化差異提供不同的電子商務服務以促進行跨組織協同新產品開發效能。

關鍵字：電子商務、半導體產業、新產品開發、協同合作

1. INTRODUCTION

After several decades' evolution, the global semiconductor industry has been appearing a complex network structure that comprises of a variety of vertically integrated and specialized firms. On the one hand, the integrated device manufacturer (IDM) designs, produces, and markets its own products and thereby takes advantages of hierarchy mechanism to coordinate the product design and manufacturing process for gaining the competitive advantage of cost effectiveness and the unique integrated knowledge assets. On the other hand, specialized firms such as the integrated circuit (IC) design house (or fabless) and the silicon wafer manufacturer (or foundry), which only focus its core competency on product design and manufacturing respectively, try to gain comparative advantage from their specialties and take advantages of market mechanism to exchange the specialty assets and lower the entry barrier of industry. However, the high interdependency between sophisticated manufacturing and design technologies incurs huge communication cost for the two specialized entities in developing a new IC product collaboratively. If the communication cost of the specialized firms were higher than the integrated firm's management cost, the diseconomy of inter-firm coordination between design and manufacturing functions would become a key incentive for vertical integration (Monteverde, 1995). Recent studies seem to support the evidence that advances of information and communication technologies, especially those internet-based applications, have significantly enhanced the efficacy of inter-organizational communication and collaboration that contributes a lot to the success of "disintegration" model in semiconductor industry (Macher et al. 2002; Dhayagude et al. 2001). Professional market research institution also endorse the industrial disintegration trends with reporting the specialized semiconductor foundry already became the main manufacturer that account for more than 20% worldwide semiconductor production and predicted the ratio will grow to 50% (IC Insights 2005).

Both the fabless and the IDM, named "product firms" collectively in this paper, are possible to jointly develop new IC products with the foundry. Without self-owned production facilities, the fabless has no choice other than outsourcing the wafer fabrication activity to the foundry for delivering their products to the market. As to the IDM, if the foundry can well protect their intellectual properties and provide attractive price, it could also leverage the foundry's manufacturing capacity as a buffer to fulfill the uncertain demands. No matter the fabless or the IDM, they have to heavily exchange design and advanced process technological knowledge with the foundry for assuring the high production yield, which is the most important competitive factor of low cost. The collaborative new product development (NPD) process necessitates the cost-effectiveness e-commerce system (ECS) solutions to reduce the huge cost and increase productivity of inter-firm communication and coordination especially when the distance is far between the two parties' location. Although some academic and practical researches already qualitatively described the importance of information systems in such a collaborative NPD process, the statistical test on the correlation between the ECS usage and the NPD performance under the semiconductor industrial context has not been conducted.

To better understand the application of ECS in the collaborative NPD process and the relationship between the ECS usage and collaborative NPD performance, this study proposed a two-phase research design for utilizing the advantages of both qualitative and quantitative research techniques that provided data and methodological triangulation to increase research validity in this case study (Creswell 1994). At the first research phase, this study selected a foundry company to conduct experts interviews for collecting in-depth qualitative data that described how a foundry facilitating collaborative NPD activities with particular ECS. At the second research phase, based on the interview archives analysis and literature review, this study proposed a set of preliminary hypotheses on the relationship between ECS usage and collaborative NPD performance for empirical test. Real business transactional data of collaborative NPD projects and ECS usage time of 106 sample semiconductor companies were collected for statistical analysis.

The rest of this paper is organized as follow. Section 2 presents a brief review of relevant literatures for giving a background to this research. Section 3 reports the case company profile and qualitative data analysis. A set of preliminary hypotheses about the relationship between the ECS usage and the collaborative NPD performance was developed in section 4. The quantitative data analysis and hypotheses test results are presented in section 5. Finally, research findings and managerial implications are discussed and the suggestions for future study are provided in the last two sections.

2. LITERATURE REVIEW

Before the advent of the foundry business model, most of the semiconductor firms vertically integrated both design and manufacturing functions under one roof (Dhayagude et al. 2001). There were many advantages of taking the vertical integrated organization form in the semiconductor industry (Monteverde 1995; Holbrook et al. 2000). One of the most popular and convincing theoretical explanations is based on transaction cost theory. Firms would integrate vertically to avoid high transaction costs incurred by bilateral monopoly (Besanko et al. 2004). That is, if one or both trading parties were requested to invest transaction-specified assets for the minimum cost production, they might have the motivation to merge as a single hierarchy because it is a more efficient governance structure to reduce opportunitism (Williamson 1999). Monteverde (1995) identified and tested the “unstructured technical dialogue” was one of the major transaction cost that promoted vertical integration in the semiconductor industry. From this viewpoint, inferior technical dialogue coordination mechanism through the market could be the main disadvantage of adopting the specialized organization form. Thus, the fabless should have incentive to integrate manufacturing function in the long run because it could take the advantages of better coordination of technical dialogue and of avoiding the risk of manufacturing capacity insufficiency (a specialty asset controlled by the foundries) over the upturn period of business cycle. Based on the author’s inference, the foundry might lose its legitimacy of existence if it were not able to conquer the transaction cost problem of inter-organizational technical dialogue.

According to Dhayagude et al. (2001), there are three kinds of transaction costs that led semiconductor firms to adopt IDM model. The first one is the “Intellectual Property Risks”. It’s meant by that when the fabless revealed its product design to a foundry, it would take a risk that its design know-how might be leaked to its competitors by the foundry. The second transaction cost comes from the “Hold Up” issue. Without its own production capacity, the fabless always has to face the capacity shortage risk. It frequently happens especially in the upturn period of the business cycle. The third transaction cost is the “Communication Difficulties”. In practice, there are many electronic design automation (EDA) tools used in different product development stages from high-level architecture design to physical circuit layout. Due to the diverse EDA tools might adopt different data formats, terminologies and communication protocols, the cost of aligning and integrating these tools among the collaborative partners became very high.

