Global Sourcing in Innovation:

Theory and Evidence from the Information Technology Hardware Industry

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Abstract

Economists, including Paul Samuelson and Jagdish Bhagwati, vigorously debate whether offshore outsourcing in high-tech industries helps or harms the U.S. economy. The main issue is whether insourcing countries, such as China or India, will catch up with and eventually outcompete the U.S. Moreover, the dearth of offshore outsourcing data has hindered the study of the impact of offshore outsourcing. To explore the impact of offshore outsourcing, I examine how the heterogeneity of offshore outsourcing demand affects insourcing firms' innovation choices and how these innovation choices connect with the technology-driven productivity growth of the insourcing industry. This paper contributes to our understanding of offshore outsourcing in three vital ways: First, I collect firm-level data of offshore outsourcing in IT hardware industries, a type of data that was previously nonexistent but sorely needed to deepen our understanding. Second, my empirical results show that the rise of offshore outsourcing, especially outsourcing in R&D activities, does help our overseas partners, such as China, gain technology-driven productivity growth, and hence narrows the technology gap between firms in outsourcing countries and in insourcing countries. This result offers some support for Samuelson's negative view that offshore outsourcing enhances Chinese productivity growth in the IT industry, with subsequent adverse impacts on the U.S. economy. Adverse effects, however, still depend on market forces behind the identified asymmetric holdup problem between outsourcing and insourcing firms. Third, this paper goes beyond the debate by showing why U.S. IT firms are increasingly outsourcing innovation overseas. These results have policy implications regarding strategic supplier management, technological progress, reverse brain drain in new industries, and the rapid market growth in China and India.

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1 Introduction

In recent years there has been growing concern in the U.S. over the impact of global outsourcing on the nation's ability to sustain high living standards. The main issue is whether insourcing countries, such as China or India, will catch up with and eventually outcompete the U.S. Contrary to the mainstream view of offshore outsourcing, Samuelson (2004) models a scenario in which, in a two-good model, the U.S. begins with comparative advantages in information technology (IT) products and China in textiles. At some point, our trading partner, China, experiences technology-driven productivity growth in IT products such that it reshapes comparative advantages between these two countries. Because of its growth, China starts exporting IT products to the U.S. or other countries. In other words, it starts competing with the U.S. in international IT markets (Klenow 2005). As a result of the competition, the U.S. may see its terms of trade worsen and its original gain from trade wiped out. In sum, this scenario suggests that China's productivity growth in the IT industry will have adverse impacts on the U.S. economy.

However, Samuelson's scenario does not clearly account for China's technology-driven productivity growth in high-tech goods and how this growth relates to the fact that U.S. high-tech firms outsource activities to China. In particular, how does the rise of offshore outsourcing in high-tech industries help China gain technology-driven productivity growth in offshore outsourcing goods? The lack of an explicit link between these two circumstances makes many of the participants in the debate assert that his model is not applicable to offshore outsourcing (Bhagwati et al. 2004; Panagariya 2004). Nonetheless, his critics agree that Samuelson's proposed scenario is an international trade problem.

On the whole, however, it seems fair to say that we should not ignore the crucial gain to insourcing regions derived from offshore outsourcing in areas such as manufacturing and design know-how. These gains help insourcing regions accumulate various endowments, thus possibly reshaping existing comparative advantages in the evolved industry among different trading countries. It is important to model the multifaceted nature of the global outsourcing phenomenon, which involves complex relationships and dynamic interactions between outsourcing and insourcing firms. Given that economists have oversimplified the story of insourcing firms, this type of model is important to truly understand the forces which govern this phenomenon.

This paper suggests that Samuelson's outsourcing model is theoretically legitimate but argues that we need to further examine whether his model truly captures the essence of the complicated global outsourcing phenomenon. Additionally, not only do we care about the impact of offshore outsourcing but about its causes as well. In order to make the point, I develop an insourcing firm's innovation investment model and use data from an IT industry survey conducted overseas between 2004 and 2005 to shed light on two key questions: First, can offshore outsourcing in the IT industry help the insourcing industry gain technology-driven productivity growth? In answering this question, I can begin to ask my second question: Why are U.S. IT firms increasingly outsourcing activities overseas? The answer is shown to lie in the bi-directional influence between offshore outsourcing demand and the insourcing firm's technology expertise (see Figure 1).

I first present a model to analyze how the heterogeneity of offshore outsourcing demand affects the insourcing firm's R&D choices. I design the model with two types of offshore outsourcing demands and two types of R&D investments. Combined with data, this model design can not only investigate the impact of offshore outsourcing demand on the insourcing firm's R&D investment but also capture an important causality effect. That is, the type of the insourcing firm's technology expertise, measured in terms of its R&D composition, can explain IT firms' outsourcing decisions on what to outsource, which Helpman (2006) points out as one of two important outsourcing questions that have not been answered.

In order to test my model and estimate its parameters, I successfully collected survey data from 28 world-class insourcing firms in the IT hardware industry, which Mann (2005), using Bhagwati et al.'s (2004) definition, identifies as an enabling industry. This industry can transmit productivity externalities to the recipient industries, a fact which makes it as one of the most crucial industries to study the impact of offshore outsourcing. Survey data include firm-level information on both types of offshore outsourcing contracts and both types of R&D investments. Unlike trade data's limitations of measuring offshore outsourcing activities, my data allow me to analyze the characteristics and impact of offshore outsourcing directly without having the potential problem of inferring the wrong conclusion by using trade data. For example, based on U.S. trade data prior to 1995, a time before the rapidly rising global IT outsourcing phenomenon, Antras (2003) concluded that offshore outsourcing industries were mainly labor intensive, a conclusion that cannot be applied to the IT hardware industry. One of many counterexamples to Antras's conclusion is Taiwan Semiconductor Manufacturing Co. (TSMC), which is the world's top foundry and highly capital intensive, and produces customized chips for many U.S. IC design companies (Saxenian 2006).

I combine my model and data to answer the two questions raised earlier. In answering the first question, the empirical evidence shows that the rise of offshore outsourcing in the IT industry does help the insourcing industry gain technology-driven productivity growth. This new evidence offers some support for Samuelson's view that offshore outsourcing in high-tech industries may potentially lead the U.S. economy to suffer. In particular, I provide two approaches to connecting the missing link in Samuelson's argument between offshore outsourcing in the high-tech industry and technology-driven productivity growth in the insourcing industry, which is called hereafter "Samuelson's missing link." One approach is to show that offshore outsourcing demand has a positive relationship with both the amount and intensity of the insourcing firm's R&D investment. The other approach is to show that the heterogeneity of offshore outsourcing demand does affect the insourcing firm's innovation choices. Given that the industry's R&D intensity, process R&D, and product R&D all have positive relationships with its total factor productivity (TFP) growth (Griliches and Lichtenberg 1984), we can reasonably conclude that offshore outsourcing in the IT industry does help the insourcing industry gain technology-driven productivity growth.

This conclusion is important to answer my second question: Why are U.S. IT firms increasingly outsourcing activities overseas? In particular, I am interested in why they are increasingly outsourcing R&D overseas, given that Technology Forecasters Inc. reports that U.S. companies have increased outsourcing innovation overseas from less than US $30 billion in 2000 to over US $60 billion in 2004, and the number will be over US $100 billion by 2007 (Engardio and Einhorn 2005). Contrary to current dominant outsourcing models adopting the transaction cost theory (Antras 2003, 2005; Antras and Helpman 2004; Grossman and Helpman 2002), I show that, rather than transaction costs including information costs from incomplete contracting problems, the types of IT insourcing firms' technology expertise can explain outsourcing firms' decisions on what to outsource. In fact, transaction costs alone cannot explain U.S. IT firms' different outsourcing behaviors in the same industry, product category, and exchange environment. This argument is further supported by the observations of the clustering phenomenon associated with IT offshore outsourcing.

Answering the above two questions leads to the conclusion that offshore outsourcing demand and insourcing firms' technology expertise bi-directionally influence each other. The more IT industries and firms outsource overseas, the more insourcing industries and firms make technological progress, and technological progress, once developed, can attract more IT industries and firms to outsource. This conclusion provides an important explanation of why U.S. IT firms are increasingly outsourcing R&D overseas because outsourcing R&D overseas not only reduces both the amount and risk of their capital investments, but also allows them to exploit insourcing firms' innovation investments and capabilities.

Moreover, given that IT offshore outsourcing helps the insourcing industry gain technology-driven productivity growth, Samuelson predicts that IT offshore outsourcing may cause the U.S. economy to suffer. We, however, are aware that whether the suggested scenario occurs depends on if U.S. terms of trade change. By which I mean, if the insourcing firm makes technological progress and increases innovation capabilities to act as the virtual R&D and production unit of its outsourcing customers, what would stop it from further integrating into the downstream and competing with its outsourcing customers in the end market?

My answer is that some of the market forces determining U.S. terms of trade are also the same forces governing the relationship between outsourcing and insourcing firms. Before the insourcing firm gains technology-driven productivity growth, comparative advantage between the two sides determines the international division of labor; after the growth, competitive advantage determines U.S. terms of trade. Suppose both insourcing and outsourcing firms are identical in technology, a firm's competitiveness in the end market depends on its international marketing know-how and brand reputation. Because of a limited domestic market and a lack of international marketing know-how, the insourcing firm does not have an outside option. In contrast, the outsourcing firm will not encounter any significant readjustment costs of R&D and production and thus, it has an outside option of bringing its outsourcing activities back in-house. In sum, the holdup problem is more serious on the insourcing side, a situation of which I call the asymmetric holdup problem. And, the asymmetric holdup situation empowers outsourcing firms to exploit most of the benefits of global economies of scale from offshore outsourcing.

The remainder of this paper includes five parts. Section 2 shows the model's logic and sets out the formal model. Section 3 reports the empirical analysis. Section 4 proves how to connect Samuelson's missing link and explains why U.S. IT firms are increasingly outsourcing R&D overseas. Section 5 offers some policy implications, and finally, Section 6 offers some conclusions and suggestions for future research.

2 The Insourcing Firm's Investment Decision in Innovations

2.1 The Heterogeneity of Offshore Outsourcing Demand and the Insourcing Firm's Innovation Choices

To capture the impact of offshore outsourcing demand on the insourcing firm's innovation choices, I design the model with two types of offshore outsourcing contracts and two types of R&D investments. Once engaging in offshore outsourcing, a firm must decide whether to outsource production alone or both production and design. These two choices correspond to the services or products that an insourcing firm offers. Hence, I define two products that an insourcing firm offers: OEM and

ODM. OEM and ODM are terms of art used by those in global outsourcing markets. An original equipment manufacturing (OEM) supplier is a firm that only produces a product following precise blueprints supplied by its outsourcing customer. An original design manufacturing (ODM) supplier, however, is a firm that not only produces but also designs the product. In this setting, many insourcing firms produce both products because they simultaneously offer OEM and ODM services for different outsourcing customers.

To compete in each market, an insourcing firm needs to have a different portfolio of competitive advantages. To compete in the OEM market, an insourcing firm needs to be competitive not only in cost but also in quality. In addition to the competitiveness in cost and quality, the ODM market is more demanding such that an insourcing firm needs to be creative in product design.

Therefore, to achieve competitiveness along all dimensions of cost, quality, and product design, an insourcing firm has to invest in two types of R&D: *process* R&D and *product* R&D. Process innovation provides the insourcing firm with the benefits of cost reduction and quality improvement; product innovation provides with the benefits of new or incremental product features (Mansfield 1988). In particular, in an industry with constantly advancing technologies, such as the IT industry, dividing R&D into these two types allows us to ask how different offshore outsourcing demands affect the insourcing firm's R&D composition, which can indicate the development direction of its technology expertise. The resulting understanding is critical and cannot be derived simply by examining the firm's total R&D expenditure.

2.2 The Insourcing Industry's Market Structure and the Asymmetric Holdup Problem

Because some of the market forces determining U.S. terms of trade are also the same forces governing the asymmetric holdup problem between outsourcing and insourcing firms, it is important to clearly state the assumptions of the industry's market structure and the degree of the supply side competition. In the model, I assume that each insourcing industry's market structure is oligopolistic in terms of the number of firms, but the nature of competition is perfect competition. All insourcing firms are perfect competitors along the dimensions of price, quality, and innovation. In addition, there is no strategic interaction among their R&D investment decisions.

My assumptions clearly differ from the conventional economic doctrine on the basic relationship between the number of firms and the degree of competition, which in fact fails to distinguish the determinants of competition in market negotiations from the determinants of the number of firms from which production will issue after contractual negotiations have been completed (Demsetz 1989). In his work on the U.S. utility industry, Demsetz (1989) gives a lucid and compelling explanation for the relationship between the number of firms and the degree of competition. He points out that competitiveness of price cannot be judged simply by knowledge of market structure and that the price is determined in the bidding market. Even with few firms dominant in the market, the utility industry was competitive and each firm acted as a competitive player to compete for the field. That is, we cannot infer the competitiveness of price from observed market structure and competition for the field can dissipate monopoly rent through price cutting during the bidding competition and yield a competitive outcome.

Demsetz's finding that the market structure alone cannot predict the degree of competitiveness in the industry is consistent with our observations on global IT hardware outsourcing. On the one hand, although facing an oligopolistic insourcing industry, most outsourcing firms adopt a multiple-supplier strategy, which not only reduces their risk of a holdup problem with a sole supplier but also enhances the supply side competition. On the other hand, to support its growth and operations, the insourcing firm acts much as a competitive player to compete for the field. Because major outsourcing contracts normally involve significant capital investments, losing any of them will cause a costly distruption to the insourcing firm's operations (i.e., it will face a high penalty by breaching the contract). For example, Quanta, the world's top notebook PC insourcing firm, had 25.6% of worldwide market share in 2004, but its top 3 outsourcing customers occupied almost 55% of its production capacity (Quanta 2005). Because of the potential negative impact from losing any major outsourcing customers, it will try its best to meet their requests. This example shows that even in an oligopolistic industry, the insourcing firm has incentives to act much as a perfect competitor.

The above observations imply that the holdup problem is asymmetric and more serious on the insourcing side. On one side, under a scenario of a broken deal with its existing supplier, the outsourcing firm does not face any major readjustment costs of bringing outsourcing activities back in-house. Given that it has the same technology expertise as the insourcing firm does, if choosing not to outsource, the outsourcing firm has an outside option of producing and designing products in-house. In addition, by adopting a multiple-supplier strategy, it can switch to other suppliers at a low cost through contract stipulation. On the other side, the insourcing firm lacks marketing know-how in key international markets to forward integrate into the downstream (i.e. selling its own-brand products in the market). Further, I assume that the insourcing firm faces a limited domestic market which cannot support its growth and operations. In other words, the insourcing firm does not have an outside option if it breaches the outsourcing contract or disagrees with the terms that its outsourcing customers set. Therefore, the relative bargaining power between the two sides is unbalanced and the situation favors the outsourcing side.

2.3 The R&D Investment Model

Modifying the theoretical framework derived by Cohen and Klepper (1996), who analyzed the relationship between a firm's sales and its R&D composition, I develop a two-product model to analyze how the heterogeneity of offshore outsourcing demand affects the insourcing firm's innovation choices. As described in Section 2.1, an insourcing firm produces two products, OEM and ODM. Because both products demand the insourcing firm being competitive in cost, both of them provide incentives for the firm to invest in process R&D. The ODM product, however, provides an additional incentive for the insourcing firm to invest in product R&D. That is because, besides being cost competitive, only ODM contracts demand the insourcing firm to be competitive in innovation, such as the ability to create new or improved products.

