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PRODUCTION AND LOCATION CHOICES OF FIRMS IN THE TAIWANESE ELECTRONICS SECTOR

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Yi Lee

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The thesis of Yi Lee was reviewed and approved* by the following:

Bee Yan Aw
Professor of Economics
Thesis Advisor, Chair of Committee

Mark J. Roberts
Professor of Economics

James R. Tybout
Professor of Economics

Jill L. Findeis
Professor of Agricultural, Environmental & Regional

James S. Jordan
Professor of Economics
Acting Head of Department of Economics

*Signatures are on file in the Graduate School.

Abstract

Increases in wages and the appreciation of the New Taiwanese dollar since the mid-1980s have significantly altered the environment in which firms operate and survive. In particular, as more countries have liberalized their trade and foreign investment policies, Taiwanese firms have been pressured to respond to the increased international competition for the pool of foreign investment funds.

This thesis uses micro data from Taiwanese electronics industry to present two firm strategies in response to competition from other low-wage countries: identify low-cost production sites and change product mix. Chapter 1 introduces the background and evolution of the Taiwanese electronics industry. Chapter 2 presents a theoretical model which captures the different incentives of Taiwanese multinationals investing in high- and low-income countries, and an empirical analysis of the link between firm heterogeneity and location choices. Chapter 3 empirically analyzes the product choices of Taiwanese multi-product plants during the 1990s.

Chapter 2 examines the extent to which the location decisions of Taiwanese multinationals reflect underlying patterns of firm productivity. In the theoretical model, heterogeneous firms in a middle-income country decide on the optimal production locations for serving three geographically separate markets: domestic, foreign high-income and foreign low-income. The model shows that the equilibrium decision of a firm depends on its fixed investment cost of establishing foreign subsidiaries, production costs, transportation costs, market size and its own productivity level. The empirical work in this chapter is based on firm-level data in the Taiwanese electronics industry in 2000. Firms are decomposed into four different categories: non-FDI, investors in China only, investors in the USA only, investors in both China and the USA. I use a multinomial logit model to link firms' location choices with their productivity, controlling for country, industry and other firm characteristics. The findings indicate that more productive firms engage in outward FDI, with the most productive ones investing in both China and the USA.

Due to smaller fixed investment costs in China relative to the USA, Taiwanese multinationals investing only in the USA are more productive than those investing only in China.

Chapter 3 examines the diversification strategies of multi-product plants in the Taiwanese electronics sector during the 1990s. Using plant-level and product-level data, I first examine if multi-product plants benefit from scope economies arising from joint production. Next, I introduce a dissimilarity index to capture the technological gaps between each pair of products within a multi-product plant. This index is used to analyze how multi-product plants choose their product mix in the face of increased competition. I find no evidence of scope economies. The findings suggest that multi-product plants whose products have bigger technological gaps are more likely to give up some product lines. Moreover, multi-product plants are shown to exit markets where production technologies are farthest away from their primary products.

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Chapter 1

Introduction

The rapid expansion of per capita Gross Domestic Product (GDP) during the 1990s in the newly industrializing economies (NIEs) (Hong Kong, Singapore, South Korea and Taiwan) over the last two decades has attracted much attention of researchers. Understanding how East Asian latecomers like Taiwan successfully upgraded their industrial base, shifting from an economy of low added value industries to one of exporting high-technology products, is important for policy makers in other less developed countries (LDCs).

In 1960, per capita GDP in Taiwan was less than US$ 200, less than that of other LDCs such as Malaysia (US$ 275) and the Philippines (US$ 251). Since then, the annual growth rates of Taiwan's per capita GDP averaged at 10 percent, driven by an export boom based on labor-intensive consumer goods like clothing, textiles and toys. In the late 1960s, Taiwanese manufacturers started subcontracting work in the electronics industry. By the end of the 1980s, Taiwan emerged as a major player in the electronics industry. By 2001, Taiwanese companies manufactured 70 percent of all personal computer (PC) motherboards, 55 percent of all laptops, 56 percent of all liquid crystal display (LCD) monitors and 51 percent of all color display tube monitors (Berger and Lester 2005). Between the 1980s and 2001, the key manufacturing sector moved from textiles to the electronics sector whose share of production value in total manufactures grew from 8.9 percent in 1981 to 30 percent in 2001. The substantial expansion in the electronics industry helped raise Taiwan's per capita GDP from less than US$ 200 in 1960 to US$ 12,500 in 2001.

How did Taiwan achieve this? As in other developing countries, economic infrastructure and government policies facilitated rapid growth in Taiwan. Taiwan was colonized by Japan before 1945 and Japanese authorities invested heavily on social infrastructure such as transportation systems and educational programs. The well-developed economic infrastructure and low-wage, skilled labor offered a better investment environment than other LDCs for foreign investors. In the 1960s, the Taiwanese government targeted key sectors and directly intervened in them through policies permitting 100 percent foreign ownership, tax- and duty-free export processing zones (EPZs) which encouraged investment in processing and assembly of labor-intensive goods like textiles, garments, electrical and consumer electronics products. A combination of cheap and well-trained labor and the non-existence of labor strikes attracted considerable investment and subcontracting work from the USA and Japan. In the absence of pioneering production technology, Taiwanese firms relied heavily on technological assistance from advanced countries made possible through inward foreign direct investment or subcontracting work.

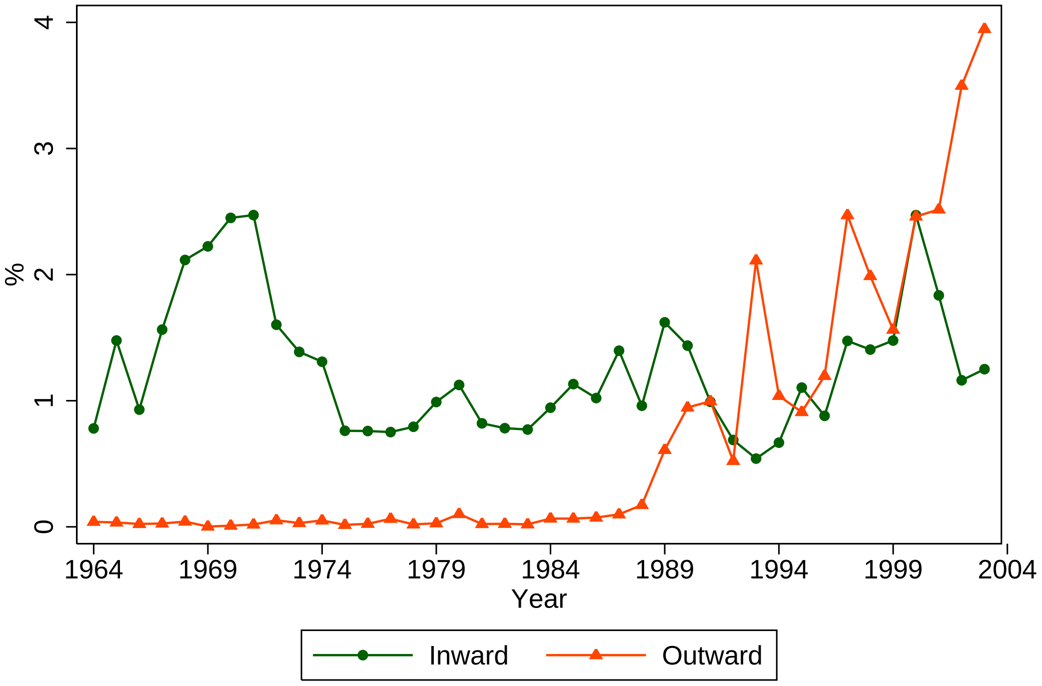
Following the sharp increases in real wages and land prices, and growth in environment protection issues in the mid 1980s, Taiwan lost its comparative advantage in labor-intensive production. In order to compete with other less developed countries in Latin America and Southeast Asia, Taiwanese entrepreneurs moved from labor-intensive operations to capital- and technology-intensive sectors, such as information technology products and high value-added semiconductors. At the same time, the Taiwanese government created Hsinchu Science Based Industrial Park where companies enjoyed a five-year tax holiday, import duty exemptions and the benefit of technology transformation from nearby universities and a public research laboratory, the Industrial Technology Research Institute (ITRI). These relevant government policies encouraged a rapid output growth in the electronics industry beginning in the 1990s: the total production value in the electronics industry grew by 141 percent between 1991 and 1996 and by 67.9 percent between 1996 and 2001, while the total production value in the textile industry grew by only 21.5 percent between 1991 and 1996 and shrank by 2.3 percent between 1996 and 2001.

However, Taiwanese electronic firms that relied heavily on original equipment manufacturing (OEM) and original design manufacturing (ODM) always lacked their own brands, and their profits depended on relationships with the leading companies in advanced countries. This lack of cutting-edge skills and focus on the bottom-end market led to fierce competition from firms in low-wage countries. In an attempt to survive under the stiffer competitive pressure in the international market, Taiwanese firms began seeking out low-cost production location (location strategy) and changing the composition of their products (product strategies).

1.0.1 Location Strategies

Since 1987, firms in Taiwan started to undertake outward foreign direct investment (FDI) at a remarkable rate. Figure 1.1 shows the outward FDI-GNP ratio over time. FDI outflows were trivial before 1985 and experienced a noticeable expansion in the 1990s. Some macro-environmental factors contributed to

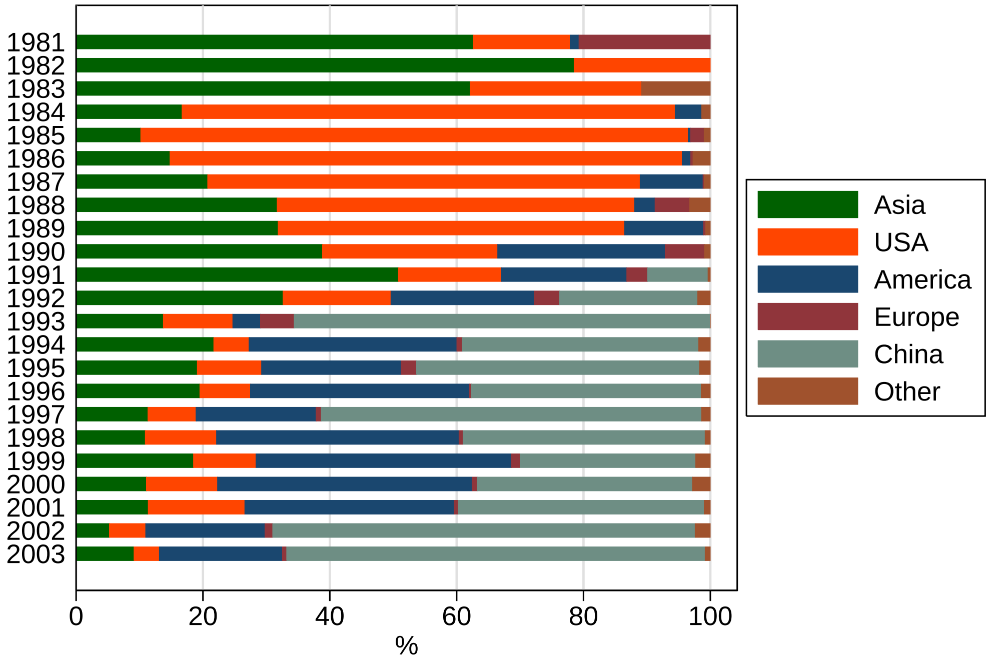
Figure 1.1. Inward FDI/GDP & Outward FDI/GNP



Source: Investment Comission, MOEA

the substantial expansion of outward FDI. First, the New Taiwanese Dollars appreciated rapidly against U.S. Dollars during 1985 and 1988. Second, real wages and real estate prices increased substantially after 1985. In 1985, the Taiwanese government adopted the Labor Standards Law, which included regulations with regard to minimum wage levels, pension and severance pay and overtime premiums. Third, growing environmental concerns made it less acceptable to utilize polluting production technologies. Rising costs of labor and land and restrictions on pollution emission began undermining Taiwanese competitiveness and discouraging new investment. Finally, the Taiwanese government dismantled its foreign exchange control in 1987. Project investments have been allowed to remit up to US$ 5 million annually out of the country. Until 1996, a company with an investment project smaller than US$ 20 million was automatically approved after registering with the Investment Commission of the Ministry of Economic Affairs (MOEA).

Figure 1.2. Share of Outward FDI, by Destination



Source: Investment Comission, MOEA
Asia excludes China and America excludes the USA

Figure 1.2 presents the share of outward FDI decomposed by the destination countries from 1981 to 2003. Over the 1980s, other Asia countries and the USA were the most important host regions of Taiwanese outward FDI. After the Taiwanese government allowed firms to invest in China in 1991, China comprised about half of the total FDI outflows. Firms operating abroad in developed countries (DCs) and LDCs have different incentives. Firms may invest in DCs in order to acquire more advanced foreign technology and establish distribution networks. Alternatively, firms may invest in LDCs to outweigh the disadvantage of high production costs in the global market. Table 1.1 summarizes the incentives to undertaking outward FDI into different destinations.

Table 1.1. Incentives of Investing Abroad, by destination

Regions	Incentives
DCs	• Invest in the final market to lower transportation costs. • Seek advanced technology. • Expand its sales network through mergers and acquisitions (M&A) investment in local companies. • Fear of regional protection, like NAFTA and EU.
Asian LDCs	• Cheap labor and lands and rich natural resources. • Local government policies.
China	• Same language and culture. • Large potential market size. • Satisfy customers' request.