More and more famous semiconductor companies such as Freescale (previously known as Motorola) and LSI Logic had announced to move to so-called “Fab-Lite” or Fabless model. To some extent, it indicates that the industry seems to become more and more specialized. Some studies (Macher et al. 2002; Dhayagude et al. 2001) had been trying to explain the trend of moving to disintegration in this industry from the perspective of the economy of scale in production and the effective reduction in transaction cost. Currently, the major challenge was placed on mitigating the “Communication Difficulties” cost because that the “Intellectual Property Risk” and “Hold-Up” issue are relatively easy to be resolved by cautious business contract formation. Since the advanced design and manufacturing technologies and the related EDA tools knowledge spread in different specialized firms among the collaborative partners, how to cost- effectively coordinate the team members becomes one of the key success factors in the collaborative NPD process.

Generally speaking, NPD is a complex problem-solving process of developing products based on customer’s requirements that are ambiguous (Rodgers et al. 1999). It involves multidisciplinary members who are independent to complete NPD activities (Xie et al. 1998). For a semiconductor firm, the performance of a new IC product is jointly decided by the excellent circuit design and the advanced process technology to implement it. In other words, a successful IC product requires the closed cooperation of skilled experts both in design and manufacturing. Owing to the collaborative NPD product designers and the process engineers belong to two different firms, the needs for technical dialogue between them could be frequently and costly. Wheelwright and Clark (1992) found that effective technical dialogue is particularly critical in collaborative NPD because of the cross-functional technical project characteristics. In the semiconductor industry, the technical dialogue could be categorized into two types in terms of the occurring point in different product development stage. The first type of technical dialogue was design-related and its goal is to make sure that the product designers take the full advantages of process technology (TSMC 2001). If the process technology were improved, the designers should be informed about the change notice and obtained the newest design rules and other design parameters for refining the circuit design with the new data. The other type of technical dialogue is engineering-related (Macher et al. 2002) and its goal is to make sure that the product can be produced in the highest yield. Due to the semiconductor fabrication comprised of very complex physical and chemical processes, there are numerous causes that result in low yield production that could be occurred by contamination in a specific process step or by the rule-violation design. To resolve the production yield problem in collaborative NPD process, the process technology experts need to work with the product designers to find the root causes.

In response to the shortened product life cycle and rapid technological change, many manufacturing firms pursue collaborative NPD strategy for gaining competitive advantages (Krause et al. 1998). However, the success of this strategy will depend on the performance of collaborative NPD. Lam and Chin (2005) found that inter-organizational communication, especially the technical dialogue, is a critical success factor of collaborative NPD through a large-scale survey across different industries. Lack of cost-effective and efficient technical dialogue could frequently induce conflicts in collaborative NPD thereby results in inferior NPD performance. Boubekri (2001) and Humphreys et al. (2001) indicated that the information systems are the enablers of inter-organizational collaboration and can improve the communication between the partners. Lam and Chin (2004) also showed the information system is a critical success factor of communication and conflict management in collaborative NPD process.

Plenty of theoretical researches studied on the inter-firm relationship and argued the possible significant strategic advantages of inter-firm collaboration. Dyer (1998) claimed that firms could obtain competitive advantage by realizing the relational rents, which might come from relational-specific assets, inter-firm knowledge sharing routines, complementary resources and capabilities, or effective governance. In knowledge-based view, inter-firm collaborative arrangements are efficient mechanism to transfer and integrate explicit knowledge (Grant 1995). Empirical studies supported the theoretical propositions as well. By studying a real product innovation project, Ding and Peters (2000) argued that the discontinuous innovation in new businesses and product lines development required distinct inter-firm knowledge management practices. Other studies were also conducted to demonstrate the benefits and rationales of inter-firm collaboration in various contextual situations and fields (Matt & Wolff 2004; Suarez-Villa 2004; Smith & Dickson 2003; Miozzo & Dewick 2004).

For maximizing the performance of the inter-firm collaborative NPD, the information systems were tremendously used to facilitate inter-organizational business process integration and knowledge interchange (Grover et al. 2002; Clemons et al. 1993). Gunter and Butler (1999) offered a comparison of two case studies that illustrated how the use of a collaborative information system could support the competitive advantage. Neubert et al. (2004) investigated the role of information systems played in inter-firm collaboration and integration in supply chains. The authors highlighted the industrial cross-functional integration through co-managed processes that integrate both suppliers and customers could be efficiently supported by information systems. Other various ECS topics such as supply chain collaboration (Subramani 2004; Raghunathan & Yeh 2001), product development (Bochenek & Ragusa 2004; Max et al. 1998) and strategic applications (Kumar & Van Diesel 1996) were conducted by pervious studies as well.

Information systems are widely adopted to support other business functions for improving a firm’s performance (Melville et al. 2004; Sabherwal & Chan 2001). Despite there were a vast amount of researches studying the relationship between the ECS usage and the firm’s performance, the collaborative NPD performance has received only few attentions in limited industries. To better understand the fast-increasing collaborative NPD practices and innovative ECS application in present semiconductor industry, this study selects a leading foundry as a case for detailing the research context, and then proposes a quantitative research model for empirical testing the relationship between the ECS usage and the collaborative NPD performance.

3. CASE STUDY – QUALITATIVE ANALYSIS

3.1 Background

This study selected Taiwan Semiconductor Manufacturing Co. (TSMC), the largest semiconductor foundry in the world, as the research subject for the following reasons: Firstly, TSMC initiates most of the industrial ECS innovations that successfully strengthens the legitimacy of foundry business model. Secondly, most of the product firms in the world doing business with TSMC and its broad customer base can cover the complete semiconductor product market segments. Lastly, TSMC accounts for almost 60% market share of global foundry business. To some extent, this case can represent the whole industry situation.