2.3.1 The Investment in *Process* Innovation

When investing in a process innovation, an insourcing firm improves its existing manufacturing processes or creates new ones to achieve a higher degree of efficiency and better quality in producing each product, thus lowering its average cost of each product through process innovation. In this model, the insourcing firm seeks to maximize its profit of investing in process R&D:

$$\pi_1 = g_1 \cdot (q_1 + \alpha q_2) \cdot I_1(r_1) - r_1 \tag{1}$$

where q_1 and q_2 denote the *ex ante* outputs of OEM and ODM, respectively. r_1 is the insourcing firm's spending on process R&D and g_1 is the length of time before process savings are matched by its competitors. The parameter α, assumed to be ≥ 1, is the ratio of the unit profit margin of the ODM product to that of the OEM product by investing in process R&D, and $I_1(r_1)$ is the decrease in the insourcing firm's average cost from its process innovation. Furthermore, I assume that there is no uncertainty between R&D investments and innovations. To reflect the idea that more process R&D yields greater manufacturing cost reductions but at a declining rate, this model also assumes that $I_1'(r_1) > 0$ and $I_1''(r_1) < 0$ for all $r_1 \geq 0$.

Although a process innovation lowers the average cost of each product, the insourcing firm, a price taker, still charges the outsourcing firm the same prices for its OEM and ODM products. Note that in practice the sales price of each product is negotiated and fixed in the contract beforehand. The price can be changed by periodic renegotiations and cost saving plans. Given that, an insourcing firm can increase its unit profit for each product by cost savings resulting from process innovation.

Besides, under the assumption of perfect competition, any cost advantage from an insourcing firm's process innovation will eventually be matched by its competitors. Once the cost savings are matched, market competition will drive down the prices of OEM and ODM products by the decrease in average cost realized from the process innovation. The insourcing firm will eventually cease earning a return from its process innovation. Therefore, how long an insourcing firm can keep its cost advantage will also affect its investment decision in process innovations.

In the model, the insourcing firm does not license process innovation. In fact, due to the nature of process innovation, studies have shown that patents are more effective in protecting product innovation than process innovation. Most firms, therefore, keep process innovation as trade secrets instead.

2.3.2 The Investment in *Product* Innovation

Unlike process innovation, which increases the firm's unit profit through average cost reduction, product innovation increases the insourcing firm's unit profit margin by increasing the price outsourcing firms are willing to pay for its product. By creating new products or new product features, an insourcing firm can gain transient monopoly power and raise the prices of its products. In addition, contrary to process innovation, which reduces costs on existing output, product innovation allows the insourcing firm to reach new ODM customers. In the model, the insourcing firm seeks to maximize its profit of investing in product R&D:

$$\pi_2 = g_2 \cdot (hq_2 + k) \cdot I_2(r_2) - r_2 \tag{2}$$

where g_2 is the length of time before the new product variant is imitated by its competitors and k is the amount of new ODM customers that the insourcing firm can attract by investing in product innovation. The role of k is important in capturing the causality effect: a positive k means that the investment in product R&D attracts more ODM contracts, and a negative k means otherwise. In addition, because outsourcing firms have different preferences to product features, only h, a fraction of the existing ODM customers, will buy the new product variant at the higher price. Similarly, r_2 is the insourcing firm's spending on product R&D and $I_2(r_2)$ is the unit profit margin earned on the new product variant, which has the property that $I_2'(r_2) > 0$ and $I_2''(r_2) < 0$ for all $r_2 \geq 0$.

In addition, under the assumption of perfect competition, new product advantages from product innovation will be matched eventually by its competitors. Because of this, how long it can maintain its product advantage from the innovation will also affect the insourcing firm's investment decision in product innovation. Besides, I assume that there is no major breakthrough in product innovation from the insourcing firm and thus no license revenue resulting from it.

2.3.3 Model Predictions about the Insourcing Firm's R&D Investment Behavior

To derive model predictions, I assume that $I_i'(r_i)$, where $i = 1$ or 2, has the concave form, $I_i'(r_i) = b_i r_i^{-1/\beta_i}$, for all $r_i > 0$ (note that $b_i > 0$ and $\beta_i > 0$). The quantity $1/(\beta_i r_i)$ defines the rate at which the marginal return on the *i*th type of R&D declines, and the parameter b_i indicates the industry's technological opportunities for the *i*th type of R&D. To maximize its profit from process R&D investment, the insourcing firm will choose the optimal process R&D expenditure:

$$r_1^* = [(b_1 g_1)(q_1 + \alpha q_2)]^{\beta_1} \tag{3}$$

Similarly, to maximize its profit from product R&D investment, the insourcing firm will choose the optimal product R&D expenditure:

$$r_2^* = [(b_2 g_2)(h q_2 + k)]^{\beta_2} \tag{4}$$

Combining (3) with (4) yields the optimal process R&D share,

$$p_{\text{share1}} \equiv \frac{r_1^*}{r_1^* + r_2^*} = \left[1 + \frac{(g_2 b_2)^{\beta_2}}{(g_1 b_1)^{\beta_1}} (q_1 + \alpha q_2)^{-\beta_1} (h q_2 + k)^{\beta_2}\right]^{-1} \tag{5}$$

This equation provides information about how the insourcing firm optimizes its R&D composition between the two innovation choices, and it also gives three predictions about the insourcing firm's R&D investment behavior.

- ***Prediction 1: The heterogeneity of offshore outsourcing demand does influence the insourcing firm's R&D investment behavior.***
  The types of offshore outsourcing demand affect the insourcing firm's R&D composition. Other things equal, as the OEM sales (q_1) increase (i.e., receiving more contracts of outsourcing production only), Equation (5) states that as $\beta_1 > 0$, p_{share1} increases (i.e., the insourcing firm invests more in process innovation), which provides the benefit of cost reduction through achieving greater efficiency in manufacturing. In contrast, as the ODM sales (q_2) increase, (i.e., receiving more contracts of outsourcing both production and product design), one can show that, when $\beta_2 > \beta_1$, p_{share1} decreases (i.e., the insourcing firm invests more in product innovation), which provides the benefit of unit profit increase through creating new products or new product features.

- ***Prediction 2: Given a fixed combination of two offshore outsourcing demands, the insourcing firm's individual characteristics affect its R&D investment behavior.***
  If we fix the sales composition of two types of offshore outsourcing demands (q_1/q_2), the insourcing firm's individual characteristics modeled by β and g will also affect its R&D composition. Indeed, the insourcing firm's history will affect or impose constraints on its

knowledge about and its ability to alter the way it functions and competes. For example, if the insourcing firm begins with competitive advantage in process technologies (which can be characterized by a greater β_1 or a greater g_1), it will invest more in process R&D as predicted by Equation (5). That is because the process R&D investment can maintain its competitiveness and prolong the time for its competitors to match its cost savings through process innovation. In addition, by continually focusing investment in process technologies, in which its competitive advantage lies, the insourcing firm can increase its speed of commercialization and have a smaller declining rate of its marginal return on process R&D investment (i.e., β_1 increases). A company such as Hon-hai Precision has competitive advantage in tooling technologies, which provides the benefit of commercializing its products faster than its competitors. Because of this benefit, it has strong incentives to keep investing in tooling technologies to maintain its competitive advantages (Zhang 2005). Therefore, the firm's individual characteristics, such as its existing competitiveness, will also shape how it develops its technology expertise.

- ***Prediction 3: Given a fixed combination of two offshore outsourcing demands, the industry's technological opportunities for each type of R&D affect the insourcing firm's R&D investment.***
  The insourcing industry's technological opportunities (b) depend on several potential sources, including the nature of the industry, clusters, and reverse brain drain. For instance, if the insourcing firm and its suppliers cluster together in the same region and specialize in IT manufacturing, the industry's technological opportunities for process R&D are greater than for product R&D. In other words, a successful cluster specializing in manufacturing provides economic externalities for its regional firms to be competitive in process innovation (i.e., a greater b_1). As a result, the insourcing firm will invest more in process R&D (i.e., a greater p_{share1} when b_1 increases, as predicted by Equation (5)). In addition, the degree of the linkage between the insourcing cluster, such as Hsinchu Science Park in Taiwan, and other advanced clusters, such as Silicon Valley, may also influence the industry's technological opportunities as well (Saxenian 2000; Bresnahan et al. 2001).

3 The Empirical Analysis

Many scholars have pointed out that the biggest hurdle of studying offshore outsourcing is the dearth of data. This difficulty arises from the fact that outsourcing firms are unwilling to release or compile the data either due to political or corporate considerations (Session on Offshoring, 2006 ASSA Conference). To date, economists mainly rely on trade data, which has its limitations. For example, trade data is contaminated by intra-firm trade and cannot capture the type of offshore outsourcing activity where the outsourcing firm has its overseas insourcing firms directly serve its foreign market demand. That is, trade data alone can significantly underestimate the degree of offshore outsourcing aimed at serving overseas markets, especially for those markets experiencing rapid growth. For example, Dell is the world's top PC seller and outsources the majority of its products. Its overseas sales, which occupied over 43% of its total sales quantity in 2005, were directly shipped by its overseas suppliers and were not counted in the U.S. trade data. In addition, its 2005 sales growth was mainly driven by its overseas sales growth in regions, such as the Asia

Pacific markets. Moreover, the U.S. PC market only accounts for 30% of the world market and international markets consistently perform much better than the U.S. (IDC 2006). Because of this limitation, U.S. trade data may not truthfully reveal the impact of offshore outsourcing on the insourcing side. In addition, to provide just-in-time service, many IT insourcing firms have their U.S. subsidiaries import products from overseas plants and then sell them to their U.S. outsourcing customers. These types of activities also cannot be revealed from trade data without imposing further assumptions.

To directly address the above issues, I collected firm-level data on offshore outsourcing by collaborating with Market Intelligence Center (MIC), a leading IT industry research and consulting service provider in the Asia Pacific region. MIC, based in Taiwan, has clients that include a number of Fortune 500 companies as well as Taiwan's most prominent high-tech companies whose combined production value contributes 85% of the annual output of the Taiwanese IT industry. Through this collaboration, I successfully conducted an industry survey and collected data from 28 world-class insourcing firms in the IT hardware industry.

3.1 The Target Industry: The IT Hardware Industry

My empirical analysis focuses on the IT hardware industry, an enabling industry. Compared with the IT software industry, this industry has a longer history of global outsourcing in both production and product design. In particular, I focus on the Taiwanese IT hardware industry. Can the Taiwanese IT hardware industry truly represent the insourcing side of the story and capture the IT offshore outsourcing phenomenon? We can answer this question by citing an article in *Business Week* on May 16, 2005: "*Why Taiwan Matters?*" To indicate why the Taiwanese IT hardware industry is essential for the offshore outsourcing of the U.S. IT industry, the journalist asked a top executive at a U.S. high-tech giant: "Couldn't U.S. industry develop sources of IT supply that don't involve the Taiwanese?" And, the executive replied: "That's like asking: What's the second source for Mideast oil?" Indeed, as shown in Tables 1 and 2, Taiwanese insourcing firms dominate the world's IT hardware industry. For example, in 2004, Taiwanese notebook PC insourcing firms occupied 73% of the world's notebook PC market and 94% of the sales came from offshore outsourcing contracts.

The article also points out two important features of the IT offshore outsourcing phenomenon, which are related to my research. First, it reports that "insiders estimate that it would take a year and a half to even begin to replace the vast web of design shops and mainland [China] factories the Taiwanese have built." That is, it is difficult for other regions' producers with cheaper labor costs to replace the Taiwanese. Moreover, despite having their bases in Taiwan, the majority of Taiwanese insourcing firms mainly operate in the regions combining China and Taiwan. They exploit and utilize regional resources and advantages by keeping R&D in Taiwan and production in China. MIC's data show that in 2005, Taiwanese IT hardware firms produced almost 80.6% of China's total IT hardware production value. For example, despite being a Taiwanese insourcing firm with annual sales around US $21 billion in 2005 (Cheng 2006), Hon-hai Precision was China's largest exporter in 2002 (Prestowitz 2005). Strikingly, on the Annual Patent Scorecard in the 2004 MIT Technology Review, it surpassed its outsourcing customers, such as Dell (17th) and Apple (24th), and was ranked as 12th in the computer sector (Mably 2004).

The second feature is that the global IT outsourcing phenomenon co-exists with the clustering phenomenon of insourcing firms and industries. For example, as a top executive for the handheld business of palmOne Inc., Ken-Wirt stated: "The IT model is not one built on second-sourcing." The statement is consistent with what we observe in practice: global IT hardware outsourcing is concentrated in a group of Taiwanese firms clustering in the same regions. And, we also observe another insourcing cluster of IT software industries forming in India (Saxenian 2000; Bresnahan et al. 2001). The clustering phenomenon implies that, in global IT outsourcing, location does matter.

Indeed, Porter (1998) argues that the current world economy is dominated by clusters that specialize and dominate particular fields. Clustering of related industries is not a new phenomenon. Marshall (1920) showed why clustering could help enterprises, especially small ones, to compete. He suggested that the agglomeration of firms engaged in similar or related activities generated three sources of localized external economies that provided cost comparative advantage for clustered producers. Such sources included a thick skilled labor market, easy access to specialized input or service suppliers, and quick knowledge spillovers.

3.2 The Taiwanese IT Hardware Industry

Since the mid 1980s, the Taiwanese IT hardware industry has been experiencing spectacular growth and has since achieved a dominant position in the world market, as shown in Tables 2 and 3. It is noteworthy that it only took two decades for the Taiwanese industry to achieve its current status. This achievement can be explained by the development of the Taiwanese notebook PC industry, which perfectly exemplifies how fast global outsourcing in the IT hardware industry has increased over time and how it has been helping the Taiwanese IT hardware industry grow rapidly.

Table 1 covers the Taiwanese notebook PC industry from 1990 to 2004 and it shows several salient features. First, as the world market size grew, the Taiwanese notebook PC industry grew as well but at a higher rate. Second, during the same period, the Taiwanese notebook PC industry increasingly dominated the world market. In 2005, it already controlled 79% of world market in the notebook PC sector. This shows that the target of global outsourcing in the notebook PC industry has been increasingly concentrated in a group of Taiwanese firms. In addition, the first two points indicate that the Taiwanese industry has expanded its operation scale rapidly by exploiting global economies of scale. Third, the degree of sales from offshore outsourcing contracts increased over time and the majority of the sales increase came from offshore outsourcing contracts. In 2004, 94% of sales were from offshore outsourcing contracts. Fourth, as world market size grew, the degree of the division of labor increased as well, which conforms to Smith's theorem (Smith 1776; Stigler 1983). Fifth, offshore outsourcing in the notebook PC industry started in the early 1990s when the technologies of notebook PCs were not standardized and advanced rapidly. This important fact means that offshore outsourcing in the IT industry can happen at the early stage of the product life cycle. This contrasts with the common fallacy that the rise of IT offshore outsourcing is mainly caused by the fact that product technologies are standardized and cheap labor cost is the only concern.