1.0.2 Product Strategies

Product diversification is a strategy that may be adopted by a firm in order to exploit the potential market size and/or economies of scope. While the economies of joint production may reduce the average costs of production by offsetting the costs which are not exhausted for each product line, this diversification strategy may leave average costs at uncompetitive levels if it leads to low output per product. The relative importance of scale and scope economies in the face of higher competition in the global markets affects a firm's decision to re-configurate their product mix.

Moreover, Teece argues that although the achievement of economies of scope can explain joint production, joint production need not be organized within a single production unit. Teece emphasizes that joint production can proceed by contractual cooperation in the absence of large transaction costs. The Taiwanese manufacturing industry consists mainly of small and medium-sized enterprises (SMEs). Small size restricts a firm's ability to achieve economies of scale and economies of scope, which are important factors for diversification. In addition, the highly developed networking systems reduce transaction costs between businesses. The size distribution and networking system caused Taiwanese electronics companies to become more specialized in order to exploit economies of scale.

This thesis consists of two chapters related to these two strategies. They both employ plant-level data collected by the MOEA in Taiwan. The first chapter develops a model that examines how heterogeneous firms self-select into different production location combinations. The second chapter addresses two questions: whether economies of scope determines product mix at the plant level; and how multi-product plants adjust their extensive margin in order to survive in the face of more competitors in the international market.

Chapter 2

Firm Heterogeneity and Location Choice for Taiwanese Multinationals

2.1 Introduction

International production expanded sharply in the 1990s. By 2001, the gross product of foreign affiliates accounted for 10% of world GDP. Worldwide sales of foreign affiliates grew by 7% per year in the 1990s, a rate that exceeded that of exports.[1] This rapid expansion has triggered research into multinational investment patterns. However, the bulk of recent research on outward foreign direct investment (FDI) has been restricted to developed countries (DCs) like the U.S. and Japan.[2] This chapter uses micro-level data from the Taiwanese electronics industry to examine the linkage between Taiwanese multinationals' location choices and firm-level heterogeneity in productivity.

Traditional multinational corporation theory distinguishes between two forms

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[1] UNCTAD World Investment Report 2002.

[2] An exception is Debaere's (2004) discussion on FDI in Newly Industrialized Economies (NIEs) in 1990s.

of outward FDI-activities, horizontal FDI and vertical FDI. Vertical multinational firms geographically separate production stages to different countries, with the goal of conserving production cost. For example, Helpman's (1984) model shows multinational firms in the North investing in the South, using cheaper resources for production and exporting the final goods back to the North. In contrast, horizontal FDI firms often replicate the production activities in another country and sell goods in the local market, thereby conserving on trade costs.

In practice, multinational firms' investment behaviors are more complicated, combining both vertical and horizontal FDI. For example, a non-U.S. multinational firm may build a plant in Mexico and export the final goods to the U.S. conserving on both production and trade costs since Mexico and the U.S. are both bound by NAFTA[3]. This type of export-platform FDI is also found in Ireland where multinational firms set up production plants to export to other European Union (EU) countries. A two-country model cannot explain this complicated foreign investment behavior. Ekholm et al. (2004) develop a three-country model to show how trading costs affect the production location choices for a firm. However, Ekholm et al.'s paper ignores firm heterogeneity. A key stylized fact emerging from firm-level studies is that there is a high degree of firm heterogeneity within industries. Recent empirical research has also found a systematic relationship between the characteristics of business firms and their participation in foreign trade and investment.[4] These firms are generally more productive and larger. To explain this systematic, empirical fact, recent trade models in the literature has increasingly relied on models with heterogenous firms.[5]

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[3] Hanson et al. (2001) report a substantial increase in Mexico and Canada on the average share of exports in affiliates sales after the passage of NAFTA.

[4] Firms that export or/and invest abroad are showed to be more productive. See Aw et al. (2000), Bernard and Jensen (1999) and Helpman et al. (2004).

[5] Melitz (2003) for export and Helpman et al. (2004) for horizontal FDI.

Models focusing on FDI flows from DCs to LDCs or between DCs cannot explain the outward FDI activities from middle-income countries such as Taiwan and South Korea,[6] where wages are sandwiched between those in DCs and other LDCs. We introduce a simple one-stage production model based on a modified version of Grossman et al.'s (2006) framework to explain heterogeneous firms in middle-income countries investing in developed countries (North) or developing countries (South). Each firm chooses production locations for its global sales. Firms investing in the North save on trading costs to serve the foreign market while those investing in the South are attracted to low production costs and access to the local market. Firms' location decisions will depend on industry characteristics, such as fixed investment costs of building a foreign plant, market size and trading costs. This model captures both market-seeking and resource-seeking incentives for multinational firms.

Table 2.1 presents some stylized facts of a sample of Taiwanese multinational firms that engage in outward FDI. This sample comprises 75% of the entire Taiwanese manufacturing multinationals. It summarizes the sales of manufactured goods by foreign affiliates of Taiwanese multinationals in different host countries. Affiliates' sales are broken down into export sales back to Taiwan, local sales in the host country, and export sales to third countries. One striking feature of Taiwanese affiliates in the U.S. is that 73% of their output is sold in the U.S. Affiliates in Asian LDCs are more likely to engage in both local sales and export to third countries. The high proportion of affiliates sales consumed locally in the U.S. may

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[6] Debaere, Peter (2004) emphasizes this issue and indicates that multinationals from middle-income countries relocate labor-intensive activities to more labor-abundant countries, and move capital-intensive components to more capital-abundant countries. Using South Korea firm-level data, Debaere shows that South Korea multinational parents indeed decrease the capital-labor ratio after investing into capital-abundant countries, while this capital-labor ratio increases for those parents relocating to labor-abundant countries.

indicate the important role of conserving transportation costs. The concentration of local sales and sales of exports to third countries of FDI in Asia suggest the importance of conserving both transportation costs and production costs.

Section 2.2 reviews the literature related to outward FDI and details the contributions of this chapter to this literature. A description of Taiwanese FDI in the 1990s and the data used for the empirical estimation are found in Section 2.3. Section 2.4 develops a theoretical model for firms' production location choices. Section 2.5 provides the empirical specifications and Section 2.6 reports the estimation results. We summarize the findings and present conclusions in the final section.

2.2 Literature Review

The most fundamental question about FDI is why a firm chooses to serve a foreign market through subsidiary production rather than through other options, such as exporting or licensing. The proximity-concentration hypothesis indicates that firms should engage in horizontal FDI whenever the advantage associated with access to the destination market outweigh the advantage from production scale economies.

Brainard (1997) provides a mixed equilibrium where some firms undertake FDI and other firms export. By choosing FDI instead of exporting, a firm gives up the scale economies in production but saves on trading costs (variable costs). Brainard proposes an econometric model in which the share of firms doing export and FDI depends on firm-specific and plant-specific economies of scale, industry- and country-specific trade costs, and a set of control variables related to the host country characteristics. While the results support the proximity-concentration hypothesis, the model ignores the role of firm heterogeneity.

Helpman et al. (2004) add a role for productivity differences into this proximity-concentration trade-off model to explain the choices across firms within the same industry. Their model focuses on a firm's choice between exports and horizontal FDI. A new entrant draws its productivity level from a distribution after paying an entry cost. A firm may decide to exit or continue production after observing its productivity level. If it chooses to produce, it bears a fixed production cost. Any firm which remains in the industry always serves its domestic market and can decide to serve foreign markets through exporting or FDI. If the firm chooses to export, it bears additional fixed cost f_X and an iceberg transportation cost. On the other hand, if this firm serves the foreign market through FDI, then it bears the fixed cost f_I. A firm's decision between exports and FDI is driven by the proximity-concentration trade-off whereby FDI saves on transportation costs but incurs higher fixed costs relative to export. Given the assumption on the relationship between fixed costs, relative production costs between domestic and foreign countries and transportation costs[7], the most productive firms will prefer FDI over exporting. Helpman et al.'s (2004) empirical tests focus on the effect of some measures of the dispersion of productivity, fixed costs and trading costs on the cross-country and sector variation of the volume of exports relative to FDI. They find that the ratio of industry exports to FDI sales is positive correlated to plant scale economies, but negative correlated to trading costs and the dispersion of productivity.

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[7] In their model, the operating profits for domestic firms, π_D, exporting firms, π_X and FDI firms, π_I, can be expressed as: $\pi_D = (w_i a)^{1-\sigma} B_i - f_D$, $\pi_X = (w_i t a)^{1-\sigma} B_j - f_X$ and $\pi_I = (w_j a)^{1-\sigma} B_j - f_I$, where i presents domestic market, j presents the foreign market, and B and a presents market size and firms' efficiency levels, respectively. If the condition $w_j^{\sigma-1} f_I > (w_i t)^{\sigma-1} f_X > f_D$ is satisfied, then the most productive firms will choose FDI, firms with productivity levels fall into the middle range become exporters and the least productive firms only serve the domestic market.

Instead of using aggregate information, Yeaple (2005) uses U.S. firm-level data to do an extensive analysis of the Helpman et al.'s (2004) model. Yeaple depicts the important role of firm heterogeneity as well as the geographic sorting across industries and countries. He shows that more productive firms are more likely to invest abroad, but a firm's productivity level is less important in relatively attractive (that is, bigger) countries. Besides the U.S. case, Head and Ries (2003) and Girma et al. (2005) using micro-data in Japan and the UK, respectively, also find evidence that heterogeneous firms self-select into exporting or FDI.

Although the substitute relationship between exports and FDI is prevalent in recent research, empirical evidence suggests that multinational corporations have complex integrated strategies. Hanson et al. (2001) use detailed U.S. data to characterize different motivations of U.S. multinational firms by describing three types of FDI: export-platform FDI, vertical-specification FDI and distribution-oriented FDI. They find evidence that U.S. affiliates export around one-third of their total production, import goods for further processing from their parents, and participate in wholesale-trade activities in the foreign countries. Based on the fact that multinationals also export, a number of papers have recently begun to sketch out more complex patterns of FDI by adding more countries and stages of production into previous models. For instance, Ekholm et al. (2004) use a model with two homogenous monopolists to explain the export-platform FDI in some integrated regions, such as the EU or NAFTA countries. The model includes two identical northern countries (West and East) and one southern country (South) with low production costs. Given the fact that the West and the South are within a free trade area, it is always optimal for the monopolist in the West to produce in the South and then export final goods back to the West market. Because of the asymmetric trading costs, East has advantages in producing in the South for the final West market (export-platform FDI).

Instead of focusing on country-specific characteristics, Grossman et al. (2006) develop a complementary strategy model incorporating firm heterogeneity to combine horizontal and vertical FDI. They show that even within the same industry, (i.e. where each firm faces the same market size, fixed costs and transportation costs), firms differing in productivity have different optimal strategies. In their model, a firm performs intermediate stages of production in a country with low production costs and subsequent stages (assembly) in another country close to the final market to save on transportation costs. There are two identical northern countries and one southern country with low production costs and small market size. Each firm chooses the production sites for intermediate and assembly stages for serving the global market. Grossman et al. conclude that the least productive firms produce in the Home market, firms engaging in FDI are more productive, and the most productive firms will move both intermediate and assembly stages into the South. The integration strategies will depend on the scale of trading costs and the relative fixed costs of the intermediate and assembly stages. In the case of the low trading cost of final goods, firms will not produce in the North. As the transportation costs on final goods increase, firms are going to spread out assembly into all final markets. When there are transportation costs on intermediates, firms prefer to combine these two stages in the same country.

Several researchers have made notable progress in describing the complicated structure of FDI. Yeaple (2003) indicates that the patterns of FDI should vary across country-industry pairs depending on both market access motives and comparative advantages motives. The strength of market access motives differs by country-industry characteristics, such as trading costs, market size and fixed investment costs. The comparative advantage motives result from the variation of relative production costs across countries and industries, whereby a labor-intensive industry, for example, will have comparative advantages in undertaking FDI in a labor-abundant country. Yeaple uses the industry-country pairs information of U.S. outward FDI and finds evidence that U.S. outward FDI is consistent with both comparative advantages and market access motivations. Blonigen et al. (2004) use data on OECD countries to estimate the spatial dependence between FDI into the host country and alternative countries. Their findings support the evidence that U.S. multinationals conduct export-platform FDI into Europe.

Firm-level data has also been used to test the complex motivations of FDI. Belderbos and Sleuwaegen (1996) distinguish different determinants for Japanese firms investing in DCs from investing in countries in Southeast Asia. They demonstrate the importance of firm-intangible assets for investments in DCs, while FDI in Southeast Asia is driven more by human resources and inter-firm linkages.[8] Katayama et al. (2005) examine the engine of tax/subsidies from the local governments for foreign investors under the assumptions that FDI in LDCs is export-oriented, and multinationals view DCs as consuming countries. High unemployment in LDCs leads the local government to offer low taxes on foreign investment in order to increase local job opportunities. These lower taxes on foreign investment reduce the cost of investing in LDCs relative to DCs, permitting relatively less efficient multinationals to do business in LDCs. Katayama et al.'s empirical results, drawn from a firm-level data set from the Japanese manufacturing sector, suggest that more productive firms invest in consuming countries, and less-productive firms practice export-oriented FDI in LDCs.