Seven middle and high level managers of e-commerce, strategic marketing and customer service in the case company were invited for one-on-one interview. These managers have direct business responsibility on collecting customer requirements, developing ECS and rolling out ECS-related services to customers so that the interviewees can provide this study with the thorough viewpoint on the roles that the ECS plays to facilitate collaborative NPD. To increase the quality of information contents, a question list was sent to those managers one week before the interview conducted in order to encourage interviewees collecting data as complete as possible. Since one of the authors had been working in TSMC for six years, this study can assure that the research questions were realized by interviewees correctly and their answers will not be misinterpreted. Except for the interview records, this study also analyzed the case company's internal literature and external press and reports for validating temporary conclusions resulted from this research phase.

3.2 Company Profile

TSMC created the semiconductor dedicated foundry industry when it was founded in 1987. Until now, it is still the largest pure-play semiconductor foundry company in the world. For realizing the innovative foundry business model, the slogan "TSMC - Your Virtual Fab" was set as the corporate strategic goal to align the company-wide efforts. The term "fab" refers to the factory where the semiconductor wafer was produced.

To become an ideal "Virtual Fab" means that the customer can treat the foundry's fab as though it is the customers' own, except it is better (TSMC 2001). In addition to optimize the production efficiency for gaining low production cost advantage, TSMC utilizes various information technologies to provide customers with advanced ECS to make the "Virtual Fab" strategy real. Customer can have not only all production information in hand as the products are manufactured in their own fab, but also the advanced process technology and engineering online services to support their NPD throughout the entire collaboration process.

TSMC brands its ECS as "eFoundry Services" that comprises of three categories of applications: design collaboration, engineering collaboration, and logistics collaboration. To support the inter-firm collaborative NPD process and provide customers with Time-to-Market value are the main missions of the information systems. TSMC recognizes its customers facing keen competition in the semiconductor market, and its success is built on the customer's success. Seamless collaboration with customers on product design, yield enhancement, production, and logistics is the key to achieve its strategic objective. Figure 1 exhibits the framework of the company's ECS. In what follows, the three categories of ECS will be detailed.

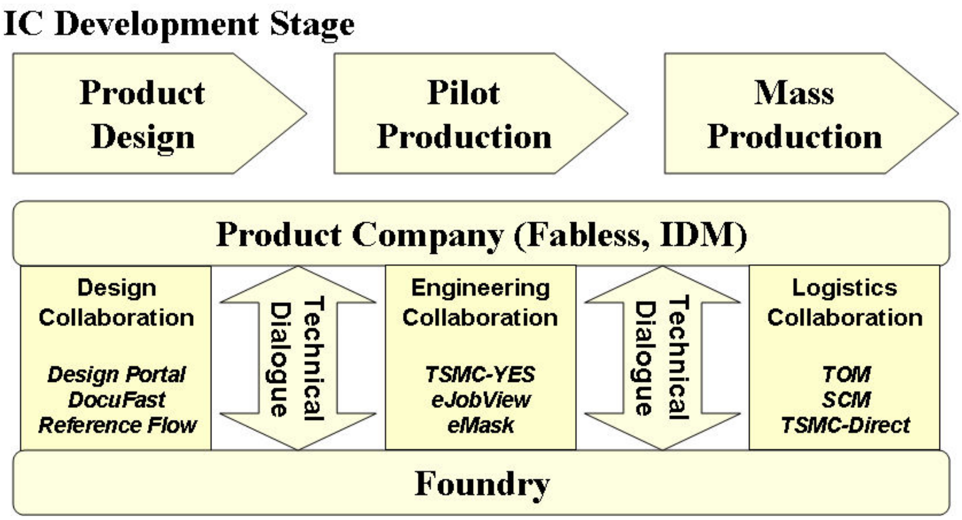

Figure 1: TSMC e-commerce system framework

3.3 Design Collaboration Systems

The objective of design collaboration is to facilitate collaborative process of IC design between TSMC and customers through the ECS. Tremendous amount of technical document exchanges and communication activities occur at this stage. IC designers develop their product based on a series of design rules and parameters that provided by foundry engineers. Careless using different version of the same process technology design rules and parameters could lead to flawed design. Hence, precise design document version control and delivery mechanism is critical to the IC designers. Although most of the foundry firms have already provided customers with an electronic access to the design-related documents, customers are still requested to handle the version control issue by themselves. To help customers reducing the flawed design risk occurred by misusing outdated documents, TSMC innovated a unique inter-firm ECS, *DocuFast,* to assist customers to manage all the design documents needed during the period of product development. This system provides customers a dashboard to exhibit the status of each document with different color of "light." *DocuFast* logs every customer download records in database. Once customer log on the system, *DocuFast* automatically check the status of each document that customer already downloaded. If the document version has been updated, a blue light symbol would show on the dashboard to remind customers of downloading the newest version. A red light symbol appears when the document is obsolete so that customers know that it could very risky for continuously using the old document in product design. Owing to the interrelation between different types of design documents, when a version conflict occurred among them, a yellow light symbol is activated to warn customers of the possible side effect.

Before the *DocuFast* released, IC designers were usually unaware of using the wrong version of design documents until the new product was sent to foundry for production. Without the *DocuFast's* help, considerable "unstructured technical dialogue" would waste a lot of valuable time for both the designers and fab engineers who have to ensure the document integrity. The extra coordination cost and time not only pushes the customer into a disadvantage corner, but also is a strategic threat to foundry business model.