Despite the fact that all IT hardware industries have grown very fast in the past two decades, only a few firms dominate each industry. Table 4 shows the degree of market concentration in Taiwan's different IT hardware industries in 1998. For example, the Taiwanese notebook PC industry controlled 39% of the world market, but the top 5 players controlled almost 72% of the industry's sales. Additional data from MIC show that the market concentration of the Taiwanese IT industry has been increasing since 1998. In 2001, the market share of the top 3 notebook PC firms increased from 42.0% in 2000 to 50.0%. Given that only a few players dominate each industry in this IT sector, it implies that those Taiwanese insourcing firms can exploit vast economies of scale and grow in size rapidly.

Although the market concentration in this IT sector is high, Taiwanese IT insourcing firms have incentives to act as competitive players. On the one hand, outsourcing firms, such as HP and Dell, adopt a two- or three-supplier strategy (see Tables 5 and 6) to minimize their risk of a holdup problem with their suppliers and to enhance the supply side competition. On the other hand, to support their growth and operations, insourcing firms have to try their best along all dimensions of price, quality, and product design in order to compete for the field. As shown in Quanta's case, losing any major outsourcing customers will cause costly disruptions to its operations. Besides that, Taiwanese insourcing firms not only lack international marketing know-how to forward integrate into the downstream but also face a limited domestic market which cannot support their growth and operations. That is, compared with their outsourcing counterparts, they encounter a more serious holdup problem. Nonetheless, given that they lack an outside option, it is still in line with insourcing firms' incentives to try their best to fulfill their outsourcing contracts satisfactorily.

3.3 Data

3.3.1 Data Source

The Taiwanese IT hardware industries cluster in certain regions, including Hsinchu Science Park in Taiwan and Shanghai in China, and only a few major players dominate each industry. Their dominance in the world market with an oligopolistic market structure (i.e., in terms of the number of firms) provides a clear advantage to focus my data collection from Taiwanese IT insourcing firms.

In this research there are three main data sources: MIC in Taiwan, the public data of insourcing firms, and my industry survey of Taiwanese insourcing firms. Collaborating with MIC, we conducted an industry survey in three stages in Taiwan. First, we sent a questionnaire to 134 firms in MIC's database, including companies in PC, mobile, and communication industries. Second, based on the initial feedback, we deleted 10 non-insourcing firms, leaving 124 firms in the sample. Finally, because the data needed to be collected from different departments within a company, we conducted telephone interviews to complete the survey. We obtained data from 28 companies, which cover 75.8% of the Taiwanese IT hardware industry's 2004 sales, almost US $70 billion. Table 7 shows the list of questions in the questionnaire.

3.3.2 The Survey Summary

I summarize the survey results in Table 8. The survey data cover 12 industries and the years 2002 to 2004. The second column indicates, for each industry, how many companies are included in the sample. The third column indicates the market concentration of each industry, and the fourth column shows the world market share of each industry. The rest of the columns are data from the survey, including the average R&D intensity, the average product R&D share, the average OEM and ODM shares, and the annual average patent numbers per firm, all by industry.

3.3.3 Data Analysis

A key result of the survey is shown in Figure 2, where plotted are the data points and the 2-dimensional interpolation for the process R&D share versus the OEM and ODM shares. This figure shows that when the OEM share is not significant, the insourcing firm invests at a relatively stable level around 20% of R&D resources in process R&D. When the OEM share is significant, however, the insourcing firm could increase its process R&D share to a much higher level.

A regression analysis on the surveyed data provides several important results. First, Tables 9 and 10 show that as offshore outsourcing demand increases, the insourcing firm increases both the amount and intensity of its R&D investment. And, based on the R^2 values, ODM sales have more explanatory power in the R&D expenditure than OEM sales. Besides, Table 11 shows that rather than the OEM sales growth, the ODM sales growth has a greater positive relationship with the insourcing firm's sales growth. Second, Table 12 shows both offshore outsourcing demands have positive relationships with process R&D investment but OEM has a higher regression coefficient. These results indicate that the data are consistent with my model assumptions on the relationship between process R&D investment and each type of offshore outsourcing demand, OEM or ODM. Third, Table 13 shows that, as the OEM share increases, the insourcing firm will increase its process R&D share as well. For the ODM share, however, the opposite relationship holds. In addition, the regression analysis also shows that, for the IT industry, sales alone are not a good predictor of a firm's process R&D share, which is consistent with Cohen and Klepper's (1996) result. Instead, in IT offshore outsourcing, we can better predict the process R&D share by using the information on different outsourcing demands.

The above regression analysis provides some insightful information about how different offshore outsourcing demands relate to the insourcing firm's R&D investment behavior. But, we know that other factors, including the firm's individual characteristics and the industry's technological opportunities for each type of R&D, will also affect the insourcing firm's innovation choices. All these factors are characterized by the parameters in my model (see Equation (5)), which can be estimated through the comparison between the model and the survey data. Because the data set includes a wide range of company sizes and IT sub-industries, each type of outsourcing demand sales is normalized to each company's total sales in the model fitting. The procedure of nonlinear fitting, including error estimation through the bootstrap method, is described in detailed in Appendix A. Figure 3 shows the data, the best-fit model, and the optimal values of the 9 model parameters. From the least square fit with 1000 bootstrap resamples, Figure 4 shows the distribution, the mean value, and the standard deviation of each parameter. These results indicate that the IT insourcing hardware industry has the following important properties.

First, given that $g_1 < g_2$ in terms of their optimal values, product innovation can better protect the insourcing firm from market competition than process innovation. In some industries, such as pharmaceuticals, it is harder for process innovation, which is normally kept as trade secrets, to spill over to other firms. But, in the IT hardware insourcing industry, the existence of clusters and the free mobility of skilled labors within the cluster facilitate the spillover of process innovation. This provides an explanation of why product innovation can better protect the insourcing firm from market competition.

Despite insourcing firms having incentives to invest more in product innovation, they are still forced by the high degree of market competition to invest in both types of R&D to survive and keep up with their competitors. It is true that insourcing firms may have fewer incentives to invest in both types of R&D, given that the IT insourcing cluster has greater technology spillovers within the region and the degree of appropriability of innovation is essential for firms to commit R&D investments (Arrow 1962). Nonetheless, the R&D investment is critical for them to learn and create new knowledge in order to compete (Cohen and Levinthal 1989).

Second, given that $b_1 < b_2$ in terms of their optimal values, the industry's technological opportunities for product R&D are greater than for process R&D. This can be explained by the fact that the majority of insourcing firms receive greater demand from the ODM market. Competing in the ODM market will drive the firm to invest more in product R&D. Given the rise of ODM demand, the insourcing industry invests more in product R&D and nurtures the human capital and knowledge capital within the insourcing cluster. One should note that, besides quick knowledge spillovers, the insourcing cluster also has two other localized external economies: a thick skilled labor market and easy access to specialized input or suppliers. Hence, the higher degree of product R&D investment in the industry provides a better product technology environment. In addition, given that $\beta_1 < \beta_2$ in terms of their optimal values, marginal return on product R&D investment is declining more slowly than that on process R&D investment.

Third, given that $\alpha = 1.15$, the ODM product does carry a price premium and 70% (h) of existing outsourcing customers will continue to buy new products or existing products with new features at a higher price. And, the investment in product innovation does attract an additional 13% (k) of new ODM customers. This shows that investing in product design expertise will increase the ODM demand.

Finally, given that the type of the insourcing firm's technology expertise affects the outsourcing firm's decision on what to outsource, I also develop a dynamic model of the insourcing firm's innovation investment, as shown in Appendix B. The dynamic model provides a theoretical framework for future studies to investigate the time-dependent characteristics of the insorucing firm's innovation choices in response to a changing market environment.

4 Samuelson's Missing Link and the Rising Global IT Outsourcing Phenomenon

4.1 Connecting Samuelson's Missing Link between Offshore Outsourcing in the High-tech Industry and Technology-driven Productivity Growth in the Insourcing Industry

As described below, my empirical results show that the rise of IT offshore outsourcing does help the insourcing industry gain technology-driven productivity growth. This finding offers some support for Samuelson's view that offshore outsourcing in high-tech industries may potentially lead the U.S. economy to suffer. Specifically, I provide two approaches here to connecting Samuelson's missing link between offshore outsourcing in the high-tech industry and technology-driven productivity growth in the insourcing industry. In the first approach, the regression analysis shows that, as offshore outsourcing demand increases, the insourcing firm increases both the amount and intensity of its R&D investment. Given that an industry's R&D intensity has a positive relationship with its TFP growth, we can then reasonably conclude that there is a positive relationship between offshore outsourcing in high-tech industries and technology-driven productivity growth in the insourcing industry.

The second approach is not only to show the link but also how they link. This approach connects Samuelson's missing link based on three findings. First, my model (*Prediction 1*) shows that the heterogeneity of offshore outsourcing demand influences the insourcing firm's innovation choices and the data confirm a positive relationship between the type of offshore outsourcing demand and the type of R&D investment. Contrary to the traditional mechanism of foreign direct investment (FDI) in production in which overseas subsidiaries import technologies from their parent companies, IT offshore outsourcing provides strong market incentives for insourcing firms to constantly invest in both types of R&D and eventually generate indigenous technologies. For example, TSMC, the world's top foundry of custom-made chips, has even been licensing its patents on process technologies to U.S. semiconductor firms (Tseng 2004).

The second finding is obtained by the results in Table 14, which shows the regression of R&D investments on the lagged values of OEM and ODM sales. Both positive and negative time lags between the independent variables and the dependent variables are examined to find the causality direction. It is found that the explanatory power of the regression analysis with a 1.5-year lag is consistently higher than that of a -1.5-year lag. This result supports the argument that offshore outsourcing demand does affect the insourcing firm's R&D investments.

More importantly, the third finding is that the history of the IT insourcing industry clearly shows that offshore outsourcing demand was initially exogenous. As recounted by Saxenian (2006), the overseas Chinese in Silicon Valley provided Taiwan's first OEM contracts of its IT industry. In the early 1980s, Qume, a Silicon Valley company and founded by a overseas Chinese, placed the first OEM contracts to three small Taiwanese companies: Multitech (the forerunner of Acer), Mitac (one of the world's top 10 notebook PC insourcing firms), and Compeq (one of the world's top 10 makers of Printed Circuit Board). Qume sent a team from the U.S. to Taiwan to teach the engineers of its three small suppliers how to manufacture and test IBM PCs. This fact clearly indicate that the Taiwanese IT insourcing firms gained technological progress from the initial technological transfer of the U.S. outsourcing firm.

Based on the above three findings, not only can we connect Samuelson's missing link, but also conclude that different offshore outsourcing demands affect the insourcing firm's different R&D investments. Given that both process R&D and product R&D are positively related to an industry's TFP growth, I reasonably conclude that IT offshore outsourcing does help the insourcing industry gain technology-driven productivity growth. Lastly, in the IT hardware industry's history, while the quality improvement of the IT products has been increasing, their prices have been decreasing. This implies that IT insourcing firms have been consistently delivering products with increasing quality improvement and decreasing cost benefits, which shows their gain in technology-driven productivity growth.

4.2 Why Are U.S. IT Firms Increasingly Outsourcing R&D Overseas?

In his Nobel Prize lecture, Coase (1991) states: "Businessmen in deciding on their ways of doing business and on what to produce have to take into account transaction costs. If the costs of making an exchange are greater than the gains which that exchange would bring, that exchange would not take place and the greater production that would flow from specialization would not be realized. In this way, transaction costs affect not only contractual arrangements but also what goods and services are produced." In other words, he argues that transaction costs will determine whether the division of labor across firms will take place. As pointed out by Demsetz (1988), his argument implicitly assumes that specialized firms will deliver the goods with equally satisfying quality.

This implicit assumption has greatly influenced the research direction on offshore outsourcing. Current dominant outsourcing models (Grossman and Helpman 2002; Antras 2003, 2005; Antras and Helpman 2004) adopted the transaction cost approach and assumed that all insourcing firms were identical and that there were many of them. In fact, when studying global IT outsourcing, this implicit assumption is invalid and transaction costs alone, including information costs from incomplete contracting problems, cannot explain IT firms' different outsourcing behaviors in the same exchange environment. The reasons are as follows.

First, the IT industry's technologies are constantly advancing and not free for all firms (Darby and Zucker 2006). Because technologies are costly to produce and maintain, to compete and survive in the IT industry, insourcing firms need to consistently invest in different types of R&D to improve their product features or reduce their production costs. Their different R&D investment behaviors will determine the types of innovations and products that they can produce. That is, their R&D investment behaviors can shape their technology expertise, which is the source of their heterogeneity. Both my model and data indeed show that there is cross-firm heterogeneity in innovation investments. For example, in the notebook PC industry, the eight insourcing firms' product R&D shares range from 54% to 77%. Second, outsourcing firms show different outsourcing behaviors, such as outsourcing production only or outsourcing both production and product design, even in the same industry, product category, and exchange environment. That is, even in the same product market, each insourcing firm has a different sales composition of OEM and ODM from others, which implies that outsourcing firms make different decisions on what to outsource. It is clearly evident in my data that the ODM shares of the same eight PC insourcing firms can range from 33% to 100%. Given that it is very unlikely for U.S. outsourcing firms to face significantly different transaction costs when dealing with the same group of Taiwanese insourcing firms, the heterogeneous outsourcing behaviors in the same exchange environment cannot be explained by transaction costs alone. So the question follows: If all insourcing firms could produce goods equally well, then transaction costs within the same industry, product category, and exchange environment should be almost the same. Yet, why do we observe cross-firm heterogeneity in offshore outsourcing behaviors?

Clearly, in global IT outsourcing, other factors beyond transaction costs matter more. Stigler (1983) states that we partition the firm by its functions and the cost of each individual function will be related by technology. Besides the consideration of transaction costs, the cost benefits of outsourcing also depend on insourcing firms' technologies. Outsourcing firms will outsource production when insourcing firms have the process technology expertise necessary to provide a low-cost production solution. And, outsourcing firms will outsource both production and product design when insourcing firms not only have process technology expertise but also have product design expertise necessary to provide a product with a good design and at a competitive price. Hence, I argue that the types of insourcing firms' technology expertise will affect outsourcing firms' decisions on what to outsource.

Moreover, decisions on where and what to outsource are also related to the comparative advantages of insourcing firms and their regions, which involves considerations beyond transaction costs. In the IT industry during the 1980s, the outsourcing country began with comparative advantage and the insourcing country did not begin with all the technology expertise that outsourcing firms demanded. Even if transaction costs are low, outsourcing firms will not outsource R&D to insourcing firms that do not have the required technology expertise. So, the technology gap between outsourcing firms' need and insourcing firms' capabilities clearly matters. Grossman and Helpman (2003) recognize and incorporate the technology gap into their model. Because this paper examines the data from insourcing firms in which outsourcing firms did not choose whether to outsource (which they already did) but what to outsource, insourcing firms should have the required technology expertise.