This chapter makes two main contributions to the literature. First, we develop a

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[8] Chen and Chen (1998) also point to the effects of different determinants on choosing different destinations for Taiwanese FDI.

three-country model which accounts for the interdependence between host country and other final consumption countries. Our model resembles those of Ekholm et al. (2004) and Helpman et al. (2004). The key difference is that we explicitly model the effects of firm heterogeneity and the interaction of country characteristics on firms' location choices. By introducing firm heterogeneity into Ekholm et al.'s framework, we allow firms with different productivity levels to choose different production locations based on factor price differentials, fixed investment costs and market size across countries. In contrast to Helpman et al. (2004), we introduce the strategy of exporting from a third country.

Second, in sharp contrast with existing empirical work which focus primarily on investments flowing from countries in the North to those in the South, or among countries in the North, we introduce a middle income country that is just as likely to invest in the South as it is to invest in the North. More specifically, by simplifying Grossman et al.'s (2006) two-stage production model to a one-stage model, we concentrate on the production destinations of firms from Taiwan to China and the U.S. This model allows us to take full advantage of the unique data set we have which contains information on the destination of outward FDI among Taiwanese firms. Given Taiwan's middle-income status, we have the opportunity to provide insights into the economic rationale for the growing trend towards outward FDI among firms in rapidly growing developing countries.

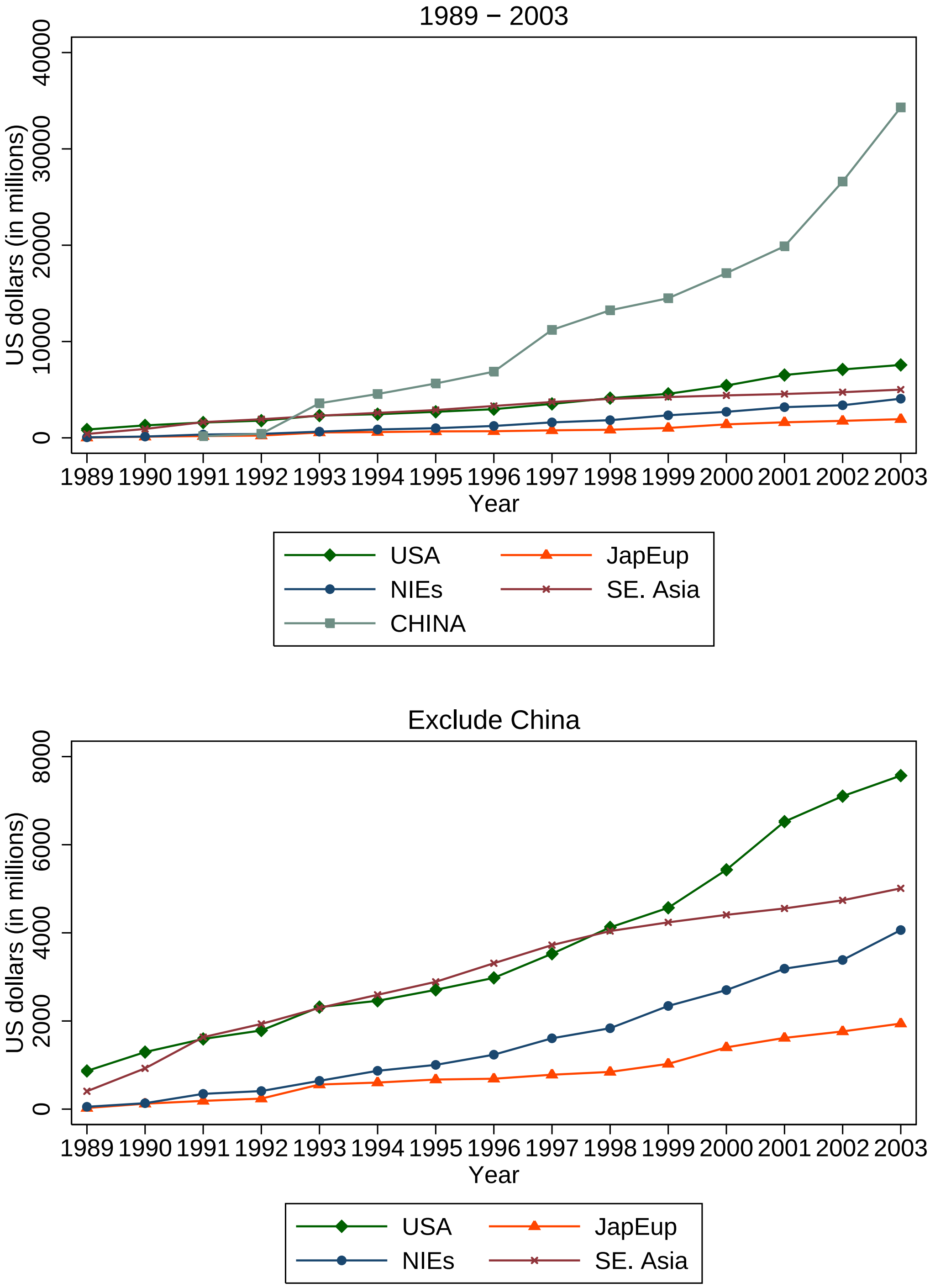
2.3 Pattern of Taiwanese Outward FDI and Data Description

2.3.1 Pattern of Taiwanese FDI

In the late 1980s, outward FDI among Taiwanese firms occurred at a remarkable rate. Some macro-environmental factors contributed to the substantial expansion of outward FDI. First, the New Taiwanese dollar appreciated rapidly against U.S. Dollars during 1985 and 1988, from \$0.025 to \$0.035. Second, real wages and real estate prices increased substantially after 1985. Third, growing environmental concerns made it less acceptable to utilize polluting production technologies. Rising costs of labor and land and restrictions on pollution emission began undermining Taiwanese competitiveness and discouraging new investment. Fourth, the Taiwanese government dismantled its foreign exchange control in 1987. Project investments have been allowed to remit up to US\$ 5 million annually out of the country. Until 1996, a company with an investment project smaller than US\$ 20 million was automatically approved after registering with the Investment Commission of the Ministry of Economic Affairs (MOEA). Finally, the Taiwanese government permitted Taiwanese firms to invest in China starting from 1992.

Table 2.2 shows the overall share of GNP contributed by outward FDI, exports as well as the FDI-export ratio in the last two decades. Relative to export shares, the absolute magnitude of FDI shares in total GNP is small. However, while export shares stayed stable over the period from 1981 to 2000, FDI shares rose from 0.0004 to 0.0195; the FDI-export ratio grew by 470% in the twenty-year period. This rapid expansion of FDI reflects the change of the globalization strategies in Taiwan since the mid 1980s.

Figure 2.1. Cumulative Outward FDI, by Destination



Source: Investment Comission, MOEA
NIEs: Hong Kong, Singapore and South Korea
JapEup: Japan and Europe

Electrical and electronics manufacturers are responsible for Taiwan's largest share of outward FDI within the manufacturing sector. By 2004, the entire manufacturing sector accounted for 61% of the stock value of FDI, with the electrical and electronics industry making up 40% of this stock. Among overseas investors, the U.S. and China were the most attractive investment destinations for Taiwanese manufacturing firms in the 1990s.[9] Figure 2.1 presents the trend of FDI stocks broken down by the major destinations. The bulk of Taiwanese FDI went to China during the 1990s. The country with the next largest amount of Taiwanese FDI stock is the U.S. In this chapter we focus on Taiwanese electronics firms' investments in China and the U.S.

2.3.2 Data Description

This chapter is based on plant-level data collected by the Ministry of Economic Affairs (MOEA) on the Taiwanese manufacturing sector in 2000. A plant registered with the MOEA provided information on revenue, total employment, and R&D expenditures. This data set also includes a unique firm identification number for each plant so that we can identify the owner of each plant. While this data is collected annually, in 2000, the MOEA also collected information on a plant's direct investment abroad by country of destination.

Since the FDI decision is made by a firm, not a plant, we construct firm-level data by summing up the information across plants with the same ownership.[10] When the firm owns multiple plants in different industries, we define the main industry for the firm based upon the plant with the largest revenue. In addition,

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[9] The MOEA started to record Taiwanese outward FDI in China in 1992.

[10] In Taiwan, only 5% of manufacturing firms are multi-plant firms. Approximately 10% of the computer and telecommunications equipment industry, and 8% of the parts and the electronic components industry are multi-plant firms.

we classify firms' investments types into four categories: non-FDI, FDI in China, FDI in the U.S., and FDI in both the U.S. and China. Exporting firms without any foreign affiliate are included in the non-FDI group[11]. Firms belonging to the second and third groups go abroad only to China or the U.S. The last category includes Taiwanese multinationals active only in both the U.S. and China. In order to focus on firms' location choices between China and the U.S., we ignore firms that also invested in other countries besides the U.S. and China.[12]

Table 2.3 provides some summary statistics[13] of firms in the electronics industry by different destination countries. The details on the construction of these variables are reported in Appendix A. From Table 2.3 it is clear that FDI firms are more productive, larger, more R&D-intensive and they engage in more innovation activities relative to non-FDI firms. However, among FDI firms, firms investing only in China on average have the lowest values for all these performance indicators.

2.4 The Model

We develop a simple model in which firms engaging in production activities choose the production locations to sell goods globally. Firms serve each market by either producing in its foreign subsidiary or exporting from another country. A multinational firm pays a fixed investment cost for building a plant outside the home country. If a firm chooses to export, there is an iceberg transportation cost. Firms make their production location decisions by comparing the variable costs with fixed investment costs. To capture the fact that most Taiwanese multinational

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[11] We exclude pure domestic firms since we are primarily interested in firms participating in foreign markets.

[12] This results in a lost of 6.9% of firms in the electronics industry

[13] The definition of each variable is shown in Appendix A.

firms conduct FDI in China or the U.S. as described in the previous section, we construct a three-country model to analyze the determinants of multinational firms' location choices.

Firms in the Home market are willing to offer final goods in three countries: Home (H), North (N) and South (S). Each firm produces a single differentiated product. Consumers in all countries have the same CES utility function in the consumption of product i, q_i, such that:

$$U = \big(\sum_{i=1}^{n} q_i^{\alpha}\big)^{\frac{1}{\alpha}}, \quad 0 < \alpha < 1 \tag{2.1}$$

With this utility function, we can write down the demand function of product i for consumers in country k as:

$$q_{ik} = Y_k p_{ik}^{-\sigma} \quad \text{where } \sigma = \tfrac{1}{1-\alpha} > 1, \;\; Y_k = \tfrac{E_k}{\tilde{P}_k}, \;\; \tilde{P}_k = \big(\sum_{i=1}^{n_k} p_{ik}^{1-\sigma}\big) \tag{2.2}$$

Here country index $k = N, H, S$ represents North, Home and South, $\sigma > 1$ is the elasticity of substitution between any pair of goods, E_k is the total expenditure in country k and $\tilde{P}_k$ is the price index for all products in country k.

Countries differ in their market sizes E_k, factor prices w_k and fixed investment costs f_k. Here we assume $f_H = 0$. Firms are heterogeneous in their productivity level ρ, which is firm-specific such that each subsidiary belonging to a firm is endowed with the same productivity level in different production locations. Assume that production only requires labor input in the production function, $q_i = \rho_i l_i$. This production technology incurs a constant marginal production cost of product i, $MC_{ik} = \frac{w_k}{\rho_i}$, produced by a subsidiary in country k with productivity level, ρ. *World Competitiveness Report (2000)* indicates that the U.S. has the highest average wage rate, the wage rate in Taiwan is the median and the lowest wage is found in China.[14] These stylized figures are consistent with the basic premise of our model where the wage level is highest in the North, lowest in the South and intermediate in Home, i.e. $w_N > w_H > w_S$. If a firm chooses to export, it incurs a symmetric transportation cost, $t > 1$.[15]

The optimal pricing rule for a CES-induced demand function is $p_{ik} = \frac{C_{ik}}{\alpha}$, where $C_{ik} = MC_{ik}$ if firm i serves market k from its local subsidiary and $C_{ik} = MC_{ij}t$ if this firm produces in country j and then exports final goods to market k. Solving the profit, π_{ik}, for firm i serving country k, we obtain

$$\pi_{ik} = (p_{ik} - C_{ik})q_{ik} - f_k = (1-\alpha)Y_k C_{ik}^{1-\sigma}(1/\alpha)^{1-\sigma} - f_k = B_k(\tilde{w_k})^{1-\sigma}\theta_i - f_k \quad (2.3)$$

where $B_k \equiv (1-\alpha)Y_k(1/\alpha)^{1-\sigma}$ and $\theta_i \equiv \rho_i^{\sigma-1}$. If firm i produces and serves in country k, then $\tilde{w_k} = w_k$. If firm i produces in country j and exports to country k, then $\tilde{w_k} = w_j t$

In order to simplify the notations in the model, we normalize the wage in Home to be one ($w_H = 1$) and re-scale foreign market sizes relative to the Home market size by $B_H = B$, $B_S = \beta_S B$ and $B_N = \beta_N B$. We define (x, y, z) as the choice set from serving the Home, North and South markets in production locations x, y and z, respectively. For example, (H, H, S) describes a firm that has plants in Home and in South. This firm provides final goods to the Home and North markets from the subsidiary at Home and to the South market from the plant located in

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[14] The total hourly compensation for manufacturing in 1999 is \$18.56 in the U.S., \$5.45 in Taiwan and \$2.11 in China according to *World Competitiveness Report (2000)*.