3.4 Engineering Collaboration Systems

The objective of engineering collaboration is to resolve low-yield production problems. Many factors are possible to cause low-yield production: At manufacturing side, for example, tiny particles contaminate any process step of wafer fabrication can cause severe defects that disable the chip function. Since it is commonly that there are several hundreds of steps in wafer fabrication process, engineers are hard to identify which step goes wrong. On the other hand, the low-yield production can be due to the circuit design. IC designers sometimes would take an over-aggressive design rule to save the die area for reducing the chip cost, but such doing invites low manufacturability as well. Therefore, if low-yield wafers were produced, customer and TSMC engineers usually would have to get together to identify the root cause and resolve the issues. In practice, engineering data analysis is a basic and the most important work to start the problem-solving process. To facilitate the inter-firm technical dialogue, TSMC innovated a collaborative ECS, *TSMC-YES,* for conducting the engineering data analysis by both TSMC and customer engineers. With *TSMC-YES*, customer and TSMC engineers can analyze the same data set and adopt the same analysis procedures to resolve the problems. This system provided collaborative team members with a "common language", which diminished the unnecessary misunderstandings and arguments that caused by different data and analysis methodology. Consequently, the time and cost of yield enhancement process were tremendously reduced and the business relationship was improved.

3.5 Logistics Collaboration Systems

The objective of logistics collaboration is to provide customers with the complete and timely logistics data from order status to shipment information. The centre of the whole logistics collaboration is an inter-firm collaborative supply chain management system. Given the industrial characteristics of capital intensiveness and the long lead-time of major production equipments, the fab capacity is hard to expand in short term and could be assumed fixed. To TSMC's customers, real time information of available capacity and production cycle time are essential to make product time-to-market. Through this system, customer can fully control the production status of their products, foresee the future available-to-promise capacity, and update their demand forecasting. In addition to the information sharing services, this inter-firm ECS can help TSMC and customers generating the optimized supply chain management plan by its collaborative workflow engine and advanced decision support models.

In this case, we found TSMC deliberately design its ECS to fulfill different customer needs in the collaborative NPD process. Although the circuit design is not a foundry's activity, to help customer at this early stage can not only reduce the possible mistakes made by circuit designers, but also reduce the possible reworking at the production stage. Engineering collaboration systems is the core competency of a foundry because only those foundries who bring the highest production yield to the customers can win the legitimacy to stay in this industry. Without such inter-firm ECS's help to reduce the technical dialogue cost, the specialized firms are hard to compete with the integrated ones. The amounts of available production capacity usually impact the NPD schedule directly since the time to deliver product to market is an important strategic decision. By the logistic collaboration systems, TSMC can bring the valuable production and logistic information to customers for managing the NPD projects.

4. WORKING HYPOTHESES

While knowing how a foundry, such as TSMC, planned and implemented the ECS for facilitating the collaborative NPD process to support the product firms, this study is interested in understanding the effects of using ECS on the collaborative NPD performance as well. Many indices were used to measure the consequence of using information systems on firm performance, such as profitability, cost reduction, inventory turnover rate, and other operational and financial metrics (Devaraj & Kohli 2003; Hitt & Brynjolfsson 1996; Melville et al. 2004), but there were few studies investigating the influence of ECS usage on collaborative NPD performance.

According to the inter-firm collaboration theory (Grant 1995; Dyer & Singh 1998), the cooperative parties could appropriate the benefits of integrating complementary specialty assets such as knowledge, resources, and capabilities to accomplish the goal that they cannot make independently. In this study, the focal point of the inter-organizational collaboration is the NPD. As we know from the previous case study, three kinds of ECS are identified in the collaborative NPD process. The design collaboration systems are used to support the collaborative NPD at design stage. Designers at product firms reduce the time spent on communicating technical details with manufacturing engineers at the foundry by the assistance of such ECS. Besides, the system's automatic error-checking function decreases the risk of producing flawed products as well. Hence, we propose the first hypothesis:

H1: The design collaboration systems usage (DCSU) has positive correlation with the collaborative NPD performance (CNPDP).

When a new product moves to the pilot production stage, there can be a lot of engineering problems to be solved because the production equipments might need to be fine tuned or the circuit design might need to be revised for reaching the high production yield setting. The same situation as in the product design stage, the product designers and manufacturing engineers might be able to improve the collaborative NPD performance by using the engineering collaboration systems. Consequently, we proposed a hypothesis as:

H2: The engineering collaboration systems usage (ECSU) has positive correlation with the collaborative NPD performance.

Despite manufacturability has been proved, a new product cannot be successful unless it is accepted by customers and is able to fulfill the market demand in time. To coordinate the production capacity and the marketing plan between two individual firms is a big challenge. The precision of product firms' demand forecast is critical and important to the foundry because a large deviation can lead to capacity loss or excess inventory in the supply chain. To conquer this problem, the product firm and the foundry needs to heavily exchange the logistics information and synchronies the marketing and manufacturing plan. With the assistance of logistics collaboration systems, both the cooperative parties can reach the goal efficiently and cost-effectively. Therefore, we proposed:

H3: The logistics collaboration systems usage (LCSU) has positive correlation with the collaborative NPD performance.

Learning from the interview with the managers in TSMC, the ECS usage is not mutually independent in the three kinds of collaboration systems. For instance, when the product designers work with the process engineers to resolve engineering problem, they may concurrently use design and engineering collaboration systems. Likewise, while using logistics collaboration systems to jointly plan the production and marketing schedule, the cooperative parties may use other collaboration systems for estimating the yield and available capacity at the same time. In other words, the interaction between the different collaboration systems may have significant effect in NPD performance as well. Consequently, this study proposed the hypotheses:

H4: The interaction between design collaboration systems usage and engineering collaboration systems usage (DCEC) has positive correlation with the collaborative NPD performance.

H5: The interaction between design collaboration systems usage and logistics collaboration systems usage (DCLC) has positive correlation with the collaborative NPD performance.

H6: The interaction between engineering collaboration systems usage and logistics collaboration systems usage (ECLC) has positive correlation with the collaborative NPD performance.

H7: The interaction among design collaboration systems usage, engineering collaboration systems usage and logistics collaboration systems usage (DCECLC) has positive correlation with the collaborative NPD performance.