In fact, in global IT hardware outsourcing, transaction costs are not crucial for outsourcing firms' decisions on whether and what to outsource. This characteristic is evidenced by several facts. First, my data show that IT insourcing firms and industries cluster together in the same regions, and therefore the transaction costs within the cluster should be low (e.g., Porter 1998). Second, given the fact that the scale and the scope of global IT outsourcing are increasing rapidly, transaction cost theory (Coase 1937) suggests that transaction costs are not critical in IT outsourcing firms' decisions. Third, to reduce transaction costs, the IT industry has developed a well-operating market mechanism, including annual world IT trade shows in Germany, Taiwan, and the U.S., where insourcing firms present their prototypes and new products to their existing and potential outsourcing customers. Fourth, transaction costs are also reduced by both the insourcing industry structure and insourcing firms' increasing brand reputation. My data show that every Taiwanese insourcing industry is oligopolistic and increasingly concentrated. For example, in 2004, the top 5 Taiwanese notebook PC insourcing firms occupied almost 72% of the Taiwanese notebook PC industry and the whole industry occupied 79% of the world market share. The firms surviving this increasingly concentrated environment are gaining ground by increasing their brand reputations among outsourcing firms. For example, when Sony entered the PC market in the late 1990s, it chose the leading Taiwanese insourcing firms, Quanta and Asus, as its major competitors did (see Table 6). Fifth, transaction costs from incomplete contracting problems are greatly reduced by outsourcing firms' multiple-supplier strategy. This outsourcing strategy enhances insourcing firms' competition and forces them to deliver the products at the required terms, which in term reduces outsourcing firms' risk of holdup problems with their suppliers. In addition, as argued before, the holdup problem is more serious on the insourcing side; nonetheless, to compete for the field and support its growth, the insourcing firm will try its best to attract, maintain, and fulfill its outsourcing contracts.

Given that transaction costs are not critical and cannot explain different IT outsourcing behaviors, the next question should be: Does the insourcing firm's technology expertise affect the outsourcing firm's decisions on what to outsource? To answer this question, I refer to two results described in Section 3. First, the regression result shows a positive relationship between the outsourcing firm's decision on what to outsource and the insourcing firm's decision on what type of technology expertise that it invests. But, this positive relationship between the two alone cannot answer for the direction and extent of causality. The second result, however, can identify both the direction and extent of causality by examining the sign and magnitude of k, a parameter that defines the new ODM demand due to product R&D investment (see Equation (2)). Without imposing any constraints on k in the model fitting, the bootstrap estimation (see Appendix A) of k's probability distribution shows a medium value at 7%, with the 25th percentile at 4% and the 75th percentile at 10% (see Figure 4). Because the value of k is clearly positive, this result confirms that the insourcing firm's investing in product innovations can increase its new ODM demand. In other words, outsourcing firms will choose what to outsource according to insourcing firms' different technology expertise.

An IT insourcing firm's technology expertise indeed can be measured by its R&D composition. In practice, for an IT insourcing firm to be competitive in the ODM market, it needs to produce as efficiently as the insourcing firm that mainly engages in the OEM market, defined as the OEM-market oriented insourcing firm. While in general all insourcing firms can produce both OEM and ODM products, compared with OEM-market oriented insourcing firms, ODM-market oriented insourcing firms are not only competitive in cost but also superior in product innovation. Given that an increase in product R&D investment will attract new ODM demand, insourcing firms' relative technology expertise can be measured by their R&D composition. The higher product R&D share the insourcing firm invests, the higher product design expertise it has.

In sum, based on the connection of Samuelson's missing link and the above result from the estimation of k, I show that there is a bi-directional influence between IT offshore outsourcing demand and the insourcing firm's technology expertise. And, this bi-directional influence provides an important explanation of why IT outsourcing firms are increasingly outsourcing innovation overseas. IT offshore outsourcing initially provides nutrition for the insourcing firm to grow quickly and become more capable in terms of its sales and technology expertise, respectively. As it develops and accumulates more technology expertise, the increase in its technology expertise will motivate the outsourcing firm to increase its outsourcing demand. By doing that, outsourcing firms not only can reduce both the amount and risk of their capital investments, but also exploit insourcing firms' innovation investments and capabilities.

4.3 The Benchmark Case, the 80-20 Rule, and Vernon's Trade Patterns

My model can also be used to derive a benchmark case to explore whether the non-outsourcing firm will show a different R&D investment behavior as the ODM-market oriented insourcing firm. The benchmark case is a hypothetical case in which the outsourcing firm purchases an insourcing firm as its new FDI subsidiary devoted to designing and producing its products. The R& D investment behaviors of this FDI subsidiary follow the same equations described in Section 2.3, except in this case $\alpha = 1$ and $q_1 = 0$, converging to the same mathematical form as modeled by Cohen and Klepper (1996). Incorporating these additional conditions and $q_2 = 1$ (100% ODM) into Equation (5), we can predict the FDI subsidiary investment in process R&D by using the same estimated parameter values obtained by the model fitting (See Figure 4), as the new FDI subsidiary can be located in the same insourcing region.

The result shows that this FDI subsidiary will invest 23% of R&D resources in process R&D and 77% in product R&D, an R&D composition which is very similar to those of ODM-market oriented insourcing firms in my survey (see Figure 2). In other words, as the degree of offshore outsourcing in R&D increases, the insourcing firm will increasingly engage in a similar R&D investment behavior to non-outsourcing firms that keep product design and production in-house.

It is worthwhile to compare the above result with a survey conducted by Mansfield (1988), who examined the innovation choices of 50 U.S. firms and 50 Japanese firms, including pharmaceutical and computer firms. In the 1980s, before engaging in large-scale offshore outsourcing, U.S. firms on average invested around 67% of their R&D resources in product R&D. In contrast, Japanese firms on average invested around 33% of their R&D resources in product R&D. Moreover, in 2006, Business Week and Boston Consulting Group also conducted a survey of the largest 1500 global corporations, with over 75% of respondents from Western companies, and concluded that on average they invested 21% in process innovation (McGregor 2006).

The similarity among my findings, Mansfield's results, and Business Week's survey provides several important implications. First, the sales increase in ODM contracts drives the insourcing firm to develop a similar R&D investment behavior to their Western counterparts that keep R&D in-house. Second, the insourcing firm's innovation behavior is different from Japanese firms' in the 1980s. At that time, Japanese firms produced and commercialized new products more efficiently. They invested the majority of their R&D resources in process R&D (67%), to exploit the product ideas that were originally developed by the U.S. In the era of offshore outsourcing in innovation, however, U.S. firms focus more on maintaining and building international brands and marketing capabilities, and outsource some or all parts of their R&D activities overseas. Indeed, in their study of the PC industry in the late 1980s, Bresnahan et. al. (1997) conclude that rather than being a technology leader, having a leading brand provides a company with a great advantage in increasing its market demand. Corresponding with U.S. firms' shifting strategic focuses, insourcing firms assume more responsibility in creating product ideas. And, their R&D investment behaviors are increasingly similar to those of U.S. firms in the 1980s, the time before they engaged in large-scale offshore outsourcing, or those of current global Western corporations.

More importantly, both my findings and Business Week's survey point to what I call the 80-20 rule: 80% of R&D resources invested in product R&D and 20% in process R&D. In practice, firms that retain innovations, such as product design, seem to follow this rule in conducting their R&D. This discovery shows that, through its experience of supplying ODM services, the insourcing firm develops product design expertise and its R&D investment behavior is similar to those of U.S. firms that retain innovations.

Lastly, the continuing investment in both types of R&D is also necessary for insourcing firms to learn and create new knowledge and products in the IT hardware industry, which has the crucial feature that product technologies, even post-dominant design developments, are constantly advancing (Adner and Levinthal 2001). The consistent R&D investment starts to bear fruit. Indeed, we observe that insourcing firms are generating indigenous technologies in both process and product technologies. For example, as mentioned before, some insourcing firms are actually licensing technologies to U.S. high-tech firms, as shown in the TSMC's case. And, some of them even surpassed their U.S. outsourcing customers in major international patent ranking, as shown in the Hon-hai Precision's case. In addition, in recent years, many Taiwanese IT insourcing firms have increasingly claimed their U.S. patents and the world's four major design awards, such as Germany's prestigious iF design award (Lai 2005). All these results show that, in the new outsourcing era with advances in communication and transportation technologies, Vernon's (1966) views on product life cycle and its implied trade patterns no longer hold. Contrary to Antras's (2005) findings, which are mainly based on research in and before the 1980s, my findings are based on the data from the IT industry, in which the offshore outsourcing phenomenon started around the 1980s and has grown rapidly in the past 15 years. Different from FDI, IT offshore outsourcing provides a new mechanism for insourcing firms to constantly invest in innovations, to generate indigenous technologies, and to reduce their reliance on outsourcing countries' or firms' technologies.

5 Policy Implications

5.1 A Trilogy of Technological Progress

Researchers have been studying how FDIs influence the technological progress of developing countries. They suggest that offshore production helps developing countries make technological progress through importing technologies and reverse engineering. In other words, offshoring production of physical goods helps raise the level of technological performance in developing countries. The technologies, however, are still tied to advanced countries and local firms lack strong incentives to invest in R&D.

Observations show that some of the FDI regions later become the offshore outsourcing target of high-tech firms in developed countries. The rising offshore outsourcing in high-tech industries provides a new market mechanism for firms in the insourcing region to constantly invest in R&D and generate indigenous technologies. As the ODM demand increases, insourcing firms increasingly assume greater responsibility in creating new products or technologies. In addition, we also observe that insourcing firms in high-tech industries are gaining ground in recent world design competitions. These observations suggest that, because of longer and greater experience with global outsourcing, insourcing firms in high-tech industries are gaining momentum in creativity. The question remains: How did the whole process happen?

Based on the experience of Taiwanese IT hardware firms, I propose a trilogy of technological progress. In the first stage, through the channel of FDI in production, the subsidiaries of multinational firms import process technologies from their parent companies normally located in advanced countries. The process technologies are still tied to advanced countries, but the production subsidiaries of multinational firms act as incubators to nurture local managers and engineers to acquire production knowledge and skills. For example, PC companies, such as Digital Equipment Computer Co., set up production plants in Taiwan in the 1980s and helped the Taiwanese produce and accumulate a group of production experts for the development of its IT industry. More importantly, overseas Chinese from the U.S. returned and brought back their advanced IT product and production know-how. In an earlier paper with Saxenian, we point out that, because of the great prospect of a future economic growth and the high degree of entrepreneurship in Taiwan, new IT ventures formed by local IT experts or overseas returnees started and continued growing (Saxenian and Li 2003). In other words, new ventures exploited the local emerging accumulated human capital in latest technologies, management know-how and production capabilities.

In the second stage, with the rise of the OEM market, a new venture can exploit global economies of scale. As shown in the model, the rise of offshore outsourcing in production motivates the insourcing firm to invest in process R&D. The increase in process R&D investment helps the insourcing firm develop the ability to learn and create new process knowledge. That is, to compete in the OEM market, the insourcing firm gains in process know-how and, eventually, produces indigenous process technologies, as shown in the TSMC's case. Under the trend of concurrent engineering, offshore outsourcing also provides opportunities for insourcing firms to participate in the new product development process of their outsourcing customers at the early stage. The experience with world-famous IT outsourcing firms enables the insourcing firm to have access to advanced management knowledge, new product development, and international market preference, which helps it learn design know-how and manage new product development. By accumulating the design know-how and the capability of efficient commercialization, the insourcing firm can move upwards along the value chain to design products for its outsourcing firms.

In the third stage, the insourcing firm assumes more responsibility in creating new product ideas for its outsourcing customers. To compete in the ODM market, the insourcing firm not only invests in process R&D but also product R&D. As shown in the model, as ODM share rises, the insourcing firm will increase its product R&D share as well, which paves the way for product innovation. The increase in product R&D investment helps the insourcing firm learn and create new product knowledge. As a result of the industry's new development in offshore outsourcing markets, the insourcing firm not only produces indigenous process technologies but also product technologies. In other words, as the ODM demand increases, the insourcing firm continually accumulates innovation capabilities within its organization. In addition, through the experience, the insourcing firm acts as an incubator of world-class IT engineers and managers and helps the IT industry accumulate an endowment in human capital.

Although we can apply the trilogy of technological progress to each industry, countries such as China and India could see these three stages happen simultaneously. This synchronization occurs in countries with big domestic markets and a large pool of skilled workers. Especially, entrepreneurs can move resources relatively freely from the neighboring regions to these countries, such as the closely intertwined IT network between Taiwan and China to exploit the resources and opportunities within the combined region. Moreover, multinational firms, including Microsoft, are increasingly setting up research labs in developing countries such as China and India to exploit the abundant supply of talent in these countries. These research labs conduct both applied and basic research (Kapur and Mchale 2005).

What will happen next? This research shows that insourcing regions, such as the combined region of Taiwan and China, have gained world-class capabilities in product design, commercialization, and production. Given that U.S. firms are increasingly setting up research labs in these regions, these research labs not only provide a pool of advanced skilled workers at a cheaper cost, but they also act as incubators to train world's top engineers and researchers in these countries. This new form of FDI will increase the endowment of high-skilled human capital in these countries, which may reshape the comparative advantages of these regions in new fields.

5.2 Reverse Brain Drain in New Industries

In the U.S., 55% of advanced degrees in technology areas are earned by foreign-born students (Guardino 2004). Previously, after graduating, the most talented of these students stayed in the U.S. and contributed their skills to the U.S. economy. But now, because of the rise of living standards and business opportunities in emerging markets, we are observing an increasing degree of reverse brain drain and brain circulation (Saxenian 2000). Brain circulation, as defined by Saxenian, refers to a process by which foreign-born professionals in the U.S. increasingly return to their home countries and serve as the bridge for the flow of technology and management know-how and exploit market opportunities in both places. Forces such as reverse brain drain and brain circulation help the home country gain critical human capital to establish a new industry or move an existing industry upwards in the value chain (Saxenian 2000; Zucker and Darby 2006). Moreover, advances in communication technologies further enhance the process by facilitating faster communication of ideas across regions. Indeed, we observed that this process occurred in the Taiwanese IT hardware industry during the mid-1980s and the 1990s, and in the Indian IT software industry started in the early 2000s. We now see a similar process occurring in China's various industries, including the biotech industry.

If we combine the two facts that (1) offshore outsourcing contracts have been flocking to these regions and (2) their outstanding expatriate scientists and engineers increasingly return, this combination provides good opportunities for insourcing firms to move upwards in the value chain and assume more responsibility in new industries. Moreover, the Chinese and Taiwanese occupy around 40% to 60% of U.S. post-doctoral fellows in bioengineering and science (Guardino 2004). If most of them return to their countries, will the biotech industry show a similar development pattern as the Taiwanese IT hardware industry? Or, will the combined resources enable biotech ventures in the region to outperform their Western counterparts in new areas, especially the area in which products are still not well-defined? Yet, in practice, the U.S. is still leading in several important sectors, such as the biotech industry. To maintain its leading position, the U.S. government needs to have policies for keeping these foreign-born talents and increasing our education in science and technology.

5.3 China and India vs. U.S. Terms of Trade

In the past two decades, insourcing firms in the IT hardware industry have achieved high-level performance in innovation, commercialization, and production. U.S. outsourcing firms, however, still dominate the final segment of the supply chain: marketing and services. This situation is created by insourcing firms' lack of international marketing know-how which inhibits their forward integration into the downstream, especially major international markets in the U.S. and Europe. In addition to the lack of international marketing know-how, Taiwanese insourcing firms cannot feed their growth and operations simply by serving their limited domestic market. These facts are the forces behind the identified asymmetric holdup problem in my model. If breaching the outsourcing contract, the insourcing firm does not have an outside option.