[15] We also tried the asymmetric transportation cost case, where t_{HN}, t_{HS}, and t_{NS} represent the transportation costs between North and Home, South and Home, and North and South. Under the reasonable assumption that serving the China market from Taiwan is more profitable than from the U.S. and serving the U.S. market from China is cheaper than from Taiwan (i.e. $w_N t_{NS} > t_{HS}$ and $t_{HN} > w_S t_{NS}$), we will get the same result as in the symmetric transportation cost case.

the South. Goods selling in each market can be produced from any of these three countries, so each firm has 27 ($3 \times 3 \times 3$) possible location combinations.

Given the assumption regarding the relative wage rates, $w_N > w_H > w_S$, and the symmetric transportation cost, some location combinations can be deleted using the following rules: (1) Since the wage is higher in North than at Home and building a plant abroad incurs extra fixed investment costs, offering goods to South from North is dominated by offering goods from Home. For example, (H, H, N) is dominated by (H, H, H) since $w_N t > w_H t$. (2) A firm must serve a market by its local plant as long as this firm has a plant in that country. For example, (H, S, H) is dominated by (H, S, S) because $w_H t > w_S$ and both strategies have the same fixed investment cost f_S. (3) If a firm has a plant in South and doesn't undertake FDI in North, this firm must export final goods to North from South, not from Home. This follows from the fact that $w_S t < w_H t$ and there is no extra fixed cost since this firm already has a plant in the South.

According to these three rules, we can narrow down each firm's strategy sets into 6 possible combinations. It is now straightforward to calculate that the profit of each strategy is such that:

1. (H, H, H):

$$B_H\theta + B_N(t)^{1-\sigma}\theta + B_S(t)^{1-\sigma}\theta = B\theta[1 + \beta_N t^{1-\sigma} + \beta_S t^{1-\sigma}]$$

2. (H, S, S):

$$B_H\theta + B_N(w_S t)^{1-\sigma}\theta + B_S(w_S)^{1-\sigma}\theta - f_S = B\theta[1 + \beta_N(w_S t)^{1-\sigma} + \beta_S(w_S)^{1-\sigma}] - f_S$$

3. (H, N, H):

$$B_H\theta + B_N(w_N)^{1-\sigma}\theta + B_S(t)^{1-\sigma}\theta - f_N = B\theta[1 + \beta_N(w_N)^{1-\sigma} + \beta_S(t)^{1-\sigma}] - f_N$$

4. (H, N, S):

$$B_H\theta + B_N(w_N)^{1-\sigma}\theta + B_S(w_S)^{1-\sigma}\theta - (f_N + f_S)$$

$$= B\theta[1 + \beta_N(w_N)^{1-\sigma} + \beta_S(w_S)^{1-\sigma}] - (f_N + f_S)$$

5. (S, N, S):

$$B_H\theta(w_St)^{1-\sigma} + B_N(w_N)^{1-\sigma}\theta + B_S(w_S)^{1-\sigma}\theta - (f_N + f_S)$$

$$= B\theta[(w_St)^{1-\sigma} + \beta_N(w_N)^{1-\sigma} + \beta_S(w_S)^{1-\sigma}] - (f_N + f_S)$$

6. (S, S, S):

$$B_H\theta(w_St)^{1-\sigma} + B_N(w_St)^{1-\sigma}\theta + B_S(w_S)^{1-\sigma}\theta - f_S$$

$$= B\theta[(w_St)^{1-\sigma} + \beta_N(w_St)^{1-\sigma} + \beta_S(w_S)^{1-\sigma}] - f_S$$

It is clear that only one of the strategies (H, N, S) and (S, N, S) will be chosen, and only one of the strategies (H, S, S) and (S, S, S) will be chosen. This choice is determined by the magnitude of $(w_St)^{1-\sigma}$. If the wage in South is not low enough to overcome the transportation cost for export goods to the Home market, i.e. $(w_St)^{1-\sigma} < 1$, then serving the Home market from South is less profitable than producing and selling goods in Home. Since the data set allows us only to observe firms engaging in production activities in Taiwan, we make the assumption that $(w_S t)^{1-\sigma} < 1$ in this chapter. Based on this assumption, strategies (S, N, S) and (S, S, S) are dominated by (H, N, S) and (H, S, S), respectively. Each firm's strategy will determine its profit function, which will take one of four possible forms:

$$\pi_{HHH} = B\theta[1 + \beta_N t^{1-\sigma} + \beta_S t^{1-\sigma}] \tag{2.4}$$

$$\pi_{HSS} = B\theta[1 + \beta_N (w_S t)^{1-\sigma} + \beta_S (w_S)^{1-\sigma}] - f_S \tag{2.5}$$

$$\pi_{HNH} = B\theta[1 + \beta_N (w_N)^{1-\sigma} + \beta_S t^{1-\sigma}] - f_N \tag{2.6}$$

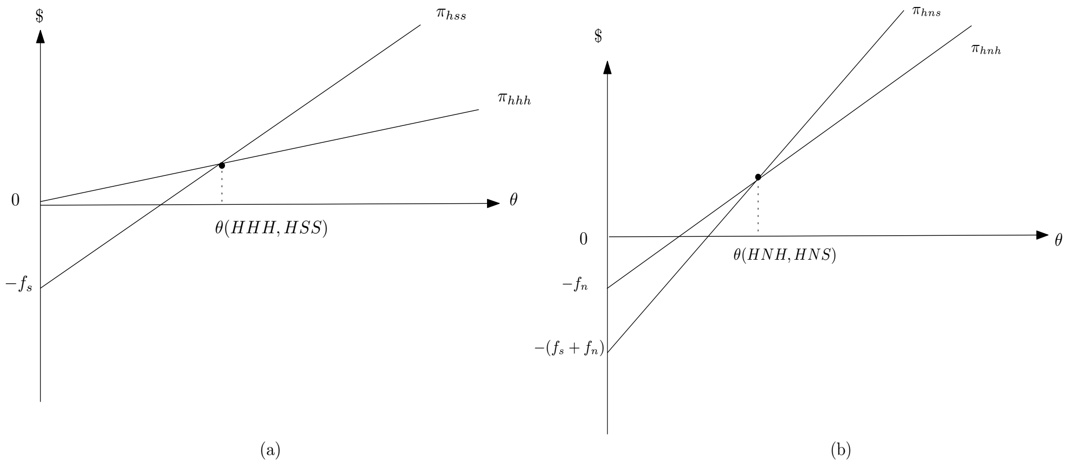
$$\pi_{HNS} = B\theta[1 + \beta_N (w_N)^{1-\sigma} + \beta_S (w_S)^{1-\sigma}] - (f_N + f_S) \tag{2.7}$$

Firms choosing the first strategy (equation (2.4)) produce in Home and then export the final goods to both the North and the South. The second strategy (equation (2.5)) combines elements of "horizontal FDI" and "export-platform FDI": firms produce in the South to serve the local (South) market and export part of their production to the North. It follows that the low wages in the South motivates production there. The third strategy (equation (2.6)) describes the market-access incentive for a firm doing business in the North. A firm builds a plant in the North to conserve on transportation costs rather than production costs. The final strategy (equation (2.7)) is one of complete FDI, whereby all production activities are performed in each market. The second and third strategies are consistent with the stylized fact, described in Table 2.1, that Taiwanese firms invest in China for local and third-country sales and invest in the U.S. for access to consumers.

We then compare the operating profits attainable for a firm with the measure of productivity, θ, from equations (2.4) to (2.7). Figure 2.2 shows the profits attainable for different levels of productivity, θ: for Home production and type

HSS in Figure 2.2 (a) and for type HNH and HNS in Figure 2.2 (b). Figure 2.2 (a) depicts the profit functions of equations (2.4) and (2.5). It shows that firms with a productivity level lower than $\theta(HHH, HSS)$ prefer Home production and firms with productivity level higher than $\theta(HHH, HSS)$ conduct FDI in South. This is in keeping with Helpman et al.'s (2004) model that exporting firms are less productive than FDI firms. The steeper π_{HSS} relative to π_{HHH} depicts that the lower cost per unit (including both production and transportation costs) gives higher return to more productive firms. Evidently, more productive firms produce more so they can benefit from the low cost per unit. Only highly efficient firms can overcome the fixed investment costs that enables them to enjoy lower unit cost.

Figure 2.2. Profit Function



(a) (b)

If we compare equations (2.6) and (2.7), π_{HNS} has a steeper slope than π_{HNH} because of $t > w_S$. Figure 2.2 (b) shows that highly productive firms engage in FDI in both North and South and firms with a productivity level lower than $\theta(HNH, HNS)$ practice FDI only in North. In order to have a complete analysis of firms' location choices, we need to combine Figure 2.2 (a) and Figure 2.2 (b) together. It is clear that there is no unique equilibrium without any advanced restriction on the scale of fixed costs, market size and wages. We will discuss the conditions to support all four strategies co-existing in the equilibrium.

First we need π_{HNS} to be steeper than π_{HSS} to make sure that the HNS strategy is profitable. That is, the transportation cost cannot be lower than the relative wages between North and South, i.e. $t > \frac{w_N}{w_S}$. Under this assumption, we readily have the complete ranking on the cost per unit: $w_S < 1 < w_N < w_S t < t$. Comparing equations (2.5) and (2.6), we see that the difference between the slopes of π_{HSS} and π_{HNH} cannot be determined by the assumptions $w_N < w_S t$ and $w_S < t$. If π_{HSS} is steeper than π_{HNH}, the relative market size between North and South, $\beta \equiv \frac{\beta_S}{\beta_N}$, needs to be higher than a threshold value, $\hat{\beta} \equiv \frac{w_N^{1-\sigma} - (w_S t)^{1-\sigma}}{w_S^{1-\sigma} - t^{1-\sigma}}$. Similarly, if the slope of π_{HSS} is lower than π_{HNH}, we require that $\beta < \hat{\beta}$ to satisfy the ranking of these slopes. We will discuss both conditions in turn.

1. **Small Market Size in South** ($\beta < \hat{\beta}$)**:** Figure 2.3 depicts the operating profits in the case of small market size in South. From Figure 2.3 we know that in order for all four strategies in equations (2.4) to (2.7) to exist, we need $\pi_{HNH}(\theta(HSS, HNS)) > \pi_{HSS}(\theta(HSS, HNS))$ and $\pi_{HNH}(\theta(HHH, HSS)) < \pi_{HSS}(\theta(HHH, HSS))$. This implies that $f_S > \delta_1 f_N$ and $f_S < \delta_2 f_N$, where $\delta_1 = \frac{(w_S^{1-\sigma} - t^{1-\sigma})\beta}{w_N^{1-\sigma} - (w_S t)^{1-\sigma}} < 1$ and $\delta_2 = \frac{(w_S t)^{1-\sigma} - t^{1-\sigma} + \beta(w_S^{1-\sigma} - t^{1-\sigma})}{w_N^{1-\sigma} - t^{1-\sigma}} < 1$. Since $\delta_2 < 1$, we have $f_S < f_N$[16].

   Figure 2.3 indicates that firms with a productivity level which is less than $\theta(HHH, HSS)$ can expect less profits from undertaking FDI and should

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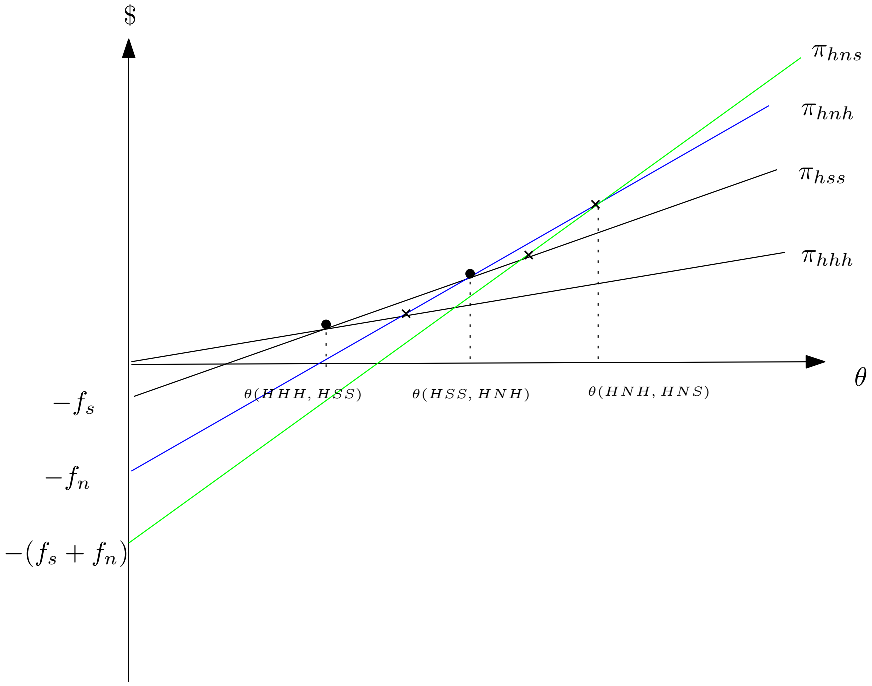
[16] If $f_S > f_N$, then strategy HSS will not be the optimal choice for firms. Small South market size favors strategy HNH, so firms prefer strategy NHN to HSS until the fixed investment cost in the North becomes high enough, $f_N > \frac{f_S}{\delta_2}$. The high fixed investment cost in the North will force less productive firms switch from strategy NHN to HSS since NHN becomes less profitable than HSS for them now.