Owing to the product firms have different organizational types (i.e. the IDM and the fabless) and locations, the relationship between the ECS and the collaborative NPD performance might be influenced by these different organizational characteristics. For example, the product firm with its own production facilities (the IDM) might have different objectives from the one without its own production facilities (the fabless) in the collaborative NPD relation. Consequently, the usage patterns of the ECS might be very different of the two kinds of product firms. In addition, the product firms locate at different region might have different cultural environment that differs the effect of the relationship between the ECS usage and the collaborative NPD performance (e.g. the Western vs. the Eastern cultural styles) (Smith & Dickson 2003). Accordingly, we set the two organizational characteristics as control variables in this study.

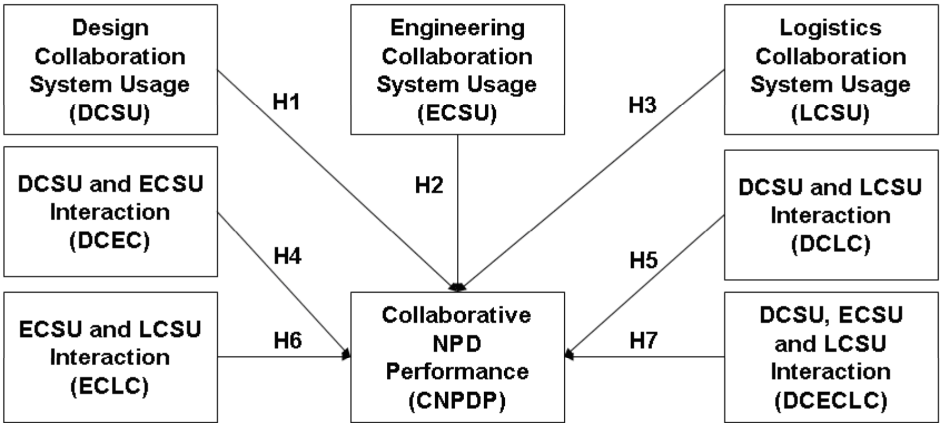

Figure 2: Research hypotheses

5. QUANTITATIVE DATA ANALYSIS AND RESULT

5.1 Measurement and Data Collection

To make sure the data was collected from long-term collaborative NPD partnership, 106 product firms that continuously co-develop new products with TSMC for more than two years were selected as the samples for this study. Among the 106 samples, 80 product firms are fabless' and the other 26 are IDMs. Categorized by firm location, the geographical distribution is as the follow: 35 firms locate in North America, 50 firms locate in Asia, 12 firms locate in Europe, and 9 firms locate in Japan.

To collect the ECS usage data, this study logged the time length of using each ECS by individual product firms. For ensuring the data quality, this study only recorded the system usage time that spent in formal collaborative activities. Formal collaborative activities here include online analytical tool using, technical document download, report generation, online meeting, data exchange, and project management. Although website surfing and system trying might be contributory to shorten the learning curve of using information systems, this study excluded the two kinds of activities for conservative principle. The number of new products that are produced in the foundry can be regarded as a performance of collaborative NPD since the high technical interdependence on product design and manufacturing technologies make it very hard to transfer the production to another foundry that is not involved in the collaborative NPD process. The descriptive statistics and correlation table of the variables are shown in Table 1. All variables were positively correlated with one another at significant level 0.05.

Table 1: Correlation table and descriptive statistics

Sample Count: 106

	1	2	3	4	5	6	7	8	Mean	SD
1. CNPDP	1.000								17.56	26.15
2. DCSU	0.964	1.000							3812	5647
3. ECSU	0.295	0.255	1.000						1447	1966
4. LCSU	0.634	0.609	0.559	1.000					5789	9475
5. DCEC	0.725	0.720	0.249	0.854	1.000				54360910	250793020
6. DCLC	0.621	0.679	0.638	0.653	0.565	1.000			8323390	24777124
7. ECLC	0.315	0.341	0.775	0.746	0.495	0.821	1.000		18689892	67574318
8. DCECLC	0.709	0.758	0.429	0.575	0.591	0.937	0.657	1.000	237041180	1115870355

SD: Standard Deviation

5.2 Data Analysis

Regressions were conducted in order to examine the main hypotheses. As detailed by Draper and Smith (1998), the existence of a relationship between predictor and outcome variables has a prerequisite that regression shows a direct effect between these predictors and outcomes. We proposed the first regression model without considering the effects of sample firm's type and geographical location.

$$CNPDP = \beta_0 + \beta_1 DCSU + \beta_2 ECSU + \beta_3 LCSU + \beta_4 DCEC + \beta_5 DCLC + \beta_6 ECLC + \beta_7 DCECLC \quad \text{(Model 1)}$$

Table 2 shows the test results of model 1. Except for DCEC, all other predictors have significant relationship with collaborative CNPDP. While DCSU, ECSU, LCSU and DCECLC have positive relationship with CNPDP, DCLC and ECLC have negative relationship with CNPDP. The Conditional Index (CI) is 16.321, which is lower than the threshold value 30 suggested by Belsley et al. (1980) and shows the multicollinearity of this model is not a problem. The variance inflation factor (VIF) of each independent variable was calculated for testing the collinearity. Suggested by Myers (1990), the VIF should not be larger than 10 or the collinearity will be severe. Since DCEC, DCLC, ECLC and DCECLC are interactive effects generated by DCSU, ECSU and LCSU, the VIFs are larger than the threshold value is anticipated. Except the LCSU is slightly larger than the threshold, the collinearity of three kinds of collaboration systems usage is acceptable. The adjusted R^2 of this model is 0.956, which shows the seven predictors can explain most of CNPDP variance. DCSU has the heaviest weight in influencing CNPDP with standardized beta coefficient 0.861. The other positive influential factors are DCECLC, ECSU and LCSU in descending order.