The situation, however, is changing. China and India are experiencing rapid economic growth and increasing their economic ranking quickly. For example, China is currently the world's second largest PC market. The rapid market growth in China and India can support insourcing firms' growth. Hence, it provides an opportunity for insourcing firms to forward integrate into the downstream. With the same culture and language, firms can move resources relatively freely within the region, including China, Hong Kong and Taiwan, thus exploiting the integrated Chinese market. That is, it provides a playing field for insourcing firms to establish themselves to compete with outsourcing firms. Because of the new outside option, the insourcing firm may reduce its holdup problem with its outsourcing customers in the near future.

In fact, some original insourcing firms have started competing with outsourcing firms in China and international markets. For example, Acer, once a top notebook PC insourcing firm, now is a top notebook PC seller in Europe, surpassing Dell and HP and experiencing rapid growth in China. Moreover, from the rankings of Taiwan's top 10 notebook PC insourcing firms in 1999 and 2005 (see Table 5 and 6), we find two important trends. First, in 1999, most outsourcing firms adopted a two-supplier strategy to reduce the risk of the holdup problem. In 2005, however, they had already expanded their supplier base from two to three suppliers. This change may be due to the fact that insourcing firms are experiencing rapid growth, and both outsourcing and insourcing industries are increasingly concentrated. Because of these facts, outsourcing firms need to further increase the supplier base to maintain their dominant power relationships with insourcing firms. Second, by 2005, Acer had already shed its role as an insourcing firm and instead became an outsourcing firm in the notebook PC market. As a result of new competition, it will be important to keep tracking the induced U.S. terms of trade change in the IT sector.

6 Conclusions and Suggestions for Future Research

The heated Samuelson-Bhagwati debate on the impact of offshore outsourcing highlights the importance in understanding the emerging new forms of international trade and cross-border businesses. This paper takes the debate seriously and the major concern is whether insourcing countries, such as China or India, will catch up with and eventually outcompete outsourcing countries, such as the U.S. Moreover, this paper goes beyond the debate by showing why U.S. IT firms are increasingly outsourcing innovation overseas.

This paper contributes to our understanding of the global IT outsourcing phenomenon in six aspects: First, I successfully collected firm-level data on offshore outsourcing in the IT hardware insourcing industry. Especially when data from outsourcing firms are unavailable, collecting data from insourcing firms, instead, can provide important insights into outsourcing firms' activities. This is a significant leap from studying trade data only.

Second, the new evidence provided by this study shows that IT offshore outsourcing helps the insourcing industry gain technology-driven productivity growth. This result connects Samuelson's missing link between offshore outsourcing demand and technology-driven productivity growth in the insourcing industry. This connection shows that the mainstream critique of Samuelson's theoretical model does not provide a strong argument against his hypothesis. That is because his critics agree with Samuelson's suggested scenario as an international trade problem: If China experiences productivity growth in the IT industry, this growth will have an adverse impact on the U.S. economy. Nonetheless, on the one hand, as shown in this paper, even in a two-good model, the occurrence of the suggested scenario will also depend on the market forces behind the asymmetric holdup problem between outsourcing and insourcing firms. On the other hand, in a multiple-industry model, market forces in different industries are more complex and different. Hence, it is important to further examine whether Samuelson's model truly captures the essence of the complicated global outsourcing phenomenon.

Third, my research goes beyond the debate by providing an important explanation for why IT outsourcing firms are increasingly outsourcing innovation overseas. My explanation is based on two major findings. The first finding is that offshore outsourcing demand initially and continually motivates insourcing firms to invest in different R&D activities and thus their persistent R&D investment helps them develop and accumulate technology expertise. The second finding is that in global IT hardware outsourcing, rather than transaction costs, the insourcing firm's technology expertise will affect the outsourcing firm's decision on what to outsource. Therefore, these two findings together show that there is a bi-directional influence between IT offshore outsourcing demand and the insourcing firm's technology expertise. This bi-directional influence provides an explanation not only for the increasing level of IT offshore outsourcing in innovation, but also for the increasing concentration of IT offshore outsourcing activities in certain insourcing regions, a clustering phenomenon shown in my data.

Fourth, in terms of R&D investments, my model predictions and data all show that, as the degree of offshore outsourcing in innovation increases, ODM-market oriented insourcing firms increasingly behave like Western firms that create and retain innovations. Through adopting a similar

R&D investment strategy as U.S. firms in the 1980s or the largest 1500 global corporations in 2006, these insourcing firms are building themselves as production houses with product design expertise. In addition, my research results point to what I call the 80-20 rule, where 80% of R&D resources is invested in product R&D and 20% in process R&D. Given that product innovation increases quality improvement to create or increase demand and process innovation reduces production cost, this R&D composition reflects what technology expertise the insourcing firm is mainly developing. This ratio shows that the insourcing firm not only becomes efficient by exploiting global economies of scale to provide a low-cost production solution but also builds up its capability of new product development to deliver a complete product for its outsourcing customers to serve the end market.

Fifth, I have developed an insourcing firm's model that predicts many features consistent with observations. Besides the above findings, it shows that other factors, including individual firm's characteristics and the industry's technological opportunities, also affect the insourcing firm's innovation choices. These factors are characterized by the parameters in my model and estimated by using survey data. Besides outsourcing demand, the supply side competition and the industry's technological environment are also driving this industry to put more resources in product innovation. The combination of my model and data confirms this drive toward product innovation, and the consistent investment in product innovation has started to bear fruit. Given that many insourcing firms have increasingly claimed the world's major design awards, these achievements cannot be done only by imitating or purchasing what others know but by learning through specialization.

Sixth, this paper identifies an asymmetric holdup problem between outsourcing and insourcing firms as well as the underlying market forces, which have important implications for economic policies and corporate strategies. For instance, we can analyze how the rapid growth of insourcing countries, such as China and India, or the growing trend of reverse brain drain in new fields, will ultimately affect the U.S. economy and its future competitiveness. As discussed earlier, contrary to conventional wisdom, the growth of international markets does not necessarily benefit the U.S.

In sum, the new mechanism of offshore outsourcing in high-tech industries provides the world economy with benefits and challenges. On the one hand, it helps the world economy achieve greater efficiency by exploiting previously impossible global economies of scale, a change which benefits the consumer. And, it provides a new opportunity for developing countries to catch up with developed countries and improve their living standards. On the other hand, as global IT outsourcing is concentrated in very few countries and the insourcing industry exhibits a clustering phenomenon, IT offshore outsourcing does not benefit all developing countries.

In addition, IT offshore outsourcing coexists with reverse brain drain in the industry. Reverse brain drain in high-tech areas increases the endowment of human capital and the expertise of developing countries. As implied by the data from the National Science Foundation, the increased mobility of human capital, however, only benefits certain countries because of an obviously uneven national distribution of U.S. trained foreign-born scientists and engineers in IT and biotech industries (see Table 15). More importantly, as the U.S. economy increasingly depends on knowledge industries, the country's ability to grow and retain high-skilled labor, including native and foreign born professionals, will determine our future competitiveness.

Finally, while my paper begins to answer some questions regarding the impact of IT offshore outsourcing on the insourcing side and what determines U.S. IT firms' decisions on what to outsource, it also paves the way for future research in a few areas. First, my paper utilizes the insourcing firm's model and data to prove that the type of the insourcing firm's technology expertise affects the outsourcing firm's decision on what to outsource. This treatment simplifies the outsourcing firm's other strategic concerns, which can be important in developing future outsourcing models. Second, both Aoki's (1988) and my studies show that transaction costs are not critical for firms' outsourcing decisions in both the Japanese auto supply chain and the U.S.-Taiwan-China IT supply chain. It can provide important policy implications by comparing the buyer-supplier systems between these two supply chains, especially when both are long and highly segmented but the Japanese system has the property of cross-share holding between the buyer and the supplier. Third, my paper connects Samuelson's missing link and this connection indicates that Samuelson's model is theoretically legitimate. More studies, however, are needed to further examine whether his model truly captures the essence of the complicated global outsourcing phenomenon across industries. This is beyond the scope of this paper, but will be an important research topic to pursue in the future.

Appendix

A. Nonlinear Fitting of Insourcing Firms' Data and Bootstrap Error Estimation

The insourcing model $p = p(q_1, q_2; \mathbf{\Theta})$ contains a set of parameters $\mathbf{\Theta} \equiv (g_1, g_2, b_1, b_2, \alpha, \beta_1, \beta_2, h, k)$ that can be estimated through an OLS fit of the data to the model. The full expression of p can be found in Equation (5).

Because Equation (5) is nonlinear, the OLS fit was preformed numerically by using the standard nonlinear optimization method (Lagarias et al. 1998). Additional constraints

$$\begin{aligned} g_1, g_2 &\geq 1, \\ b_1, b_2 &> 0, \\ \alpha &\geq 1, \\ \beta_1, \beta_2 &> 0, \\ h &\geq 0 \end{aligned}$$

are imposed to ensure that the optimal solution of $\mathbf{\Theta}$ is consistent with model assumptions. More than one hundred starting values were tried to identify the best among the optimal solutions. Note that the optimal solution of k can be either positive or negative in order to examine whether the causality effect of the increase in the insourcing firm's technological expertise to the increase in ODM demand exists in data. The optimal solutions for the nine parameters are listed in the table in Figure 4 (under the "Point Estimate" column).

To evaluate the uncertainty in estimating the parameters, resampled data are drawn from the probability distribution consistent with the data set. If $\mathbf{x_i} \equiv (p_i, q_{1i}, q_{2i})$ and $\mathbf{X} \equiv (\mathbf{x_1}, \mathbf{x_2}, ..., \mathbf{x_n})$ represents the surveyed data, we can let $\widehat{F}$ be the empirical distribution, putting probability $1/n$ on each of the observed values $\mathbf{x_i}$, $i = 1, 2, ..., n$ (= 28 in this study). A bootstrap sample is defined to be a random sample of size drawn from $\widehat{F}$, say $\mathbf{X}^* \equiv (\mathbf{x_1}^*, \mathbf{x_2}^*, ..., \mathbf{x_n}^*)$,

$$\widehat{F} \longrightarrow (\mathbf{x_1}^*, \mathbf{x_2}^*, ..., \mathbf{x_n}^*) \tag{A1}$$

If we define the OLS fit of the data to the insourcing firm's model as a function s that acts on the surveyed data and infers the values of the parameter set $\hat{\mathbf{\Theta}}$, the bootstrap replication of $\hat{\mathbf{\Theta}}$ corresponding to each bootstrap sample is

$$\hat{\mathbf{\Theta}}^{*j} = s(\mathbf{X}^{*j}), j = 1, 2, ..., B. \tag{A2}$$

The bootstrap estimates of the mean and standard deviation of the statistic $\hat{\mathbf{\Theta}}$ are plug-in estimates that use the empirical distribution function $\widehat{F}$ in place of the unknown distribution F. Namely,

$$\begin{aligned} \text{mean}_{\widehat{F}}(\hat{\mathbf{\Theta}}^*) &= \sum_{j=1}^{B} \hat{\mathbf{\Theta}}^{*j}/B, \\ \text{se}_{\widehat{F}}(\hat{\mathbf{\Theta}}^*) &= \left[\sum_{j=1}^{B} \left(\hat{\mathbf{\Theta}}^{*j} - \text{mean}_{\widehat{F}}(\hat{\mathbf{\Theta}}^*) \right)^2 / (B-1) \right]^{1/2}. \end{aligned}$$

The quantity B is the number of bootstrap samples, and it should be a number large enough to produce accurate estimates of $\text{mean}_{\widehat{F}}(\hat{\mathbf{\Theta}}^*)$ and $\text{se}_{\widehat{F}}(\hat{\mathbf{\Theta}}^*)$. According to Efron and Tibshirani (1994), very seldom are more than $B = 200$ replications needed for estimating a standard error, and even a smaller B is sufficient for estimating a mean. To ensure that there are enough bootstrap replications created, I used $B = 1000$ in estimating the mean and standard error of $\mathbf{\Theta}$, and the results are shown in Figure 4.

B. The Dynamic Model of the Outsourcing Firm's Choices and the Insourcing Firm's Innovation Investments

To examine how both outsourcing firms' outsourcing behaviors and insourcing firms' R&D investment behaviors change over time, I derive a dynamic version of the static model. Combining the static model and data shows that the outsourcing firm will choose different outsourcing behaviors based on the insourcing firm's technology expertise and offshore outsourcing demand will help the insourcing firm gain progress in different technology expertise. That is, the relationship between the outsourcing firm's decision on what to outsource and the insourcing firm's technology expertise is bi-directional. Based on this result, the dynamic model examines how this bi-directional influence evolves over time. In particular, I examine how the outsourcing firm chooses what to outsource and how the insourcing firm invests different types of R&D over time.

Besides, I assume that the outsourcing firm is a monopoly and there is still an asymmetric holdup problem between the outsourcing firm and the insourcing firm, i.e., the insourcing firm still lacks international marketing know-how to forward integrate into the downstream and the outsourcing firm can backward integrate into the upstream. In addition, I assume that the outsourcing firm has many products and assigns some of them to each insourcing firm. For each product line, the outsourcing firm faces two outsourcing choices, OEM and ODM. For each type of outsourcing choice, the insourcing firm faces the same technology requirements and service cost for any product lines. And, the outsourcing firm will decide what to outsource based on the insourcing firm's technology expertise, which is measured by the insourcing firm's R&D composition and characterized as the following decision equation:

$$\frac{q_2}{q_1 + q_2} = \theta_0 + \theta_1 \left(\frac{r_2}{r_1 + r_2} \right) + \theta_2 \left(\frac{r_2}{r_1 + r_2} \right)^2 \tag{B1}$$

where q_1 and q_2 are OEM and ODM orders, and θ_0, θ_1, and θ_2 and are the polynomial coefficients of this decision equation. The insourcing firm's sales growth pattern is defined as:

$$Q(t) \equiv q_1(t) + q_2(t) \tag{B2}$$

$$Q(t) = Q_0 + \Gamma_1 t + \Gamma_2 t^2 \tag{B3}$$

where $Q(t)$ is its total orders at time t, and Q_0 is the initial value of its sales orders. Γ_1 and Γ_2 are the polynomial coefficients of its sales growth equation.

Corresponding to the outsourcing firm's two outsourcing choices, the insourcing firm produces two products, OEM and ODM. Similar to the static model, the profit function for investing in process innovation at time t is defined as:

$$\pi_1(t) = g_1(t) \left[q_1(t) + \alpha q_2(t) \right] I_1(t) - r_1(t) \tag{B4}$$

and the profit function for investing in product innovation is:

$$\pi_2(t) = g_2(t)\left[hq_2(t) + k\right] I_2(t) - r_2(t) \tag{B5}$$

where the dynamic version of marginal return on investing in the *i*th type of R&D at time *t* is:

$$I_i\left(r_i(t)\right) = \frac{\beta_i}{\beta_i - 1} b_i r_i(t)^{1-1/\beta_i} \qquad \text{(note that } I_i'(r_i) = b_i r_i^{-1/\beta_i}\text{)} \tag{B6}$$

The state variable is $g_i(t)$, which is the length of time before the *i*th type of innovation advantage was matched by its competitors, and its rate of change is defined as:

$$\dot{g}_i(t) = g_i(t)\left(\frac{r_i(t)}{R_{i0} + w_i t} - \delta_i\right), \qquad i = 1, 2 \tag{B7}$$

where R_{i0} is the industry's average expenditure on the *i*th type of R&D, w_i is its average growth rate, and δ_i is the depreciation rate.