Figure 2.3. Profit Function, High Trading Cost and Small South Market

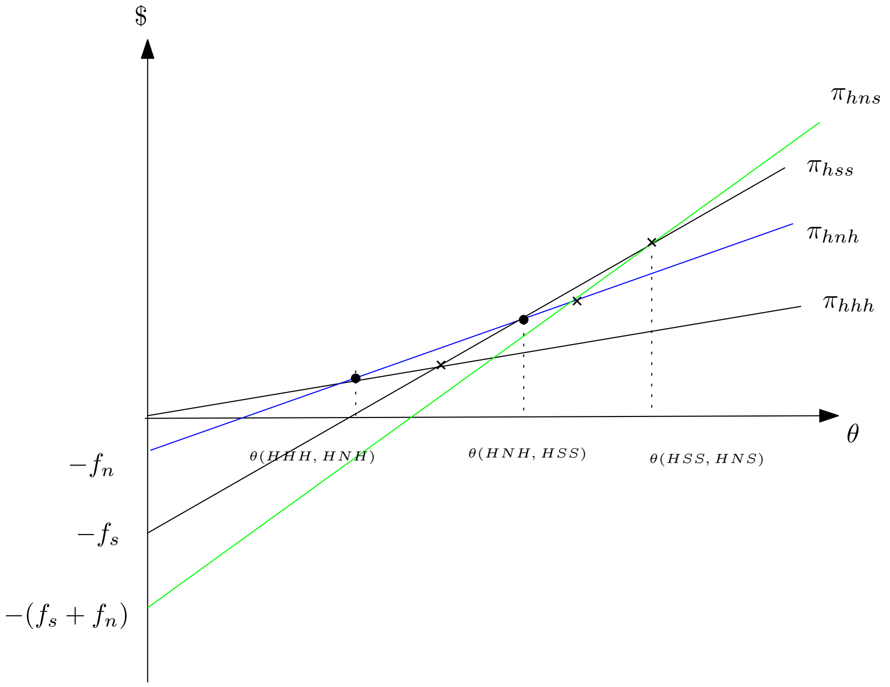


therefore concentrate on Home production. Firms with productivity levels between $\theta(HHH, HSS)$ and $\theta(HSS, HNH)$ have the highest operating profits from investing only in the South. Firms falling into the productivity ranges between $\theta(HSS, HNH)$ and $\theta(HNH, HNS)$ maximize their profits by building a foreign plant only in the North. The most productive firms will undertake FDI in both countries.

In this case, the least productive firms produce goods in the Home country and export to both the South and North. Firms investing in both the South and North are the most productive ones. In addition, if fixed investment costs in the South are smaller than those in the North, firms investing in the North will be more productive than firms investing in the South.

2. **Large Market Size in South ($\beta > \hat{\beta}$):** From Figure 2.4 we know the conditions for keeping four strategies profitable are $\pi_{HNH}(\theta(HSS, HNS)) < \pi_{HSS}(\theta(HSS, HNS))$ and $\pi_{HNH}(\theta(HHH, HSS)) > \pi_{HSS}(\theta(HHH, HSS))$. This implies that $f_S < \delta_1 f_N$ and $f_S > \delta_2 f_N$, where $\delta_1 = \frac{(w_S^{1-\sigma} - t^{1-\sigma})\beta}{w_N^{1-\sigma} - (w_S t)^{1-\sigma}} > 1$ and $\delta_2 = \frac{(w_S t)^{1-\sigma} - t^{1-\sigma} + \beta(w_S^{1-\sigma} - t^{1-\sigma})}{w_N^{1-\sigma} - t^{1-\sigma}} > 1$. Since $\delta_2 > 1$, we have $f_S > f_N$ in this case[17].

Figure 2.4. Profit Function, High Trading Cost and Large South Market



In this case, as indicated in Figure 2.4, firms with lowest productivity (below $\theta(HHH, HNH)$) will concentrate on Home production while those with the highest

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[17] If $f_S < f_N$, then strategy HNH will not be the optimal choice for firms. Large South market size favors strategy HSS, so firms prefer strategy NSS to HNH until the fixed investment cost in the South becomes high enough, $f_S > \delta_2 f_N$. The high fixed investment cost in the South will force less productive firms switch from strategy NSS to HHN since NSS becomes less profitable than HNH for them now.

productivity (more than $\theta(HSS, HNS)$) will undertake investments in both countries. These rankings mirror those for the small Southern market case. For those firms with productivity levels in the intermediate range, the relative size of the country-specific fixed costs determines the orderings of productivity levels. Firms with productivity levels between $\theta(HHH, HNH)$ and $\theta(HNH, HSS)$ invest in the North and firms' productivity levels falling into the range between $\theta(HNH, HSS)$ and $\theta(HSS, HNS)$ build a foreign plants only in the South. In other words, as long as fixed investment costs are lower in the North, firms investing only in the North are less productive than firms investing only in the South.

In summary, given the same fixed investment cost, more productive firms will choose FDI. This is consistent with Helpman et al.'s (2004) model that found FDI firms to be more productive than exporting firms. If the wage differentials across countries are not too large or the transportation costs between the North and South is high enough, i.e. $t > \frac{w_N}{w_S}$, then FDI in both the North and the South is profitable. The most productive firms undertake FDI in both North and South since they face the highest fixed investment costs, $(f_S + f_N)$. These implications are consistent with Yeaple's (2005) argument that the more productive a firm is, the more countries in which that firm will conduct FDI. The fact that the least productive firms stay in the Home country and the most productive ones invest in both South and North is independent of the market sizes in the South and the scale of the fixed costs in the South and North.

On the other hand, the ranking of productivity levels between firms that only invest in the South and firms that only invest in the North depends on the relative market size and fixed investment costs in the two markets. If the market size in the South is small and its fixed investment costs is lower than that in the North, firms investing in the North are more productive than those investing in the South.

However, if the market size in the South is large and its fixed investment costs is higher than those in the North, then firms investing in the South have higher productivity levels than those investing in the North.

2.5 Empirical Specifications

The theoretical presented in Section 2.4 predicts that the least productive firms will produce at Home and for export to foreign markets. The most productive firms undertake FDI in both the U.S. and China. The sorting of firms doing business in the U.S. or China on the basis of their productivity depends on the scale of the fixed investment costs, f_s and f_n.

We specify a firm's operating profit function for each strategy by:

$$\pi_t = \alpha_t + \beta_t Z_i + \varepsilon_{it} \quad \text{,where } t = 1, 2, 3, 4 \tag{2.8}$$

and π_1 represents the profits for type HHH, π_2 for type HSS, π_3 for type HNH and π_4 for type HNS.

A firm's profit depends on a type-specific parameters, α_t, and a vector of firm characteristics which determine the firm's production efficiency, Z_i. Each firm will choose the locations in which its operating profit is maximized. Since we only observe each firm's location choices, rather than its profit on overseas operation, a multinomial logit [18] (MNL) model is used to estimate the probabilities that a firm belongs to one of the four types, HHH, HSS, HNH and HNS:

$$P_i^t = \frac{exp[\alpha_t + \beta_t Z_i]}{\sum_{k=1}^{4} exp[\alpha_k + \beta_k Z_i]} \quad \text{,where } \ t = 1, 2, 3, 4 \tag{2.9}$$

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[18] The multinomial logit model assumes independence of irrelevant alternatives (IIA) on the error terms such that the choices for a firm are independent.

where P_i^t is the probability that firm i belongs to type t. The firm characteristics included in Z_i are labor productivity, firm size, R&D intensity, technology purchasing and the dummy variables for innovation activities. In order to identify parameters (α, β), we normalize the profit for type HHH π_1 to zero and the estimated MNL model becomes:

$$\begin{aligned} P_i^1 &= \frac{1}{1+\sum_{k=2}^{4} exp[\tilde{\alpha_k}+\tilde{\beta_k} Z_i]} \\ P_i^t &= \frac{exp[\tilde{\alpha_t}+\tilde{\beta_t} Z_i]}{1+\sum_{k=2}^{4} exp[\tilde{\alpha_k}+\tilde{\beta_k} Z_i]} \quad \text{,where} \;\; t=2,3,4 \end{aligned} \tag{2.10}$$

where $\tilde{\alpha_k} = (\alpha_k - \alpha_1)$ and $\tilde{\beta_k} = (\beta_k - \beta_1)$.

The constant terms capture country-wide characteristics which are invariant across firms within the same investment type. In our model, it represents the scale of the fixed investment costs for different investment types. We use labor productivity rather than total factor productivity as the measure of a firm's productivity since information on capital flow or stock is not avaliable in this data set. In order to distinguish the size effect from productivity, we include total employment as the measure of size in the regression. Size is also an indicator for firms' capabilities to overcome investment barriers since large firms have more resources or access to more resources to invest abroad.

Dunning (1981) presumes that a firm's FDI decision is based on organization advantages, location advantages and internalization advantages (OLI). According to Dunning's OLI framework for a firm's incentives to undertake FDI, a firm's intangible assets, such as technology capabilities, product quality and reputation can support a multinational to outweigh the disadvantages of operating abroad. R&D intensity is a common indicator of firms' capabilities.[19] In contrast to R&D, which

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[19] Yeaple (2005) uses R&D intensity as a measure of firm productivity and Brainard (1997)

can be considered an input of technological knowledge, innovation is a knowledge output that might be produced by interaction with a firm's customers or suppliers. Criscuolo et al. (2005) find that globally engaged firms in the UK innovate more, not only by hiring more researchers but by learning more through their international activities. We use both R&D intensity and innovation as proxies for a firm's technology capabilities in the empirical model.

Firms' expenditures on their technology purchases are also an important source of acquiring technology from DCs. Firms in LDCs typically lack enough knowledge of production of high-technology goods. In order to upgrade their products, firms in LDCs rely on technology imports from the technology frontier countries. Bassan and Fikkert (1996) find higher returns on productivity to technology purchasing than to firms' own R&D in India. Therefore, in addition to firms' own investments on R&D and innovation, we will include technology purchasing as a proxy for firms' capabilities.

2.6 Empirical Results

In this section, we report the estimation results. Product substitutability and fixed investment costs tend to differ across industries. To ensure comparability across firms, we estimate the location decision model separately for the computer and telecommunications equipment sector and the electronic parts and components sector within the electronics industry[20].

The results of the model are reported in Table 2.4. The constant represents the fixed costs of the various destinations of outward FDI, conditional on all firm

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uses it as a proxy for the internalization advantage.

[20] Syverson (2004) shows that product substitutability is negatively correlated with within-industry productivity dispersion and median productivity. More competitive industries (in the sense of high substitutability across products) have higher truncated productivity distribution.

characteristics, Z_i. The negative constant terms point out the barriers of conducting FDI relative to non-FDI in a particular destination. The absolute values on the scale of the constant terms are highest for firms investing in both countries, median for firms investing in the U.S., and smallest for firms investing in China. This ordering implies that the fixed investment costs are higher in the U.S. than in China. These lower fixed costs may be the result of China and Taiwan sharing the same language and culture and the close physical proximity to each other. In addition, special economic zones and tax incentives offered by the Chinese government to foreign investors lower the fixed costs of investing in China relative to the U.S.

The coefficients of MNL model in equation (2.10) show the effect of each variable on the likelihood of a firm belonging to that group relative to the base group (non-FDI). As the log-odds ratio of any two choices is given by $\log[\frac{P_j}{P_k}] = (\alpha_j - \alpha_k) + (\beta_j - \beta_k)Z_i$, the difference in the coefficients of each variable across type HSS, HNH and HNS in equation (2.10) indicates the relative importance of each variable in each strategy.

The positive and significant coefficients of labor productivity indicate that high productivity increases the likelihood of a firm engaging in FDI, even after controlling for firm sizes. In the computer and telecommunications equipment industry, increases in labor productivity have the largest impact on the probability that a firm chooses to build a plant in both China and the U.S., and the smallest effect for a firm investing only in China. Similar results are obtained for the variable representing firm size. This is consistent with other empirical research showing that large firms are more capable of overcoming any disadvantage of operating abroad.

In the parts and components industry, the coefficients on labor productivity are lowest for firms investing in China and highest for firms investing only in the U.S. This result appears to be inconsistent with the theoretical prediction that the highest coefficient should be for firms investing in both the U.S. and China. One explanation may be related to the product diversity within the parts and components industry and the various product mix for firms investing in different countries. Bernard et al. (2005) emphasize the different production techniques of products even within a narrowly defined industry such that firms differing in productivity will endogenously self-select into various products. Table 2.5 presents the product choice distributions for different investment types.[21] Figure 2.5 presents a box plot of productivity for products within the electronic parts and components industry. The full range of the box represents the inter-quartile range of labor productivity and the vertical line within the box is the median value of labor productivity for each product category. Overall, semi-conductors are more productive than passive component and power supplies. Given that firms investing in the U.S. and China concentrate on semi-conductors and passive component, respectively, the high contribution of labor productivity to the likelihood of firms investing in the U.S. may be explained by this additional source of heterogeneity within the industry.