Table 2: Regression test of model 1

	Dependent variable: Collaborative New Product Developemt Performance		
Independent variables:	β^a	p-value	VIF
DCSU	0.861 ***	0.000	5.95
ECSU	0.239 ***	0.000	3.67
LCSU	0.177 **	0.010	10.79
DCEC	0.011	0.845	6.91
DCLC	-0.447 ***	0.000	29.14
ECLC	-0.189 *	0.011	12.72
DCECLC	0.389 ***	0.000	16.60
Regression Model:			
Conditional Index	16.321		
Adjusted R^2	0.956		

[a] standardised β coefficient

* 0.05 significance level　　** 0.01 significance level　　*** 0.001 significance level

With adding a dummy variable to represent the different product firm type into the regression model, this study tests the different effect between the IDM and the fabless.

$$CNPDP = \beta_0 + \beta_1 DCSU + \beta_2 ECSU + \beta_3 LCSU + \beta_4 DCEC + \beta_5 DCLC + \beta_6 ECLC + \beta_7 DCECLC + \beta_8 FirmType \quad \text{(Model 2)}$$

Table 3 shows the test result of regression model 2. The beta coefficient of dummy variable is significant which means the two sets of data can represent different regression lines. To further test the difference in using collaboration systems between the two groups of product firms, this study executes t-test for each collaboration systems usage. The result shows that the IDM and the fabless have a significant difference in ECSU. In general, the IDM has larger average ECS usage than the fabless over all the three kinds of collaboration systems. The details are shown in Table 4.

Table 3: Regression test of model 2

	Dependent variable: Collaborative New Product Developemt Performance		
Independent variables:	β^a	p-value	VIF
DCSU	0.852 ***	0.000	5.99
ECSU	0.250 ***	0.000	3.73
LCSU	0.183 **	0.007	10.81
DCEC	0.012	0.820	6.91
DCLC	-0.411 ***	0.000	29.77
ECLC	-0.209 **	0.005	12.91
DCECLC	0.370 ***	0.000	16.77
Firm Type	0.047 *	0.028	1.10
Regression Model:			
Conditional Index	16.844		
Adjusted R^2	0.958		

[a] standardised β coefficient

* 0.05 significance level ** 0.01 significance level *** 0.001 significance level

Table 4: t-test between different firm type groups

	IDM	Fabless	p-value
Sample Count	26	80	
DCSU			
Mean	4227	3677	0.668
Standard Deviation	5034	5855	
ECSU			
Mean	2322	1162	0.033*
Standard Deviation	2472	1693	
LCSU			
Mean	7829	5125	0.208
Standard Deviation	11284	8786	
CNPDP			
Mean	17.77	17.49	0.962
Standard Deviation	17.14	28.56	

* 0.05 significance level

For knowing the effect of firm location, this study also added a dummy variable "region" into the regression model 3 for testing.

$$CNPDP = \beta_0 + \beta_1 DCSU + \beta_2 ECSU + \beta_3 LCSU + \beta_4 DCEC + \beta_5 DCLC + \beta_6 ECLC + \beta_7 DCECLC + \beta_8 FirmLocation \quad \text{(Model 3)}$$

Due to the sample numbers in Japan and in Europe were not large enough for testing, this study combined Japan and Asia samples into group "Eastern Region" and combined North America and Europe samples into group "Western Region." It is obvious that the cultural difference exists in the two regions. Table 5 shows the beta coefficient of dummy variable "region" is significant which means the two sets of data can represent different regression lines. Likewise, this study further tests the difference in using collaboration systems between the two groups of firm locations by executing t-test for each collaboration systems usage. The result shows there is no significant difference in any kind of collaboration systems usage between the two different regions. However, there is significant difference in CNPDP between the Eastern and the Western product firms. In general, the Eastern product firms have better CNPDP than the Western product firms and the Eastern product firms have larger average ECS usage than the Western product firms over all the three kinds of collaboration systems. The details are shown in Table 6.

Table 5: Regression test of model 3

	Dependent variable: Collaborative New Product Developemt Performance			
Independent variables:	β^a		p-value	VIF
DCSU	0.847	***	0.000	6.01
ECSU	0.219	***	0.000	3.78
LCSU	0.185	**	0.005	10.81
DCEC	0.005		0.922	6.92
DCLC	-0.453	***	0.000	29.15
ECLC	-0.177	*	0.014	12.77
DCECLC	0.404	***	0.000	16.67
Firm Location	0.060	**	0.005	1.08
Regression Model:				
Conditional Index	16.696			
Adjusted R^2	0.959			

[a] standardised β coefficient

* 0.05 significance level ** 0.01 significance level *** 0.001 significance level

Table 6: t-test between different firm location groups

	Eastern	Western	p-value
Sample Count	63	43	
DCSU			
Mean	4366	3000	0.223
Standard Deviation	6458	4122	
ECSU			
Mean	1662	1131	0.173
Standard Deviation	2122	1685	
LCSU			
Mean	6112	5315	0.673
Standard Deviation	9846	8996	
CNPDP			
Mean	21.59	11.65	0.03*
Standard Deviation	31.24	14.44	

* 0.05 significance level

6. DISCUSSION

The objective of this study contributed to understand how ECS is utilized to facilitate inter-firm collaborative NPD and the relationship between the ECS usage and the collaborative NPD performance in semiconductor industry. A set of working hypotheses derived from case company analysis were tested with transactional business data collected from 106 worldwide semiconductor product firms in this study. The results of regression analysis showed the ECS usage, no matter the systems are used to support design, engineering or logistics collaboration, have significant positive relationship with collaborative NPD performance. The hypothesis 1, hypothesis 2 and hypothesis 3 are supported statistically in all regression models. The design collaboration systems usage with the highest adjusted R^2 explains the most part of collaborative new product development performance variance, which means the ECS used to support collaborative NPD at design stage can play a critical role for both cooperative parties. As we found in the case study, the design collaboration systems help product designers and process engineers finding the possible errors at the earliest stage that tremendously reduces time and resource waste thereby enhances the collaborative NPD performance. Although the effects of engineering and logistics collaboration systems usage are not as large as the design collaboration systems usage in influencing the collaborative NPD performance, they both are positive factors with statistical significance. To the foundry and product firms, the ECS used to support collaborative activities at pilot and mass production stages are worth investing resources in developing new applications since they can result in substantial rewards.