The above variables can be used to build the current value Hamiltonian:

$$H = \sum_i \pi_i + \sum_i \lambda_i \dot{g}_i \tag{B8}$$

and through setting up the Hamilton's equations

$$\frac{\partial H}{\partial r_i} = 0; \quad \frac{\partial H}{\partial g_i} = \rho\lambda_i - \dot{\lambda}_i; \quad \frac{\partial H}{\partial \lambda_i} = \dot{g}_i \quad (i = 1, 2) \tag{B9}$$

we can solve the variables $r_1(t)$, $r_2(t)$, $g_1(t)$, $g_2(t)$, $\lambda_1(t)$, and $\lambda_2(t)$. To explicitly express the Hamilton's equations, we can start by considering (B1) and (B2) for which the following conditions are possible:

1. $\theta_2 \neq 0$: This condition models a quadratic relationship between $\frac{r_2}{r_1+r_2}$ and $\frac{q_2}{q_1+q_2}$. To ensure the positivity of q_1 and q_2, two ranges of $\frac{r_2}{r_1+r_2}$ are treated separately:

   (a) When $\frac{r_2}{r_1+r_2} > \frac{-\theta_1+\sqrt{\theta_1^2-4\theta_0\theta_2}}{2\theta_2}$, the quantities of OEM and ODM orders are

$$\begin{cases} q_1 &= Q - Q\left[\theta_0 + \theta_1\left(\frac{r_2}{r_1+r_2}\right) + \theta_2\left(\frac{r_2}{r_1+r_2}\right)^2\right] \\ q_2 &= Q\left[\theta_0 + \theta_1\left(\frac{r_2}{r_1+r_2}\right) + \theta_2\left(\frac{r_2}{r_1+r_2}\right)^2\right] \end{cases} \tag{B10}$$

   Substituting (B10) and (B4)-(B7) into (B8), we obtain the current value Hamiltonian

$$\begin{aligned} H = {} & g_1 Q[1 + (\alpha-1)\theta_0 + (\alpha-1)\theta_1 r_2(r_1+r_2)^{-1} \\ & + (\alpha-1)\theta_2 r_2^2(r_1+r_2)^{-2}] \cdot \frac{\beta_1}{\beta_1-1} b_1 r_1^{1-1/\beta_1} - r_1 \\ & + g_2\left\{hQ\left[\theta_0 + \theta_1 r_2(r_1+r_2)^{-1} + \theta_2 r_2^2(r_1+r_2)^{-2}\right] + k\right\} \\ & \cdot \frac{\beta_2}{\beta_2-1} b_2 r_2^{1-1/\beta_2} - r_2 \\ & + \lambda_1 g_1\left(\frac{r_1}{R_{10}+w_1 t} - \delta_1\right) + \lambda_2 g_2\left(\frac{r_2}{R_{20}+w_2 t} - \delta_2\right) \end{aligned} \tag{B11a}$$

Equations (B9) and (B11) can then be used to express the Hamilton's equations:

$$\begin{aligned}
\frac{\partial H}{\partial r_1} &= g_1 Q\left[-(\alpha-1)\theta_1 r_2(r_1+r_2)^{-2} - 2(\alpha-1)\theta_2 r_2^2(r_1+r_2)^{-3}\right] \\
&\cdot \frac{\beta_1}{\beta_1-1} b_1 r_1^{1-1/\beta_1} \\
&+ g_1 Q[1+(\alpha-1)\theta_0+(\alpha-1)\theta_1 r_2(r_1+r_2)^{-1} \\
&+ (\alpha-1)\theta_2 r_2^2(r_1+r_2)^{-2}]b_1 r_1^{-1/\beta_1} - 1 \\
&+ g_2 h Q\left[-\theta_1 r_2(r_1+r_2)^{-2} - 2\theta_2 r_2^2(r_1+r_2)^{-3}\right]\frac{\beta_2}{\beta_2-1} b_2 r_2^{1-1/\beta_2} \\
&+ \lambda_1 g_1(R_{10}+w_1 t)^{-1} \\
&= 0 \qquad \text{(B12a)}
\end{aligned}$$

$$\begin{aligned}
\frac{\partial H}{\partial r_2} &= g_1 Q[(\alpha-1)\theta_1(r_1+r_2)^{-1} - (\alpha-1)\theta_1 r_2(r_1+r_2)^{-2} \\
&+ 2(\alpha-1)\theta_2 r_2(r_1+r_2)^{-2} - 2(\alpha-1)\theta_2 r_2^2(r_1+r_2)^{-3}] \\
&\cdot \frac{\beta_1}{\beta_1-1} b_1 r_1^{1-1/\beta_1} \\
&+ g_2 h Q[\theta_1(r_1+r_2)^{-1} - \theta_1 r_2(r_1+r_2)^{-2} + 2\theta_2 r_2(r_1+r_2)^{-2} \\
&- 2\theta_2 r_2^2(r_1+r_2)^{-3}] \cdot \frac{\beta_2}{\beta_2-1} b_2 r_2^{1-1/\beta_2} \\
&- 1 + \lambda_2 g_2(R_{20}+w_2 t)^{-1} \\
&= 0 \qquad \text{(B13a)}
\end{aligned}$$

$$\begin{aligned}
\frac{\partial H}{\partial g_1} &= Q[1+(\alpha-1)\theta_0+(\alpha-1)\theta_1 r_2(r_1+r_2)^{-1} \\
&+ (\alpha-1)\theta_2 r_2^2(r_1+r_2)^{-2}] \cdot \frac{\beta_1}{\beta_1-1} b_1 r_1^{1-1/\beta_1} \\
&+ \lambda_1\left(\frac{r_1}{R_{10}+w_1 t} - \delta_1\right) \\
&= \rho\lambda_1 - \dot{\lambda}_1 \qquad \text{(B14a)}
\end{aligned}$$

$$\begin{aligned}
\frac{\partial H}{\partial g_2} &= \left\{hQ[\theta_0+\theta_1 r_2(r_1+r_2)^{-1}+\theta_2 r_2^2(r_1+r_2)^{-2}]+k\right\}\frac{\beta_2}{\beta_2-1} b_2 r_2^{1-1/\beta_2} \\
&+ \lambda_2\left(\frac{r_2}{R_{20}+w_2 t} - \delta_2\right) \\
&= \rho\lambda_2 - \dot{\lambda}_2 \qquad \text{(B15a)}
\end{aligned}$$

$$\frac{\partial H}{\partial \lambda_1} = g_1\left(\frac{r_1}{R_{10}+w_1 t} - \delta_1\right) = \dot{g}_1 \qquad \text{(B16)}$$

$$\frac{\partial H}{\partial \lambda_2} = g_2\left(\frac{r_2}{R_{20}+w_2 t} - \delta_2\right) = \dot{g}_2 \qquad \text{(B17)}$$

(b) When $\frac{r_2}{r_1+r_2} \leq \frac{-\theta_1+\sqrt{\theta_1^2-4\theta_0\theta_2}}{2\theta_2}$, the OEM and ODM quantities are $q_1 = Q$ and $q_2 = 0$.

The current value Hamiltonian becomes

$$
\begin{aligned}
H = {} & g_1 Q \frac{\beta_1}{\beta_1 - 1} b_1 r_1^{1-1/\beta_1} - r_1 \\
& + g_2 k \frac{\beta_2}{\beta_2 - 1} b_2 r_2^{1-1/\beta_2} - r_2 \\
& + \lambda_1 g_1 \left(\frac{r_1}{R_{10} + w_1 t} - \delta_1 \right) + \lambda_2 g_2 \left(\frac{r_2}{R_{20} + w_2 t} - \delta_2 \right)
\end{aligned} \tag{B11b}
$$

and the Hamilton's equations are

$$\frac{\partial H}{\partial r_1} = g_1 Q b_1 r_1^{-1/\beta_1} - 1 + \lambda_1 g_1 (R_{10} + w_1 t)^{-1} = 0 \tag{B12b}$$

$$\frac{\partial H}{\partial r_2} = g_2 k b_2 r_2^{-1/\beta_2} - 1 + \lambda_2 g_2 (R_{20} + w_2 t)^{-1} = 0 \tag{B13b}$$

$$\frac{\partial H}{\partial g_1} = Q \frac{\beta_1}{\beta_1 - 1} b_1 r_1^{1-1/\beta_1} + \lambda_1 \left(\frac{r_1}{R_{10} + w_1 t} - \delta_1 \right) = \rho \lambda_1 - \dot{\lambda}_1 \tag{B14b}$$

$$\frac{\partial H}{\partial g_2} = k \frac{\beta_2}{\beta_2 - 1} b_2 r_2^{1-1/\beta_2} + \lambda_2 \left(\frac{r_2}{R_{20} + w_2 t} - \delta_2 \right) = \rho \lambda_2 - \dot{\lambda}_2 \tag{B15b}$$

The two remaining Hamilton's equations are the same as (B16) and (B17).

2. $\theta_2 = 0$ and $\theta_1 \neq 0$: This condition models a linear relationship between $\frac{r_2}{r_1+r_2}$ and $\frac{q_2}{q_1+q_2}$. Again, the two cases $\frac{r_2}{r_1+r_2} > -\frac{\theta_0}{\theta_1}$ and $\frac{r_2}{r_1+r_2} \leq -\frac{\theta_0}{\theta_1}$ are treated individually to ensure the positivity of q_1 and q_2, and the derivation of the Hamilton's equations can be obtained in a similar fashion.

3. $\theta_1 = \theta_2 = 0$: This condition implies an oversimplified situation where OEM and ODM orders do not depend on the type of the insourcing firm's technology expertise, which is measured by its R&D composition.

For all the condition above, four of the six Hamilton's equations (B14·–B17) immediately provide the first-order differential equations (with respect to *t*) for g_1, g_2, λ_1, and λ_2. The two equations (B12·) and (B13·) associated with $\frac{\partial H}{\partial r_1}$ and $\frac{\partial H}{\partial r_2}$ require differentiation with respect to *t* and can be rewritten as

$$\begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \begin{pmatrix} \dot{r}_1 \\ \dot{r}_2 \end{pmatrix} = \begin{pmatrix} F_1 \\ F_2 \end{pmatrix}. \tag{B18}$$

It is found that $A_{21} = A_{12}$. Any time derivatives in (B18), except $\dot{r}_1$ and $\dot{r}_2$, can be expressed with r_1, r_2, g_1, g_2, λ_1, and λ_2 by using Equations (B14·–B17). Equation (B18) can be used to solve $\dot{r}_1$ and $\dot{r}_2$ as two additional first-order differential equations.

Consider $\mathbf{y} = (r_1, r_2, g_1, g_2, \lambda_1, \lambda_2)$, the set of differential equations obtained previously

$$
\begin{aligned}
\dot{\mathbf{y}} &= f(t, \mathbf{y}), \\
\mathbf{y}(t_0) &= \mathbf{y_0}
\end{aligned} \tag{B19}
$$

can be solved numerically (e.g., by a 4th-order Runge-Kutta solver) as an initial-value problem. An example is given in Figure 6, where the insourcing firm's sales are assumed to grow linearly over time (Γ_1 = 10,000, Γ_2 = 0, and Q_0 = 100,000) and the outsourcing firm places the ODM order linearly proportionally to the degree of the insourcing firm's product design expertise ($\theta_0 = -0.3$, θ_1 = 1.5, and θ_2 = 0). And, the initial values of key parameters and variables are set as $\alpha = 1.6, \beta_1 = 5, \beta_2 = 10, b_1 = b_2 = 5 \times 10^{-5}, h = 0.5, k = 10,000, R_1 = R_2 = 0.5, w_1 = w_2 = 0.6, \delta_1 = 0.1, \delta_2 = 0.6, \rho = 0.05, r_1(0) = 0.2, r_2(0) = 0.1$, and $g_1(0) = g_2(0) = 0.5$. This numerical solution shows how the insourcing firm's sales composition and innovation investment behavior changes over time corresponding to the outsourcing firm's decision rule of order placement.

References

[1] Adner, Ron and Levinthal, Daniel. “Demand Heterogeneity and Technology Evolution: Implications for Product and Process Innovation.” *Management Science*, 2001, 47(5), pp. 611-628.

[2] Antras, Pol. “Firms, Contracts, and Trade Structure.” *Quarterly Journal of Economics*, 2003, 118(4), pp. 1375-1418.

[3] Antras, Pol. “Incomplete Contracts and the Product Cycle.” *The American Economic Review*, 2005, 95(4), pp. 1054-1073.

[4] Antras, Pol and Helpman, Elhanan. “Global Sourcing.” *Journal of Political Economy*, 2004, 112(3), pp. 552-580.

[5] Aoki, Masahiko. *Information, Incentives, and Bargaining in the Japanese Economy*. Cambridge: Cambridge University Press, 1988.

[6] Arrow, Kenneth. “Economic Welfare and the Allocation of Resources for Invention,” in Richard R. Nelson, eds., *The Rate and Direction of Inventive Activity*. Princeton: Princeton University Press, 1962.

[7] Bhagwati, Jagdish; Panagariya, Arvind and Srinivasan, T.N. “The Muddles over Outsourcing.” *The Journal of Economic Perspectives*, 2004, 18(4), pp. 93-114.

[8] Bresnahan, Timothy F.; Stern, Scott., and Trajtenberg, Manuel. “Market Segmentation and the Sources of Rents from Innovation: Personal Computers in the Late 1980s.” *The Rand Journal of Economics*, 1997, 28(0), Special Issue in Honor of Richard E. Quandt, pp. S17-S44.

[9] Bresnahan, Timothy F.; Gambardella, Alfonso; and Saxenian, AnnaLee. “Old Economy Inputs for New Economy Outputs: Cluster Formation in the New Silicon Valleys.” *Industrial and Corporate Change*, 2001, 10(4), pp. 835-860.

[10] Cheng, Chen-huang. “The New Trend of Outsourcing: 3C Surpasses PC!” *Business Weekly*, 2006, 948, pp. 64-68.

[11] Coase, Ronald. “The Nature of the Firm.” *Economica*, 1937, N.S. 4, pp. 386-405.

[12] Cohen, Wesley M. and Klepper, Steven. “Firm Size and the Nature of Innovation within Industries: The Case of Process and Product R&D.” *The Review of Economics and Statistics*, 1996, 78(2), pp. 232-243.

[13] Cohen, Wesley M. and Levinthal, Daniel A. “Innovation and Learning: The Two Faces of R&D.” *The Economic Journal*, 1989, 99(397), pp. 569-596.

[14] Darby, Michael and Zucker Lynne. “Innovation, Competition, and Welfare-enhancing Monopoly.” National Bureau of Economic Research, Inc., NBER Working Papers: No. 12094, 2006.

[15] Demsetz, Harold. *Ownership, Control, and the Firm*. Cambridge: Basil Blackwell, Inc., 1988.

[16] Demsetz, Harold. *Efficiency, Competition, and Policy*. Cambridge: Basil Blackwell, Inc., 1989.

[17] Efron, Bradley and Tibshirani, Rob. *An Introduction to the Bootstrap*, CRC Press, 1994.