The coefficients on R&D intensity for firms investing in the U.S. and in both countries are positive and significant in both industries. These coefficients are greater for firms investing in both the U.S. and China relative to those investing only in the U.S. The coefficient for investing in China is negative but not statistically significant. The coefficient on the R&D variables possibly captures the technology-seeking incentives for Taiwanese multinationals in general. Products

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[21] Product information is unavailable for about 4.6% of firms in the parts and components industry.

which are produced in the U.S. are of higher-quality and more technologically sophisticated. In order to exploit external knowledge, multinationals operating in the U.S., build absorptive capacity through investing in R&D. Fosfuri and Motta (1999) show that foreign investments are used by laggard firms to acquire knowledge from the technology frontiers if knowledge spillovers are intra-national. In contrast to the results for the R&D intensity, the coefficients on technology purchasing is negative but not statistically significantly.

Technology innovation dummies are positive but only significant for FDI firms investing in the U.S. in the computer and telecommunications industry and investing in both China and the U.S. in the parts and components industry. The rapid upgrading rate and the high competition in the U.S. computer market raise the fixed cost of investing in that market. As with other proxies for firms' efficiency, the contribution of innovation is highest for firms investing in both countries in the parts and components industry.

Overall, our results provide empirical support for the theoretical predictions relating productivity and country and industry characteristics. The least productive firms do not invest abroad. Those that invest in multiple countries (China and the U.S.) are the most productive ones. This pattern is consistent with theoretical model in which fixed costs play a key role in firms production choice of location in the international market, where these fixed costs are high (the U.S.), only the more productive firms will invest in that market leaving less productive firms choosing to invest in China, where fixed costs are significantly lower.

2.7 Conclusion

Over the last two decades, outward FDI from NIEs has grown at a much more rapid pace than that in developed countries. In the 1990s, the share of the world FDI outflows from NIEs doubled (from less than 5% to 10% before the 1997 financial crisis). We use a micro-data set from Taiwan in 2000 to understand the firms' location choices.

This chapter examines the link between firm-level heterogeneity and investment location choices in the Taiwanese electronics industry. The traditional pure horizontal and vertical FDI theory cannot explain the actual, often complex pattern of FDI. Using a three-country model with different production costs, we analyze the different motivations for Taiwanese multinational firms investing in different locations.

The theoretical model in our chapter predicts that heterogeneous firms in the middle-income country (in our case, Taiwan) choose their production sites for serving three countries, namely, Taiwan, the U.S. and China. Firms serve each market by either producing in its foreign subsidiary or through exports. Firms engaging in FDI must incur fixed investment costs of building a plant in the foreign market, while exporting firms incur transportation costs. Due to the fixed investment costs involved in FDI, the theoretical model predicts that the least productive firms tend to serve the foreign markets through exporting from domestic plants. The most efficient firms, on the other hand, will incur the fixed costs associated with setting up a foreign subsidiary. As long as fixed investment costs in the South are less than in the North, Taiwanese multinational firms investing in the North will likely have higher productivity than firms investing in the South. The empirical model consists of a discrete choice specification with the elements of firm characteristics.

We use a multinomial logit model to test a firm's decisions on staying at Home, going abroad into the U.S., China or both the U.S. and China.

The findings indicate that the choice of production site is linked closely to firm productivity. More productive firms are more likely to undertake overseas investments. The rankings of productivity levels among FDI firms depend on the scale of the fixed investment costs. Our results of the scale of constant terms indicate the fixed investment costs for Taiwanese multinationals are higher in the U.S. than in China. After controlling for firm size, R&D intensity and other proxies for technological acquirement, the relatively more important role of labor productivity on firms investing in the U.S. relative to those investing in China support the theoretical prediction on the relationship between the fixed investment costs and firm productivity[22]. Moreover, the highest fixed investment costs for investing in both the U.S. and China means that only those firms with the highest productivity will engage in production activities there.

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[22] In the theoretical model, the market size in South is small, under the ranking of fixed investment costs: $f_n + f_s > f_n > f_s$, to support all four types (HHH, HSS, HNH and HNS) coexist. According to The World Factbook 2000 (CIA), GDP per capita is \$33,900 in the U.S. and \$3,800 in China, which is consistent with the small South market size model.

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Table 2.1. Distribution of Sales by Taiwanese Affiliates (%), by Destination Country (2003)

Host Country	Firms (Number)	Back to Taiwan	Local Sales	Export to Third Country
U.S.	43	9.74	73.09	17.16
Europe	2	11	56	33
Japan	2	26.50	13	60.50
Singapore	3	33.33	55	11.67
China	1172	17.59	47.27	35.14
Hong Kong	26	13.85	40.96	45.19
Thailand	13	13.38	37.92	43.69
Malaysia	16	18.19	32.25	49.56
Indonesia	3	16.67	15	68.33
Vietnam	14	5.36	52.50	42.14
Philippines	3	11.23	2	86.67

Source: Manufacturing Outward FDI Survey, the Ministry of Economic Affairs (2003)

Table 2.2. Average Export-, FDI-GNP ratio, FDI/Export in Taiwan

Period	Export/GNP	FDI/GNP	FDI/Export
1981 - 1985	0.4808	0.0004	0.0008
1986 - 1990	0.4717	0.0038	0.0088
1991 - 1995	0.4356	0.0112	0.0257
1996 - 2000	0.4995	0.0194	0.0386

Source: Investment Comission, MOEA and Taiwan Statistical Data Book, Council for Economic Planning and Development.

Table 2.3. Descriptive Statistics of Electronics Firms, by Investment Location

Firm Characteristics	Domestic	Investment Location Choice			
		non-FDI (Exporter)	China	U.S.	Both
Firms	2459	1188	204	75	25
Labor Productivity	-.249	0.295	0.451	0.798	0.696
Size	2.685	3.714	4.320	5.119	5.245
R&D Intensity	0.009	0.027	0.024	0.061	0.075
Tech. Purchasing Participation (%)	1.5	8.4	9.3	36	32
Innovation (%)	6.9	23.06	33.3	61.3	68

Table 2.4. Multinomial Logit Results of Investment Location Choice

Computer & Telecommunications Equipment				Parts & Components		
Independent Variable	China	U.S.	Both Countries	China	U.S.	Both Countries
Constant	-4.321	-6.653	-8.080	-2.832	-7.062	-9.851
	(0.483)***	(0.779)***	(1.226)***	(0.322)***	(0.795)***	(1.984)***
Labor Productivity	0.137	0.361	0.586	0.224	0.901	0.786
	(0.153)	(0.216)*	(0.306)*	(0.116)*	(0.202)***	(0.459)*
Size	0.589	0.780	0.875	0.253	0.670	0.717
	(0.112)***	(0.158)***	(0.236)***	(0.076)***	(0.143)***	(0.313)**
R&D Intensity	-1.363	4.010	4.873	-0.298	3.305	4.049
	(2.001)	(1.39)***	(2.05)**	(1.89)	(2.49)**	(3.51)**
Tech. Purchase	-0.065	-0.012	0.008	-0.020	-0.0002	-0.008
	(0.051)	(0.021)	(0.008)	(0.013)	(0.0005)	(0.012)
Innovation	0.358	1.169	0.684	0.268	0.540	2.299
	(0.281)	(0.367)***	(0.548)	(0.230)	(0.411)	(1.120)**
Observation	74	40	16	130	34	7
Sample	603			884		
Log-likelihood	-378.516			-496.572		

Standard errors in parentheses

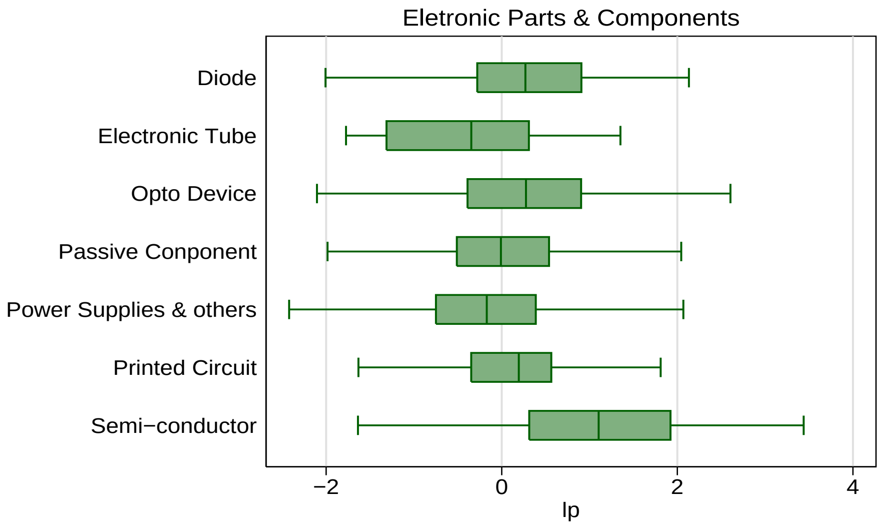
* Significant at 10%; ** Significant at 5%; *** Significant at 1%

Table 2.5. Product Distribution, Parts & Components Industry

Product	non-FDI	China	U.S.	Both
Diode	28	5	1	1
Electronic Tube	2	2		
Opto Device	51	11	4	
Passive Component	262	57	1	
Power Supplies & others	267	39	13	2
Printed Circuit	85	18		2
Semi-conductors	59	3	25	1
Total	754	135	44	6

Notes: Each cell reports the number of firms producing that product by investment types. Multi-product firms will appear in multiple columns. The product is defined by 4-digit SIC.

Figure 2.5. Productivity Distribution by Product



Note: The full range of the box represents the inter−quartile range of productivity.
The vertical line within the box is the median value of productivity.

Chapter 3

Multi-product Plants in the Taiwanese Electronics Sector

3.1 Introduction

The importance of multi-product firms is recently documented by Bernard, Redding and Schott's (2005) research on the U.S. manufacturing sector where multi-product firms account for 41% of the total number of firms but a much greater fraction (91%) of total output. In the Taiwanese electronics sector, multi-product plants make up only 9% of the total number of plants but 40% of total market output[1]. Despite playing such a significant role in total output, research into the more complex strategies of multi-product plant relative to single-product ones has been inadequate.

By using a unique product-level panel data set of Taiwanese plants, this chapter investigates the product choices of multi-product plants in the Taiwanese electron-

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[1] These numbers are sensitive to the definition of products. We define a product by 4-digit SIC in the context. If we use 7-digit SIC as a product, then multi-product plants (15% of total plants) accounted for 57% of total market output. Similarly, 10% out of total plants contributed 44% of total output by using 5-digit SIC as a product.

ics sector during the 1990s. The first objective of this chapter is to examine whether multi-product plants enjoy a cost advantage from joint production by estimating a cost function at the plant level and using the cost function parameters to obtain a measure of the degree of scope economies.

The second objective is associated with plants' dynamic changes in the composition of their product mix under increased international competition. Beginning in the late 1980s, government policies in Taiwan encouraged Taiwanese firms to invest in low-wage countries. At the same time, other Asian countries, particularly China, attracted the bulk of all foreign investment inflows into the region as a result of their own globalization policies. Increased foreign competition caused firms in Taiwan to restructure their operating activities. There has been a profusion of empirical work in the industrial organization field on the reallocation of resources that has occurred within an industry through entry, exit and the expansion or contraction for continuing firms[2]. Most of the literature treats a firm as a single-product unit and ignores the extensive adjustments undertaken by firms in adding or dropping product lines in order to survive. This intra-plant reallocation by a multi-product firm may be another source of increases in firm-level productivity. In sum, the second objective of this chapter is to focus on how multi-product plants select their product mix over time in the context of more intense international competition.

Our findings suggest that, on average, there are no scope economies from joint production for multi-product plants in the Taiwanese electronics sector. In addition, we find trends of specialization in the Taiwanese electronics sector over the

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[2] For example, Aw et al. (2001) for Taiwan, Disney et al. (2003) for the U.K. and Pavcnik (2002) for Chile. Greenaway et al. (2005) and Breinlich (2005) study another channel for firms to restructure after globalization through mergers and acquisitions (M&A) but still treat firms as single-product units.

1990s; multi-product plants manufacturing “unrelated” products are more likely to specialize in a few “core” products. By looking at multi-product plants’ product mixes closely, we find that multi-product plants tend to drop products that are technologically far from their core products.

This chapter has two main contributions. Using the unique product-level data set, we estimate the degree of scope economies for Taiwanese electronics multi-product plants. Second, instead of using product-specific measures as is typical in other empirical work in literature, we construct a plant-product level dissimilarity index. More specifically, two plants producing identical products but with different production technologies will have a different dissimilarity index. This index is then used to examine how multi-product plants choose their product mix.

The remainder of this chapter is organized as follows. Section 3.2 reviews the literature related to multi-product firms’ product choices. Section 3.3 describes the data we use in this chapter. Section 3.4 shows the frequencies of each pair of products co-produced by multi-product plants. Section 3.5 estimates cost functions and then calculates the degree of scope economies. Section 3.6 constructs the measurement of relatedness across products within a multi-product plant and provides empirical specifications for the pattern of restructure for multi-product plants. Section 3.7 summarizes our findings.