As for the interactive effect between the different collaboration systems usage, the hypothesis 4 is not supported because the interaction between design collaboration systems usage and engineering collaboration systems usage has no significant relationship with the collaborative NPD performance. The results might imply that the effect of design collaboration systems usage on collaborative NPD performance is independent to the engineering collaboration systems usage. Interestingly, the interactive effect of the design collaboration systems usage and the logistics collaboration systems usage, and the interactive effect of the engineering collaboration systems usage and the logistics collaboration systems usage have significant negative relationship with collaborative NPD performance that is opposite to the original hypotheses. To discuss the results with the managers of TSMC, we found that when the new products move into mass production stage, the collaborative parties will heavily use the design collaboration systems and engineering collaboration systems if the new products have severe production problems. That might be a possible explanation for the negative effects generated by the interaction of design collaboration systems usage and logistics collaboration systems usage and the interaction of engineering collaboration systems usage and logistics collaboration systems usage. The interaction of all three kinds of collaboration systems usage positively influences the collaborative NPD performance with statistical significance. It supports the hypothesis 7 and might represent the synergy of using all the ECS in collaborative NPD process.

Organizational characteristics such as firm type and firm location might influence the relationship between the ECS usage and the collaborative NPD performance. The empirical data showed there are different effects between the IDM and the fabless indeed. According to the testing result of regression and t-test, the IDM uses the ECS more frequently than the fabless does, especially in the engineering systems usage. This might be due to the IDM has its own production facilities and process knowledge consequently has more requirements in instructing the foundry to adjust the production line which occurs the needs for using engineering collaboration systems. As for the effects of firm location, this study found there is no significant difference in using all kind of collaboration systems between western and eastern product firms. It might be because the prevalence of the Internet, which makes the ECS usage become more and more convenient and mitigates the difference between different cultural regions.

7. CONCLUSION

The trend of vertical disintegration in semiconductor industry promotes more and more collaborative e-commerce applications for interchanging business information and facilitating timely and efficient communication between the specialized firms. While previous literature focused on the operational performance enhancement of e-commerce system (ECS) usage, this study contributed to increase understandings on the performance of using ECS to facilitate new product development (NPD) process through combining qualitative and quantitative methods in a two-phase case study.

According to qualitative data analysis, the specialized firms mainly leveraged the collaborative e-commerce systems to facilitate the “technical dialogue” between design and process engineers to conquer the technological knowledge integration issues in NPD process. ECS is mainly developed for supporting key design, engineering and logistics collaborative activities in product design, pilot production and mass production stages respectively. With support by real transactional data, all kinds of ECS usage has positive impacts on NPD performance and the design collaboration ECS accounts for the most of performance variance. In general, the integrated device manufacturing and the fabless customers have different effects of using ECS on NPD performance. With respect to the firm's location, the eastern companies obtain better NPD performance than the western companies by using those ECS. Based on the research results, this study suggests that a foundry company should develop different ECS services rather than a general solution to better support various customers that are segmented by organizational type and geographical location to achieve high NPD performance.

REFERENCE

1. Belsley, D.A., Kuh, E., and Welsch, R.E. *Regression Diagnostics: Identifying Influential Data and Sources of Collinearity*. John Wiley, New York, 1980.
2. Besanko, D, Dranove, D., Shanley, M. and Schaefer, S., *Economics of Strategy*, New York, John Wiley & Sons, 2004.
3. Bochenek, G. M. and Ragusa, J. M. "Improving Integrated Project Team Interaction through Virtual (3D) Collaboration," *Engineering Management Journal* (16:2) 2004, pp: 3-12.
4. Boubekri, N. "Technology enablers for supply chain management," *Integrated Manufacturing Systems*, (12:6) 2001, pp: 394-399.
5. Clemons, E., Reddi, S., and Row, M. "The Impact of Information Technology on the Organization of Economic Activity: The 'Move to the Middle' Hypothesis," *Journal of Management Information Systems* (10:2) 1993, pp: 9-35.
6. Creswell, J.W., *Research Design: Qualitative & Quantitative Approaches*, SAGE Publications, Inc., California, 1994.
7. Devaraj, S. and Kohli, R. "Performance Impacts of Information Technology: Is Actual Usage the Missing Link," *Management Science*, (49:3) 2003, pp: 273-289.
8. Dhayagude, T., Jayagopal, M., Manayathara, T., Suri, S., and Yaga, A., Is *the IDM Model Doomed…,* Kellogg Graduate School of Management, Northwestern University, 2001.
9. Ding, H. and Peters, L.S. "Inter-firm Knowledge Management Practices for Technology and New Product Development in Discontinuous Innovation," *International Journal of Technology Management* (20:5-8) 2000, pp: 588-600.
10. Draper, N.R. and Smith, H. *Applied Regression Analysis*, 3rd edition, John Willy & Sons, New York, 1998.
11. Dyer, J.H. and Singh, H. "The Relational View: Cooperative Strategy and Sources of Inter-organizational Competitive Advantage," *Academy of Management Review* (23:4) 1998, pp: 660-679.
12. Grant, R.M. "A Knowledge-based Theory of Inter-firm Collaboration," *Academy of Management Journal*, Best Papers Proceedings 1995, pp: 17-22.