[18] Einhorn, Bruce. "Why Taiwan Matters?" *Business Week*, May 16, 2005, pp. 76-81.

[19] Engardio, Pete and Einhorn, Bruce. "Outsourcing Innovation." *Business Week*, March 21, 2005, pp. 84-94.

[20] Griliches, Zvi. *R&D, Education, and Productivity*, Cambridge: Harvard University Press, 2000.

[21] Griliches, Zvi and Lichtenberg, Frank. "Interindustry Technology Flows and Productivity Growth: A Reexamination." *The Review of Economics and Statistics*, 1984, 66(2), pp. 324-329.

[22] Grossman, Gene M. and Helpman, Elhanan. "Integration Versus Outsourcing in Industry Equilibrium." *The Quarterly Journal of Economics*, 2002, pp. 85-120.

[23] Grossman, Gene M. and Helpman, Elhanan. "Outsourcing Versus FDI in Industry Equilibrium." *Journal of the European Economic Association*, 2003, 1(2-3), pp. 317-327.

[24] Guardino, C. Keynote Speech presented at the *Outsourcing Bay Area Employment Internationally* Conference, the Stanford Graduate School of Business, 2004.

[25] Helpman, Elhanan. "Trade, FDI, and the Organization of Firms." *The Journal of Economic Literature*, 2006, 44 (3), pp. 589-630.

[26] IDC, "PC Market Continues Rapid Growth In Fourth Quarter of 2005 as Annual Shipments Reach New Highs, According to IDC," *IDC*, January 18, 2006.

[27] Kapur, Devesh and Mchale, John. "Are We Losing the Global Race for Talent?" *The Wall Street Journal*, November 21, 2005.

[28] Klenow, Peter J. *Is Asian Growth Good for the U.S.?*, presented at Stanford Institute for Economy Policy Research, 2005.

[29] Lagarias, J.C., Reeds, J.A. and Wright, M.H. "Convergence Properties of the Nelder-Mead Simplex Method in Low Dimensions." *SIAM Journal of Optimization*, 1998, 9(1), pp. 112-147.

[30] Lai, Jewel. "Taiwan Design Power." *Business Next*, 2005, 113, pp. 19-26.

[31] Mably, Greg. "Patents 2004." *Technology Review*, 2004, pp. 65-77.

[32] McGregor, Jena. "The World's Most Innovative Companies." *Business Week*, April 24, 2006, pp. 63-74.

[33] Mann, Catherine. “Globalization, Information Technology, and US Economic Performance.” *Conference in Honor of Jagdish Bhagwati’s 70th Birthday*, 2005.

[34] Mansfield, Edwin. “Industrial R&D in Japan and the United States: A Comparative Study.” *The American Economic Review*, 1988, 78(2), pp. 223-228.

[35] Marshall, Alfred. *Principles of Economics*, London: MacMillan, 1920.

[36] Panagariya, Arvind. “Why the Recent Samuelson Article is NOT about Offshore Outsourcing.” Available at `http://www.Columbia.edu/~ap2231/`.

[37] Porter, Michael. “Clusters and the New Economics of Competition.” *Harvard Business Review*, 1998, 77(1).

[38] Prestowitz, Clyde. *Three Billion New Capitalists*, New York: Basic Books, 2005.

[39] *The Offering Memorandum of Quanta Computer Inc.*, 2005.

[40] Samuelson, Paul. “Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Supporting Globalization.” *Journal of Economic Perspectives*, 2004, 18(3), pp. 135-46.

[41] Saxenian, AnnaLee. “The Bangalore Boom: From Brain Drain to Brain Circulation?” Forthcoming in Kenneth Kenniston and Deepak Kumar, eds. *Bridging the Digital Divide: Lessons from India*, Bangalore: National Institute of Advanced Study, 2000.

[42] Saxenian, AnnaLee. *The New Argonauts: Regional Advantage in Global Economy.* Cambridge: Harvard University Press, 2006.

[43] Saxenian, AnnaLee and Li, Chuen-Yueh (Wendy). “Bay-to-bay Strategic Alliances: The Network Linkages between Taiwan and the U.S. Venture Capital Industries.” *International Journal of Technology Management*, 2003, 25(1/2), pp. 136-150.

[44] Smith, Adam. *The Wealth of Nations*, 1776.

[45] Stigler, George. *The Organization of Industry*. Chicago: The University of Chicago Press, 1983.

[46] Tzeng, Hsiao-ming. *The Focus and Defocus of the Taiwanese Industry*. Taipei: Royal Publishing Co., 2004.

[47] Vernon, Ramond. “International Investment and International Trade in the Product Cycle.” *Quarterly Journal of Economics*, 1966, 80(2), pp. 190-207.

[48] Zhang, Dian-wen. *Terry & Foxconn*. Taipei: The World Culture, 2005.

[49] Zucker, Lynne and Darby, Michael. “Movement of Star Scientists and Engineers and High-tech Firm Entry.” National Bureau of Economic Research, Inc., NBER Working Papers: No. 12172, 2006.

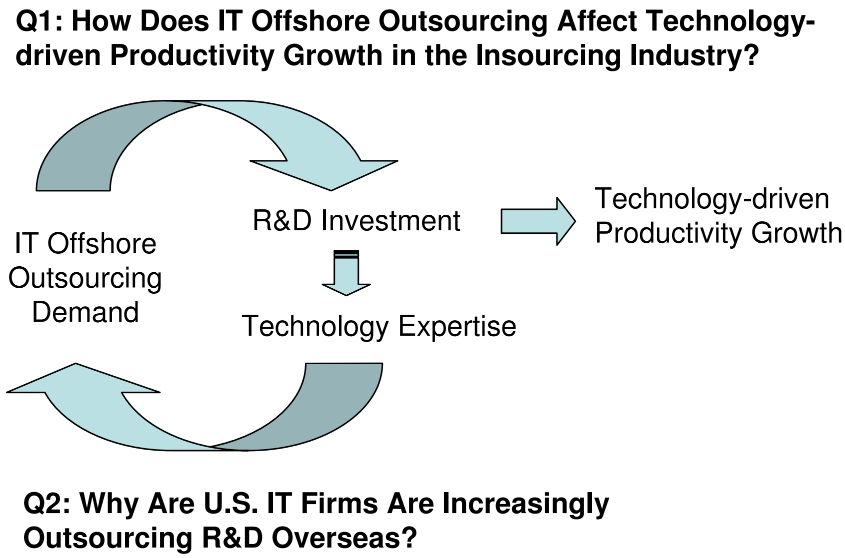


Figure 1: The Conceptual Framework

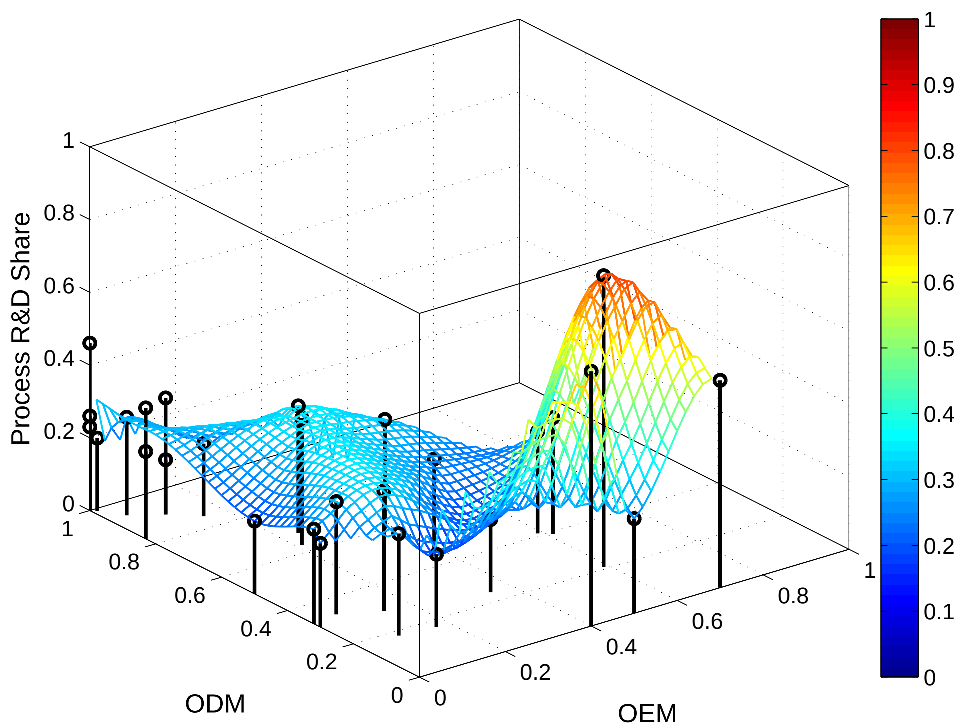


Figure 2: Survey Data of Insourcing Frims' Process R&D Shares versus OEM Shares

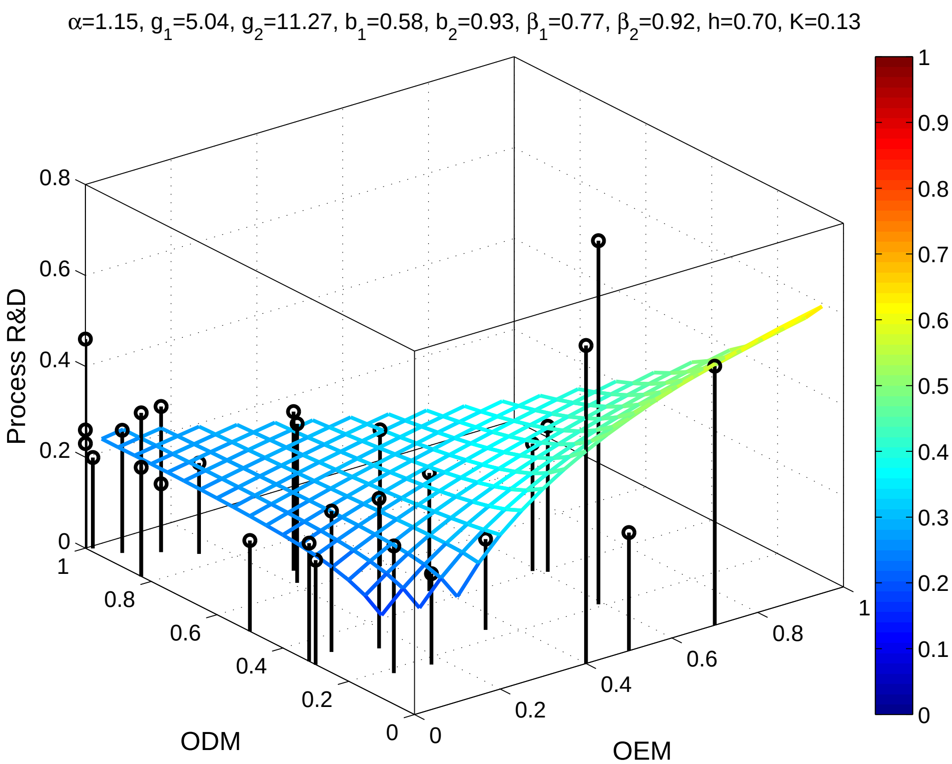
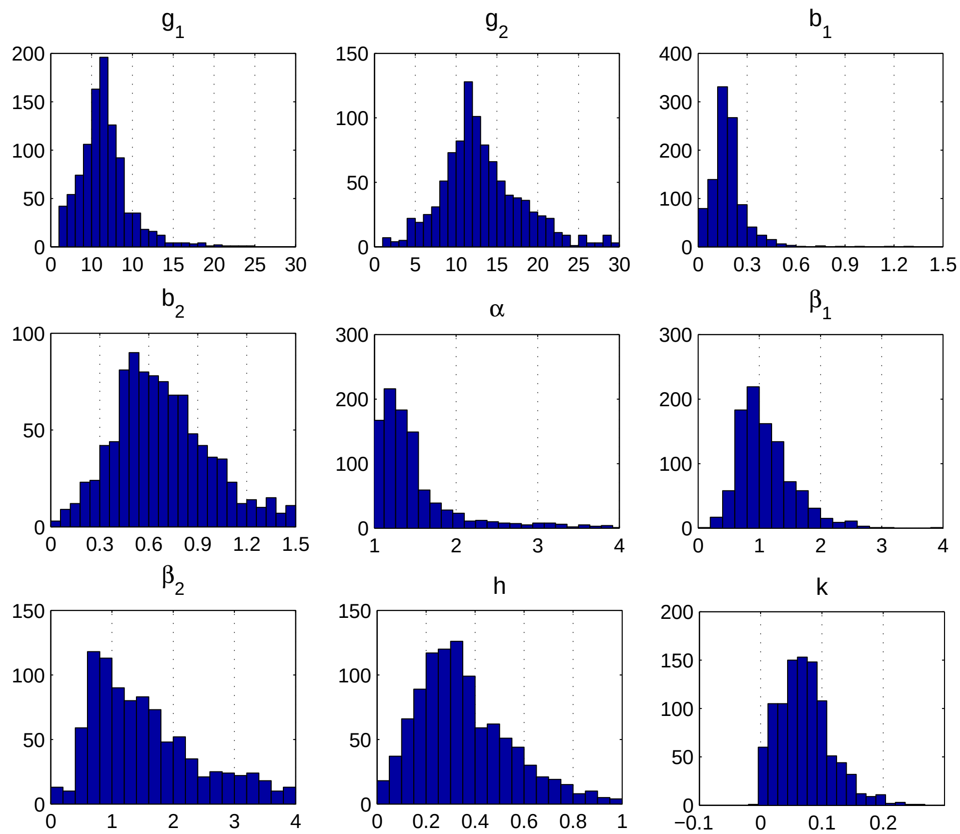


Figure 3: Data and the Best-fit Model



	25th Percentile	Medium	Mean	75th Percentile	Standard Deviation	Point† Estimate
g_1	4.84	6.32	6.77	7.91	3.99	5.04
g_2	10.14	12.42	13.74	16.09	6.67	11.27
b_1	0.13	0.17	0.19	0.22	0.12	0.58
b_2	0.49	0.67	0.75	0.91	0.42	0.93
α	1.18	1.34	1.74	1.61	1.39	1.15
β_1	0.79	1.02	1.19	1.37	0.72	0.77
β_2	0.88	1.45	1.83	2.25	1.43	0.92
h	0.22	0.32	0.35	0.46	0.19	0.70
k	0.04	0.07	0.07	0.10	0.05	0.13

†This column shows the optimal solutions using all 28 sets of data.