3.2 Literature Review

There are many theories on why firms undertake product diversification. The resource view of Penrose (1959) points out that firms diversify if they have excess capacity in production factors. Baumol et al. (1982) introduce the concept of economies of scope whereby the cost of producing a set of products jointly is less than the cost of producing the same products separately. A general source of economies of scope is the joint utilization of inputs: for example, it is less costly to produce hides and beef from the same set of cattle than from two sets of cattle, one group providing only hides and the other providing only beef. In addition to common physical inputs, intangible assets such as knowledge and research and development (R&D) are sources of economies of scope. Jovanovic (1993) offers evidence of cross-product spillovers in R&D within a firm, which supports the idea that public inputs offer an advantage in producing multiple products. More recently, Bernard, Redding and Schott (2006a) show that products in the same sectors or in related sectors are more likely to be co-produced. The uneven likelihood of co-production pattern implies that there may be cost complementarities between some products. By contrast with a Pearson χ^2 statistical test that Bernard, Redding and Schott (2006a) used to show the possible complementarities between some products, we directly calculate the degree of scope economies based on Baumol et al. (1982).

In addition to the co-production patterns of multi-product firms, Bernard, Redding and Schott also find high frequency of product-switching in U.S. manufacturing industries. On average, two-thirds of U.S. manufacturing firms altered their product mix during the five-year interval 1972 to 1997 and product additions and deletions contributed considerable influence on the change of total manufacturing output[3]. Besides the U.S., Baldwin and Gu (2005) show that Canadian firms became more specialized after the formation of the Free Trade Agreement (FTA) between the U.S. and Canada.

A number of recent studies explore trends of specialization after globalization. Baldwin and Gu (2005) propose a model in which reduction of trade costs decreases

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[3] They show that the gross product additions increased aggregate output by 189% and gross deletions reduced it by 170%.

firms' product lines. Unlike a single-product firm model, Baldwin and Gu's model allows cannibalization effects across the set of products within a multi-product firm under monopolistic competition. In their model, firms differ in their production costs, which are symmetric for each variety within a multi-product firm. There is a sunk cost for entering the industry and this cost is independent of the number of products a firm chooses. A fixed cost is incurred for each variety produced. Firms with production costs below a threshold value are able to earn positive profits and survive in the industry. A firm exporting its output incurs a transportation cost. Falling transportation costs reduces the threshold value for survival, and encourages more entry and competition which in turn causes less productive firms to exit. In addition, the increased competition decreases firms' product portfolio. Baldwin and Gu's model with symmetric production technologies within a multi-product firm offers a simple framework to explain specialization across Canadian plants after tariff reduction.

However, in practice, a multi-product firm may have different production technologies for each of its products. Teece et al. (1994) and Eaton and Schmitt[4] (1994) introduce the concept of core competence, whereby each multi-product firm has a core product in the sense of having a large cost advantage relative to other products manufactured by the firm. The costs of these peripheral products of a firm are measured in terms of the technological distance from its core product. If the production inputs or knowledge for manufacturing product i can support the production of output j, then products i and j have lower production technological distance.

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[4] Eaton and Schmitt (1994) provide a idea of flexible manufacturing, in that firms develop the ability to produce a basic product. Each product for a firm is described by some firm-level technological characteristics; the cost of expanding the production process to another variety depends on the characteristics distance of the new product from the basic product.

Bernard, Redding and Schott (2006b) introduce a model which captures asymmetric production costs for each variety within a multi-product firm. In their model, firms are heterogeneous in two dimensions: managerial ability which varies across firms and product expertise varying across products for a firm with a particular managerial ability. Managerial ability (φ) and product expertise of product i (λ_i) are drawn from two independent distributions, $g(\varphi)$ and $z(\lambda)$. After firms pay the sunk entry costs, they observe their draws of φ and λ_i and decide whether they will stay in the industry and the range of products they will produce. There is a fixed headquarters cost, f_h (f_{hx} for exporting) which is independent of the number of products and the fixed production cost, f_p (f_x for exporting products) for each product[5]. The productivity of each product of a firm with managerial ability, φ is represented by $\varphi\lambda_i$. This interaction between φ and λ_i implies that a high-managerial-ability firm can be active in product market i even if this firm gets a bad shock on its product expertise (λ_i). Greater managerial ability also allows firms to sell more in a given market. As a result, higher-managerial-ability firms have both larger intensive margin (sell more of a given product) and extensive margin (manufacture more products).

A reduction in variable trade costs encourages higher-managerial-ability domestic firms to export, and current exporters to expand their exports sales of each exporting product and to export new varieties (those with higher product expertise and selling domestically before). The higher profitability in export markets induces more entry and hence raises the competition in the industry. This competitive pressure forces lower-managerial-ability domestic firms to exit and the survivors to contract their domestic sales of each product and drop the low-product-expertise

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[5] Combining with zero profit and free entry conditions, the fixed headquarters cost will determine the cutoff value of φ (φ_x for exporters) and fixed production cost will decide the cutoff value of λ (λ_x for exporting products) for a given managerial ability, φ (φ_x).

products (focus on their core competence). Instead of independent demand across product markets, Eckel and Neary (2006) combine the concepts of core competence in the supply side and cannibalization effects in the demand side and show an inverse relation between competition intensity and firms' product ranges; if competition falls as a result of a fall in the level of product substitution, then multi-product firms are able to broaden their product range.

The empirical evidence in the literature suggests that multi-product firms adjust their product portfolio in response to changes in competitiveness such as that triggered by a tariff reduction. Greater competitive pressure from an increase in the number of potential competitors drives multi-product firms to reduce their product diversification and refocus on their core business in order to achieve a more efficient use of their resources. Bernard, Jensen and Schott (2006) offer evidence that U.S. multi-product firms adjust their product mix away from industries highly exposed to competition from low-wage countries and towards industries with a small fraction of imports from low-wage countries. In addition to the environmental shocks, Bernard, Redding and Schott (2006a) find that the firm-product variables such as relative product sales and tenure in the product market are important determinants for firms' exit decisions in each of their operating markets. Their findings support Teece et al.'s (1994) concept of core competence.

Focusing more specifically on the role of core competence, Liu (2006) shows that a rise in import competition forces firms to decrease the number of their peripheral products and refocus on their core products. Using data from U.S. multi-product plants over the period 1984-1996, Liu finds that resources shift between the core and periphery depending on the degree of complementarity between the core and peripheral products. Rondi and Vannoni (2005) use 108 diversified EU manufacturing leaders to show that EU firms responded to economic integration by expanding the output of industries around a core of related activities. They show that highly diversified firms increase the relatedness of their product spectrum in order to react to competitive pressure. Brown and Wiersema (2005) provide evidence that U.S. firms respond to increasing foreign competition in their core business by increasing the relatedness of their portfolio.

While asymmetric production technologies within a firm are addressed by recent research, some researchers have focused on the measure of the relatedness of items in their product portfolio as well as the relationship between firms' performance and their diversification level. For example, Robins and Wiersema (1995) introduce a relatedness index which captures the linkage to production knowledge of each variety a plant manufactures by using industry R&D flows between major groups of industries. They find a positive relationship between a firm's relatedness index and the firm's performance. Fan and Lang (2000) develop two measures, based on input-output tables (IO tables), to capture vertical relatedness and complementarity. They show that complementarity is associated with better firms' performance but vertical relatedness is, on average, associated with poor performance.

However, all of the above measures of relatedness used ignore firm heterogeneity. In this chapter, we construct a plant-product dissimilarity index which accounts for plant heterogeneity and then examine its influences on multi-product plants' product choice strategies. We find, after controlling for plant characteristics, that multi-product plants are more likely to drop peripheral products with higher measures of dissimilarity index.

3.3 Data Description

The data we use is derived from an annual survey conducted by the Ministry of Economic Affairs (MOEA) in Taiwan over the period 1992 to 1999[6]. A plant registered with the MOEA reports its operation information such as employment, expenditures on labor, material and energy, total revenue and the sales value of each product it produces. The MOEA separates these variables into a plant-level data set and a product-level data set. The plant-level data set includes all input usage variables and plants' total revenue, and the product-level data set reports the sales value of each product within a plant. The MOEA assigns the same identification number to each plant in both data sets so we can link a plant's product-level outputs to its factor usage accurately.

Each product is categorized into a 7-digit Standard Industrial Classification (SIC). Our definitions of industries and products are based on 1990 SIC categories[7]. We refer to 3-digit SIC numbers as industries and 4-digit SIC numbers as products in the empirical analysis. We are interested in four industries within the electronics sector: Computer & Data Storage (SIC 314), Consumer Electronics (SIC 315), Telecommunications Equipment (SIC 316) and Parts & Components (SIC 317) industries. Table 3.1 provides our definitions of products within each 3-digit industry[8]. Based on our product definition, there are five products in the

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[6] Our empirical analysis uses data from 1992, 1993, 1995, 1997, 1998 and 1999. The data set is poor in 1994 because many plants did not report their product-level information. 1996 is the Census year and the MOEA skips this survey in Census years. The Directorate General of Budget, Accounting and Statistics (DGBAS) records the population of plants in the manufacturing industry every five years. Plants in the Survey data and Census data are designated by different identification numbers, so we cannot combine these two data sets.

[7] The SIC categories were revised in 1996 and we converted 1996 SIC numbers into 1991 SIC categories to avoid confusion.

[8] We did not include plants producing SIC= 3142 (hard disk and floppy disk) and SIC= 3151 (TV and Video) because most of them are single-product plants. Including these products would raise the dimension of the cost function we need to estimate, but would create many empty sets for co-production pairs. Excluding them reduces only by around 2.8% the number of plants in

Computer & Data Storage industry, three products in the Consumer Electronics industry, four products in the Telecommunications Equipment industry and five products in the Parts & Components industry[9].

We use the plant as the business unit in the empirical analysis since plants are the most disaggregate unit in the plant-level data set[10]. It should be noted that some multi-product plants did not report commodity data for all their products. Therefore, product-level data may not be complete. Since we will be estimating the cost function, and all expenditures on input usages are reported at the plant-level, we would like to retain in our data set only those plants having complete commodity reports. To address this problem, we compare a plant's total revenue with the sum of sales for all its products in a given year. Total revenue is composed of total sales and other operating revenues. In the absence of total sales in plant-level data, we set 0.9 times total revenue (TR) as a threshold value[11] to distinguish between plants having complete and incomplete commodity information. A plant whose total sales from its product-level data is more than or equal to $(0.9 * \mathrm{TR})$ is considered to have complete commodity reporting; plants with total sales below the threshold value were dropped from the sample in this chapter. This criterion eliminated 20 % of plants.

Given our focus on the extent of multi-product plants within a narrowly defined industry, we drop from our data set those plants that are active in multiple industries. More than 95% of multi-product plants are specialized within a 3-digit

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Computer & Data Storage and 1.9% of plants in Consumers Electronics.

[9] Based on the SIC categories, there are seventy-two 7-digit products and twelve 5-digit products in the Computer & Data Storage industry, fifty-seven 7-digit and six 5-digit products in the Consumer Electronics industry, fifty-five 7-digit and seven 5-digit products in the Telecommunications Equipment industry, and seventy-five 7-digit and seven 5-digit products in the Parts & Components industry.

[10] 95% of firms in the Taiwanese electronics sector have only one plant.

[11] According to the Census publication reporting, the total sales-revenue ratio is around 0.9 in the Taiwanese electronics sector.

industry over the sample years.

Table 3.2 presents some mean characteristics of single- and multi-product plants in the four main industries from 1992 to 1999. Multi-product plants comprise a small fraction of the sample; from 2.9% in the Parts & Components industry to 8% in the Computer & Data Storage industry. The mean number of products for multi-product plants is less than three.

Multi-product plants are larger than single product plants in terms of both product sales and employment. On average, multi-product plants in the Computer & Data Storage and Parts & Components industries employ four times more workers than their single-product counterparts. Table 3.3 disaggregates plants into three different size categories: small if total employment is twenty or fewer, medium if total employment is between twenty-one and 100, and large if total employment is over 100. We report the share of multi-product plants in each size category. The fraction of multi-product plants increases as the size categories change from small to large, with the largest increase occurring between the medium and large categories. Multi-product plants are also older, more productive, more capital-intensive and more R&D-intensive than their single-product counterparts.

The higher per-product sales and larger size of multi-product plants relative to single-product plants imply that multi-product plants are likely to benefit from economies of scale in production. To diversify into a new market plants may need to pay an extra fixed cost, so that only more-productive plants are likely to do so. Jovanovic (1993) offers evidence that diversified firms are able to capture knowledge spillovers between different varieties in production. Aw and Batra (1998) use semi-parametric regression estimates to show the positive relationship between firm diversification index and firm size as well as the contribution of technology spillovers to multi-product firms in the Taiwanese electrical and electronics sector.

Although not as numerous as single-product plants, multi-product plants provide significant value of sales in each industry. Figure 3.1 shows the percentage of multi-product plants in each industry from 1992 to 1999. Figure 3.2 shows the output share within each industry contributed by multi-product plants from 1992 to 1999. Taken together, Figures 3.1 and 3.2 reveal that a significant share of industry output is produced by multi-product plants. In the Computer & Data Storage industry the output share of multi-product plants was from 30% to 50% even though they accounted for less than 10% of the sample of plants from 1992 to 1999. In the Parts & Components industry, on average, 22% of the industry output was contributed by 2.9% of total plants.