13. Grant, R.M. “Toward a Knowledge-based Theory of the Firm,” *Strategic Management Journal* (17) 1996, pp: 109-122.
14. Grover, V., Teng, J., and Fiedler, K. “Investigating the Role of Information Technology in Building Buyer-Supplier Relationships,” *Journal of Association for Information Systems* (3) 2002, pp: 217-245.
15. Gunter, K. and Butler, P. “A Comparison of Two Case Studies Illustrating the Use of a Collaborative Information System to Support Competitive Advantage,” *International Journal of Technology Management* (18:5-8) 1999, pp: 549-561.
16. Heiman, B. and Nickerson, J.A. “Towards Reconciling Transaction Cost Economics and the Knowledge-based View of the Firm: The Context of Inter-firm Collaborations,” *International Journal of the Economics of Business* (9:1) 2002, pp: 97-116.
17. Hitt, L. and Brynjolfsson, E. “Productivity, Business Profitability, and Consumer Surplus: Three Different Measures of Information Technology Value,” *MIS Quarterly* (20:2) 1996, pp: 121-142.
18. Holbrook, D., Cohen, W.M., Hounshell, D.A., and Klepper, S. “The Nature, Sources, and Consequences of Firm Differences in the Early History of the Semiconductor Industry,” *Strategic Management Journal* (21) 2000, pp: 1017-1041.
19. Humphreys, P.K., Lai, M.K. and Sculli, D. “An inter-organizational information systems for supply chain management,” *International Journal of Production Economics*, (70) 2001, pp: 245-255.
20. IC Insights, *The McClean Report*, IC Insights Inc., Arizona, 2005.
21. Kogut, B. and Zander, U. “Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology,” *Organization Science* (3) 1992, pp: 383-397.
22. Krause, D.R., Handfield, R.B., and Scannell, T.V. “An empirical investigation of suppier development: Reactive and strategic processes,” *Journal of Operation Management*, (17:1) 1998, pp: 39-58.
23. Kumar K. and Van Diesel, H.G. “Sustainable Collaboration: Managing Conflict and Cooperation in Interorganizational Systems,” *MIS Quarterly* (20:3) 1996, pp: 279-301.
24. Lam, P.K. and Chin, K.S. “Project factors influencing conflict intensity and handling style in collaborative NPD,” *Creativity and Innovation Management*, (13:1) 2004, pp: 52-62.
25. Lam, P.K. and Chin, K.S. “Identifying and prioritizing critical success factors for conflict management in collaborative new product development,” *Industrial Marketing Management*, (34) 2005, pp: 761-772.

26. Langlois, R.N. and Steinmueller, W.E. "Strategy and Circumstance: The Response of American Firms to Japanese Competition in Semiconductors, 1980-1995," *Strategic Management Journal* (21) 2000, pp: 1163-1173.
27. Macher, J., Mowery, D., and Simcoe, T. "e-business and disintegration of the semiconductor industry value chain," *Industry and Innovation*, (9:3) 2002, pp: 155-181.
28. Matt, M. and Wolff, S. "Incentives, Coordination and Learning in Government-sponsored vs. Spontaneous Inter-firm Research Cooperation," *International Journal of Technology Management* (27:8) 2004, pp: 694-711.
29. Max, J.M., Fernando, T. and Dew, P. "A Distributed Virtual Environment for Collaborative Engineering," *Presence: Teleoperators & Virtual Environments* (7:3) 1998, pp: 241-261.
30. Melville, N., Kraemer, K, and Gurbaxani, V., "Review: Information Technology and Organizational Performance: An Integrative Model of IT Business Value," *MIS Quarterly* (28:2) 2004, pp: 283-322.
31. Miozzo, M. and Dewick, P. "Networks and Innovation in European Construction: Benefits from Inter-organisational Cooperation in a Fragmented Industry," *International Journal of Technology Management* (27:1) 2004, pp: 68-89.
32. Monteverde, K. "Technical dialog as an incentive for vertical integration in the semiconductor industry," *Management Science*, (41:10) 1995, pp: 1624-1638.
33. Moran, P and Ghoshal, S. "Theories of Economic Organization: The Case for Realism and Balance," *Academy of Management Review* (21:1) 1996, pp: 58-72.
34. Myers, R. *Mplus: The comprehensive modelling program for applied researchers*. Muthen & Muthen, Los Angeles,1990.
35. Neubert, G., Ouzrout, Y. and Bouras, A. "Collaboration and Integration through Information Technologies in Supply Chain," *International Journal of Technology Management* (28:2) 2004, pp: 259-273.
36. Raghunathan, S. and Yeh, A.B. "Beyond EDI: Impact of Continuous Replenishment Program (CRP) Between a Manufacturer and Its Retailers," *Information Systems Research* (12:4) 2001, pp: 406-419.
37. Rodgers, P.A., Caldwell, N.H.M., Huxor, A.P., and Clarkson, P.J. "Webcadet: A knowledge management support system for new product development," *6th International Product Development Management Conference*, (5:9) 1999, pp: 937-948.
38. Sabherwal, R. and Chan, Y.E. "Alignment between Business and IS Strategies: A Study of Prospectors, Analysers, and Defenders," *Information Systems Research* (12:1) 2001, pp: 11-33.

39. Smith, H.L. and Dickson, K. "Geo-cultural Influences and Critical Factors in Inter-firm Collaboration," *International Journal of Technology Management* (25:1-2) 2003, pp: 34-51.
40. Suarez-Villa, L. "Collaboration in Biotechnology: How Inter-firm Relations Strengthen Research Efforts in the USA," *International Journal of Technology Management* (27:5) 2004, pp: 452-464.
41. Subramani, M. "How do suppliers benefit from information technology use in supply chain relationships?" *MIS Quarterly*, (28:1) 2004, pp: 45-73.
42. TSMC , *TSMC Foundry Service Manual 2nd Edition*, Hsin-chu, 2001
43. Wheelwright, S. and Clark, K. *Revolutionizing Product Development*, The Free Press, New York, 1992.
44. Williamson, O.E. "Strategy Research: Governance and Competence Perspectives," *Strategic Management Journal* (20:12) 1999, pp: 1087-1108.
45. Xie, J., Song, X.M., and Stringfellow, A. "Interfunctional conflict, conflict resolution, styles, and new product success: A four-culture comparison," *Management Science*, (44:12) 1998, pp: 193-206.