Figure 4: Distribution of 1,000 Bootstrap Estimates for the 9 Model Parameters

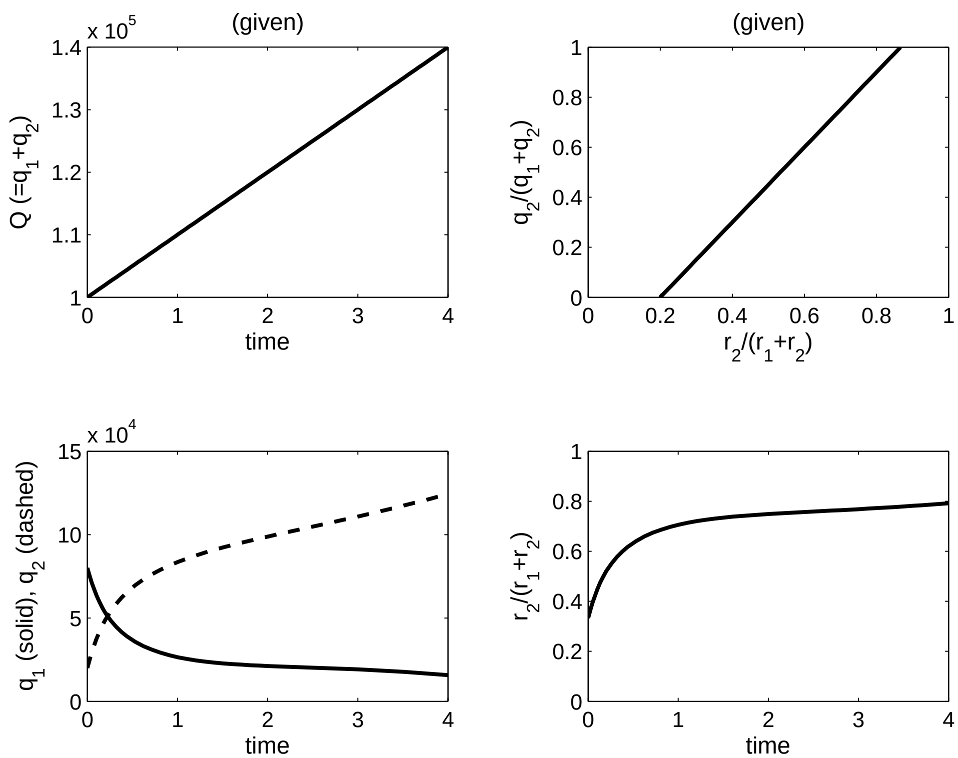


Figure 5: The Insourcing Firm’s Dynamic Innovation Choices

Table 1: Taiwan NB 1990-2004 - The Growth and the Degree of Global Outsourcing†

Year	Qty	Growth Rate	World Market Share	OEM & ODM Share	World Market Growth Rate	Production Value
1990	217	–	11%	–	–	534
1991	534	146.1%	25%	61.0%	8.3%	1,212
1992	861	61.25%	18%	64.0%	123.9%	1,220
1993	1,291	49.9%	22%	77.0%	22.7%	1,667
1994	2,057	59.3%	28%	77.0%	25.2%	2,729
1995	2,592	26.0%	27%	79.0%	30.7%	3,339
1996	3,781	45.9%	32%	82.0%	23.1%	5,331
1997	4,465	18.1%	32%	82.0%	18.1%	6,620
1998	6,088	36.3%	39%	84.0%	11.9%	8,423
1999	9,355	53.7%	49%	86.8%	22.3%	10,198
2000	12,712	35.9%	53%	90.3%	25.6%	13,554
2001	14,161	11.4%	55%	92.3%	7.3%	12,239
2002	18,380	29.8%	61%	92.3%	17.0%	13,847
2003	25,238	37.3%	67%	95.5%	25.0%	16,809
2004	33,406	32.4%	73%	94.0%	21.5%	21,831

Unit: (1) Qty: Thousand, (2) Production Value: US $1 million.
†Source: Data are provided by MIC, Taiwan and compiled by this research.
Note: In 2005, the Taiwanese notebook PC industry already controlled 79% of world market.

Table 2: The Dominant Position of Taiwan's IT firms in the World Market†

World Ranking	Product	Worldwide Market Share	Production Value
1	Router	89.2%	$0.7 billion
1	WLAN	83.0%	$1.0 billion
1	PDA	79.0%	$1.8 billion
1	Motherboard	77.9%	$6.2 billion
1	Notebook PC	72.4%	$21.8 billion
1	DSL CPE	70.9%	$1.7 billion
1	Chip Foundry	70.0%	$8.9 billion
1	LCD Monitor	68.0%	$14.0 billion
1	Cable Modem	66.3%	$14.4 billion
1	Switch	59.0%	$0.7 billion
1	CDT Monitor	56.7%	$3.5 billion
2	ODD	41.6%	$3.5 billion
2	DSC	34.6%	$2.0 billion
2	Digital Camera	34.0%	$2.0 billion
2	Server	32.8%	$1.8 billion

†Source: Data are provided by MIC, Taiwan and compiled by this research.

Table 3: The Annual Growth Rate of Taiwan's IT Hardware Industry†‡

Year	Production Value⋆	Yearly Growth Rate (%)
1986-1993		Composite average 24%
1994	14,582	28.1
1995	19,543	34.0
1996	25,035	28.1
1997	30,174	20.5
1998	33,776	11.9
1999	39,881	18.1
2000	47,019	17.9
2001	42,750	−9.1
2002	48,435	13,3
2003	57,171	18.0
2004	69,664	21.8

⋆Unit: US $1 million.
†Source: Data are provided by MIC ITIS, 1998/11, 2000/12, 2002, 2005/03 and compiled by this research.
‡Note: The numbers include production in China.

Table 4: The 1998 Market Share of Top Five Producers in Different IT Markets†

Product	Market Concentration (by # of top players)
Notebook PC	71.7% (5)
Monitor	44.5% (5)
Desktop PC	69.0% (3)
Motherboard	54.6% (5)
SPS	82.8% (5)
CD/DVD	76.5% (5)
Case	38.6% (2)
Scanner	63.2% (5)
Graphics Card	46.0% (5)
Keyboard	64.1% (3)
UPS	33.0% (5)
Mouse	61.5% (3)
Sound Card	86.2% (2)
Video Card	95.0% (4)

†Source: Data are provided by MIC IT IS, November 1999 and compiled by this research.

Table 5: 1999 Taiwan Top 10 Notebook PC Players and Their OEM & ODM Customers†

Ranking	Firm	Outsourcing Customers
1	Quanta	Dell, HP, IBM, Gateway, Apple, Siemens, AST
2	Acer	Acer/TI, IBM, Apple
3	Inventec	Compaq
4	Compal	Dell, HP, Digital, Fujitsu, Toshiba
5	Arima	Compaq
6	FIC	NEC Japan
7	Clevo	Hitachi, Epson
8	Mitac	Compaq, HP, Sun
9	Twinhead	HP, Sharp, Winbook
10	GVC	Packard Bell/NEC

†Source: Data are provided by MIC, Taiwan, 1999 and compiled by this research.

Table 6: 2005 Taiwan Top 9 Notebook PC Players and Their OEM & ODM Customers†

Ranking	Insourcing Firms	Outsourcing Customers
1	Quanta	Dell, HP, Toshiba, IBM, Acer, FSC, NEC, Sony, Apple, Gateway
2	Compal	Dell, HP, Toshiba, Acer, FSC, NEC, Lenovo
3	Wistron	Dell, HP, IBM, Acer
4	Asus	Sony, Apple, Samsung
5	Inventec	HP, Toshiba
6	Mitac	FSC, NEC, Lenovo
7	Uniwill	FSC
8	FIC	NEC
9	Arima	HP, NEC, Gateway

†Source: Data are provided by MIC, August, 2005 and complied by this research.

Table 7: The Questionnaire

Survey Items
• The category of the industry
Offshore Outsourcing Demand
• The sales
• OEM, ODM and OBM (%)
Size and skill intensity of the R&D division
• The education level of the R&D personnel: Ph.D. & M.S. and College (%)
• The R&D expenditure
• Process R&D and Product R&D (%)
Innovation Indicators
• The yearly patent numbers

Table 8: The Survey Summary†

Industry	#	M. Concen.	W.M. Share	R&D Intensity	Product R&D	OEM Share	ODM Share	# of Patents
NB PC	8	71.7% (5)	79.0%	2.01%	69.50%	13.13%	75.88%	75.25
Monitor	3	44.5% (5)	68.0%	3.08%	74.00%	4.67%	89.00%	93
D. PC	1	69.0% (3)		2.99%	65.00%	24.00%	68.00%	193
MB	5	54.6% (5)	77.9%	2.67%	70.00%	28.00%	23.80%	46.2
SPS	3	82.8% (5)		3.05%	71.33%	10.33%	78.67%	86
CD/DVD	1	76.5% (5)		0.59%	43.00%	70.00%	0.00%	67
Cellphone	4	60.0% (1)		3.93%	78.00%	2.50%	75.75%	62.75
Scanner	1	63.2% (5)		7.58%	72.00%	59.00%	41.00%	56
Chip F.	1		70.0%	10.10%	20.00%	59.00%	21.00%	245
DSL CPE	4		70.9%	5.19%	78.50%	4.50%	49.50%	84.5
D. Camera	2		34.0%	2.98%	77.00%	36.50%	34.50%	10
Wireless N	2			10.33%	75.00%	26.50%	72.50%	4

†Source: Data are provided from MIC, Taiwan and the industry survey, and complied by this research.

Note: (1) Some firms have businesses covering more than one industry. (2) The market concentration for each industry measures the percentage of sales held by the number of firms indicated in the parenthesis. (3) The world market share measures the percentage of world market occupied by the Taiwanese IT firms. (4) The rest of the columns are average numbers of the samples from the survey.

Table 9: Linear Regression Analysis on the Effect of Sales or the Sources of Sales on R&D Expenditure

	log(R&D expenditure)			
Constant	0.2117^{*}	1.2145^{**}	0.9154^{*}	0.3120^{*}
	(0.7895)	(1.0381)	(0.6438)	(0.8409)
log(Sales)	0.6122^{*}			
	(0.1803)			
log(OEM Sales)		0.4770^{**}		0.3512^{*}
		(0.2899)		(0.2904)
log(ODM Sales)			0.4900^{*}	0.3415^{*}
			(0.1577)	(0.2400)
R^2	0.6425	0.3681	0.6424	0.753
F	48.5266	41.3195	41.3195	21.3405
p value	0.0000	0.0045	0.0000	0.0001

- $^{*}p < .01$; $^{**}p < .05$; Unit: NT $1 million.
- All regression results are based on three-year averages.
- Numbers in parentheses are standard errors .

Table 10: Linear Regression Analysis on the Effect of the Composition of Sales on R&D Intensity

	R&D Intensity		
Constant	0.0291^{**}	0.0599	-0.0027^{***}
	(0.033)	(0.0492)	(0.0740)
OEM (%)	0.1090^{**}		0.1491^{***}
	(0.1100)		(0.1382)
ODM (%)		-0.0154	0.0440^{***}
		(0.0781)	(0.0914)
R^2	0.1375	0.0063	0.1701
F	4.1443	0.1646	2.5627
p value	0.0520	0.6882	0.0971

- $^{**}p < .05$; $^{***}p < .10$
- All regression results are based on three-year averages.
- Because insourcing firms also engage in the business of original brand manufacturing (OBM), the sum of OEM Share and ODM Share is on average less than one. OBM products are normally sold in local retail markets, which are different from global outsourcing markets. In addition, the quality of OEM and ODM products is normally superior to that of OBM products.

Table 11: Linear Regression Analysis on the Effect of the Types of Outsourcing Contracts on Sales Growth

	Total Sales Growth Rate
Constant	-0.0034^{*}
	(0.0818)
OEM Sales Growth Rate	0.0524^{*}
	(0.1449)
ODM Sales Growth Rate	0.7182^{*}
	(0.2662)
R^2	0.9553
F	128.219
p value	0.0000

- $^{*}p < .01$
- All regression results are based the averages of annual growth rates.

Table 12: Linear Regression Analysis on the Effect of Sales or the Sources of Sales on Process R&D Expenditure

	log(Process R&D Expenditure)			
Constant	-0.4777^{*}	0.2459^{*}	0.3227^{*}	-0.5695^{*}
	(0.9044)	(0.9882)	(0.7967)	(1.009)
log(Sales)	0.6519^{*}			
	(0.2065)			
log(OEM Sales)		0.5748^{*}		0.5372^{*}
		(0.2760)		(0.3484)
log(ODM Sales)			0.4989^{*}	0.2627^{*}
			(0.1951)	(0.2879)
R^2	0.6083	0.5133	0.5487	0.7287
F	41.9274	19.1400	27.9602	18.7991
p value	0.0000	0.0004	0.0000	0.0001

- $^{*}p < .01$; Unit: NT $1 million
- All regression results are based on three-year averages.

Table 13: Linear Regression Analysis on the Effect of Sales or the Composition of Sales on Process R&D Share

	Process R&D Share				
Constant	0.1797	-1.0225	0.2497^{*}	0.4030^{***}	0.2836^{**}
	(0.4862)	(2.5305)	(0.0704)	(0.1035)	(0.1584)
log(Sales)	0.0358	0.6235			
	(0.1110)	(1.2189)			
log(Sales^2)		-0.0702			
		(0.1450)			
OEM (%)			0.3267^{*}		0.2839^{**}
			(0.2319)		(0.2956)
ODM (%)				-0.1602^{***}	-0.0469^{**}
				(0.1642)	(0.1956)
R^2	0.0159	0.0521	0.2437	0.1338	0.2510
F	0.4387	0.7144	8.3772	4.0169	4.1890
p value	0.5133	0.4988	0.0075	0.0555	0.0269

- $^{*}p < .01$; $^{**}p < .05$; $^{***}p < .10$
- All regression results are based on three-year averages.

Table 14: The Causality Check†

Case	Dependent Variable	Independent Variables	Time Lag	R^2
1	$p_{\text{processR\&Dshare3}}$	$\text{OEM}_{1\&2\text{average}}, \text{ODM}_{1\&2\text{average}}$	1.5 (years)	**0.4476**
	$p_{\text{processR\&Dshare1\&2}}$	$\text{OEM}_3, \text{ODM}_3$	-1.5	0.3282
2	$\text{ProcessR\&D}_3$	$\text{OEM}_{1\&2\text{average}}, \text{ODM}_{1\&2\text{average}}$	1.5	**0.7445**
	$\text{ProcessR\&D}_{1\&2\text{average}}$	$\text{OEM}_3, \text{ODM}_3$	-1.5	0.6127
3	$\text{ProductR\&D}_3$	$\text{ODM}_{1\&2\text{average}}$	1.5	**0.6978**
	$\text{ProductR\&D}_{1\&2\text{average}}$	ODM_3	-1.5	0.6207

†Note that the subscript "1&2average" indicates the mean of 2002 and 2003 data and the subscript "3" indicates the 2004 data.

Table 15: Enrollment of Foreign Graduate Students in U.S. Universities for Top 5 Locations of Origin*

	1989/90			1995/96			1999/2000		
Total	386,851		100%‡	453,787		100%‡	514,723		100%‡
Top 5 total	142,140	100%†	36.74%	185,820	100%†	40.95%	214,100	100%†	41.60%
China	33,390	23.49%	8.63%	39,613	21.32%	8.73%	54,466	25.44%	10.58%
Japan	29,840	20.99%	7.71%	45,531	24.50%	10.03%	46,872	21.89%	9.12%
Korea	21,710	15.27%	5.61%	36,231	19.50%	7.98%	41,191	19.24%	8.00%
India	26,240	18.46%	6.78%	31,743	17.08%	7.00%	42,337	19.77%	8.23%
Taiwan	30,960	21.78%	8.00%	32,702	17.60%	7.21%	29,234	13.65%	5.68%

*Source: National Science Foundation, *Science & Engineering Indicators – 2002*.

†Percentage in top 5 locations of origin

‡Percentage in all locations of origin