The important role of multi-product plants in production value within an industry triggers our interest in exploring their behavior. We first examine if there exist economies of scope from joint production in Section 3.5 and then investigate how multi-product plants survive under increased international competition during the 1990s through restructuring their product mix in Section 3.6.

3.4 Product Co-production

In this section we examine if all products are equally likely to be co-produced by multi-product plants. Following Bernard, Redding and Schott (2006a) we use a Pearson χ^2 test to show that the frequency of co-production pairs is not randomly distributed.

Table 3.4 summarizes product pairs by multi-product plants within the Computer & Data Storage industry in the pooled data sets during the sample period. In every off-diagonal cell we report the observed number of plants that co-produce each pair of products. A plant is counted in a cell if it produces both the row and column products. A three-product plant will appear in two cells in a given year. For example, a plant producing products 1, 2 and 3 in 1992 and products 1 and 2 in 1993 will be counted twice in the cell (product 1, product 2) and once in the cells (product 1, product 3) and (product 2, product3). Tables 3.5 through 3.7 show the co-production pairs for the Consumer Electronics, the Telecommunications Equipment and the Parts & Components industries, respectively.

Some product combinations show relatively high frequencies. For example, in the Computer & Data Storage industry, seventy-five plants co-manufacture products 3 and 4, while twenty-three plants produce products 2 and 5 together. We use a statistical test to determine whether some product pairs are more commonly produced than other pairs. We use a Pearson χ^2 test to compare the observed number of plants to the expected number of plants in each cell under the null hypothesis that the decisions of products to be produced are independent. We discuss the Pearson χ^2 test in detail in Appendix B.

We report the expected number of plants in parentheses in each cell. The Pearson statistics for testing whether the frequencies of the entire matrix are generated randomly is expressed as

$$X = \sum_{i\,j} \frac{[O_{ij} - E_{ij}]^2}{E_{ij}} \tag{3.1}$$

where O_{ij} is the observed frequency in the cell (i,j), i.e., row i and column j, and E_{ij} is the expected frequency calculated as explained in Appendix B. The Pearson χ^2 test compares this statistic X with a χ^2 distribution with $(j-1)(i-1)$ degrees of freedom[12] and the results reject the null hypothesis that the decisions of products

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[12] According to Bernard, Redding and Schott, the degrees of freedom are ($\frac{(j-1)(i-1)}{2}$ − number of missing cells) for the symmetric matrix. We use χ^2 statistics with three degrees of freedom for the Computer & Data Storage and Parts & Components industries, and one degrees of freedom for the Consumer Electronics and Telecommunications Equipment industries. The Pearson statistics are 97.146 for the Computer & Data Storage industry, 68.3 for the Consumer Electronics industry, 40.771 for the Telecommunications Equipment industry, and 289.867 for

to be produced are independent.

Under the null hypothesis, the expected frequencies follow an independent multinomial distribution. We use the following statistics to test if there is significant difference between observed frequency and expected frequency in each cell based on the property that $\frac{O_{ij}-E_{ij}}{\sqrt{O_{ij}}} \sim N(0,1)$. If we take the combination of products 1 and 3 in the Computer & Data Storage industry as an example, we calculate the statistics for the product pair (product 1, product 3) by $\frac{58-43.9}{\sqrt{43.9}} = 2.16$ which is significant at a 5% significance level. Cells shaded light gray indicate that the observed number of plants is significantly different from the expected number. For example, products 1 and 2 are more commonly produced together and products 2 and 3 are typically produced in isolation.

This section has examined the non-randomness of co-production pairs for the multi-product plants. The fact that products are unequally likely to be co-produced suggests that there may be demand or supply complementarities across products. Significant proportions of plants having the same pairs in their product mixes observed in the data offers weak evidence of economies of scope from joint production. However, it is difficult to determine whether economies of scope from joint production exist without knowing the production or cost structure. In Section 3.5, we will first estimate the cost function, then investigate if economies of scope exist in joint production by the estimated cost function.

3.5 Cost-Side Incentive

In this section, we first estimate plants' cost functions, and then calculate a measure of the degree of scope economies in order to determine the role of cost

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the Parts & Components industry. The Pearson χ^2 test rejects the hypothesis that each cell is independent under 1% significance level for all these industries.

complementarity as an incentive for producing multiple products.

3.5.1 Cost Function Construction

A plant's total cost can be expressed as a function of its output level and its input prices. If plants are heterogeneous in their productivity levels, then their productivity levels are also a component of the cost function. Assuming that a plant's productivity level is separable from its output level and input prices, we can write its cost function as

$$C(W_{pt}, q_{pt}, A_{pt}) = A_{pt}\ F(q_{pt}, W_{pt}) \tag{3.2}$$

where W_{pt} is a vector of input prices, q_{pt} is the output vector and A_{pt} is the efficiency or inefficiency level of plant p in period t. The cost function is the same for every plant and plant heterogeneity is captured by A_{pt}.

In order to avoid the endogenous problem from the interaction effect between A_{pt} and $F(q_{pt}, W_t)$ where A_{pt} is unobservable, we choose a logarithmic form of the cost equation:

$$lnC_{pt} = lnA_{pt} + ln[F(q_{pt}, W_{pt})] + u_{pt} \tag{3.3}$$

where u_{pt} is the error term and $E(u|q) = 0$, $E(u|A) = 0$, $E(u|W) = 0$.

We define $ln[F(q_{pt}, W_{pt})]$ as a translogarithmic (translog) quadratic form:

$$ln[F(q_{pt}, W_{pt})] = \sum_{i \in M_{pt}} \alpha_i \tilde{q}_i + \sum_{i \in M_{pt}} \beta_{ii} \tilde{q}_i{}^2 + \sum_{i \in M_{pt}} \sum_{\substack{j \in M_{pt} \\ j \neq i}} \beta_{ij} (\tilde{q}_i \tilde{q}_j)$$

$$+\sum_{k}\delta_{W_k}W_{kpt}+\sum_{k}\delta_{WW_k}W_{kpt}^2+\sum_{k}\sum_{i\in M_{pt}}\delta_{W_kq_i}W_{kpt}\tilde{q_i} \qquad (3.4)$$

where M_{pt} is the set of products that plant p offers in year t, $W_{kpt} = ln(W_{kpt})$ represents the log form of input k's price and $\tilde{q_{pt}} = ln(q_{pt})$. Allowing for interaction between the prices of the factors and output renders the cost function more flexible.

The Taiwanese electronics sector is dominated by single-product plants so that many plants in the data set have zero values for some products. $ln(0)$ is undefined, so we assume that[13]

$$\tilde{q} = \begin{cases} ln(q) & \text{if } q > 0, \\ 0 & \text{if } q = 0. \end{cases}$$

Using this data we define a plant's total cost as its annual expenditures on labor, materials, energy, electricity and subcontracting work. We include subcontracting expenses since plants hiring subcontractors will include subcontracting output in their sales value. A plant reports its subcontracting expenditures in two forms in the data set: (1) the combination of the material expenses for its subcontractor and the plant's own usage, and (2) all other expenses which include subcontracting expenses. The sales value of each product includes the plant's own production and the output from its subcontractors. In order to match cost expenditures and output levels, we need to include subcontracting expenses in the total cost.

Since we have only industry-level price deflators for the Computer & Data Storage, Consumer Electronics, and Telecommunications Equipment industries, we define output of a product by deflating the sales value of a product by the common industry-level price index. In the Parts & Components industry we have detailed price deflators for each product. Griliches and Klette (1996) point out

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[13] If the output level is smaller than 1, then $ln(q) < 0$, which is less than that for zero output level in this setting. In our sample, there is no output level which is smaller than one.

that using a common price index for sales values to estimate the cost function will result in a biased estimate. For example, if there is positive correlation between output prices and sales values so that high-quality products sell at high prices, thereby generating more revenue, then the omitted plant-level price index will give us a downward bias on the coefficient of output in the cost function. Given that Taiwanese electronic sector is extremely export-oriented, often performing subcontracting work for their foreign buyers, and lack of their own brand, it is very likely that these plants are price takers in the international market. In this case, the bias from using the common price index may be minimized.

One important component of the cost function is the set of input prices. A plant's cost function is comprised of its expenditures on labor, material, energy, electricity and subcontracting, as well as prices for all these inputs. We calculate the plant-level wage by dividing a plant's total labor expenditures by its total number of paid workers in a given year. We assume that the input markets for material, and electricity are perfectly competitive so that every plant faces the same input prices. Based on this assumption, W_{pt} is decomposed into two parts: plant p's wage level in year t, w_{pt} and a constant term across plants which captures the common input price that plants face. Since input prices are sensitive to supply and demand shocks in the factor markets every year, we allow the common factor price, W_t to vary over time. In order to capture the annual variation of input prices, we add year dummies in the cost function.

Since our capital variable is measured as gross book value of capital, we estimate a short-run cost function. In the short-run, a plant decides its optimal level of input usages based on its current capital stock. We can decompose the total cost into variable cost and fixed cost such that

$$TC(q, W) = VC + FC = VC(W^{var}, q, K) + P_K K \tag{3.5}$$

where W^{var} is the price for variable inputs, K is the fixed input and P_K is the price for capital K.

If plants employ the optimal amount of capital, K^*, it must be the case that $\frac{\partial TC}{\partial K^*} = 0$ which implies that

$$\frac{\partial VC}{\partial K^*} = -P_K < 0$$

This suggests that that costs are minimized in the long-run if the plant chooses a quantity of capital such that the reduction in variable cost resulting from an increase in capital equals the marginal cost of capital, P_K. Hence, we expect that $\frac{\partial lnVC}{\partial lnK} < 0$.

Plant-level productivity A_{pt} can be decomposed into two components: one which is plant-persistent, μ_p, and another which is an transitory exogenous shock faced by each plant every year, ε_{pt}. We can rewrite u_{pt} as $\mu_p + \varepsilon_{pt}$ in the cost function. The estimated short-run cost function is specified as a quadratic log-function,

$$\begin{aligned} c_{pt} = \alpha_0 &+ \sum_{i \in M_{pt}} \alpha_i \tilde{q}_i + \sum_{i \in M_{pt}} \beta_{ii} \tilde{q}_i{}^2 + \sum_{i \in M_{pt}} \sum_{\substack{j \in M_{pt} \\ j \neq i}} \beta_{ij} (\tilde{q}_i \tilde{q}_j) + \delta_k k_{pt} + \sum_{i \in M_{pt}} \delta_{kq_i} k_{pt} \tilde{q}_i \\ &+ \delta_w w_{pt} + \delta_{ww} w_{pt}^2 + \sum_{i \in M_{pt}} \delta_{wq_i} w_{pt} \tilde{q}_i + \delta_{rd} D_{rd} + \sum_{i \in M_{pt}} \delta_{rdq_i} D_{rd} \tilde{q}_i \\ &+ \delta_{rdk} D_{rd} k_{pt} + \delta_{rdw} D_{rd} w_{pt} + D_{year} + \mu_p + \varepsilon_{pt} \end{aligned} \tag{3.6}$$

where $k = lnK$, D_{rd} is a dummy variable equal to 1 if this plant conducts R&D in year t, and D_{year} is year dummies[14].

R&D is a public input for a multi-product plant. Jovanovic (1993) offers evidence of cross-product spillovers in R&D within a firm by estimating a patent-production function that allows complementarities across the firm's knowledge for each of its products. To address this issue we add R&D dummies and interaction terms with output, wage and capital stock. Including the interaction terms allows us to see the effect of R&D on cost elasticity.

μ_p in equation (3.6) captures the time-invariant plant level heterogeneity. It is likely that μ_p is correlated with output or wage level. Baily et al. (1992) use productivity transition matrices to show the persistence of a firm's productivity level. They construct transition matrices that the fraction of plants in the top, second, third and the fourth quintiles in year (t+1) for those that were in the top quintile in their own industry in year t. Baily et al. use data from some U.S. manufacturing industries between 1972 and 1977 to show that plants falling in a productivity quintile in year t are more likely stay in the same quintile in year (t+1). Hopenhayn (1992) and Ericson and Pakes (1995) introduce models in which firms make entry decisions and the optimal output levels after they realize their productivity level. All these models show that a plant's productivity level is correlated with its output level.

Moreover, if the omitted values of input prices are plant-specific and related to other independent variables, such as wages or output level, then these omitted

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[14] In our cost function we did not include k_{pt}^2, $w_{pt}k_{pt}$ and the interaction term between year dummies and output. Including k_{pt}^2 gives us a more serious problem on the sign of $\frac{\partial lnVC}{\partial lnK}$ (we will discuss it Appendix D). $w_{pt}k_{pt}$ is highly correlated to $w_{pt}w_{pt}$, therefore we exclude this interaction term to avoid the collinearity problem (The correlation is around 0.9.). Including the interaction term between year dummies and output did not give us a significantly different result and all the coefficients on these interaction terms are insignificant.

values will be captured by μ_p. For example, large plants, which are generally more productive, also purchase greater amounts of material often at a lower unit price. In general, these plants also pay their employees higher wages. Using simple OLS or random effect panel regression, which assumes that there is no correlation between μ_p and regressors, may give rise to biased estimates. To avoid this problem, we use fixed effect panel estimation[15]. This approach eliminates the time-invariant plant-level heterogeneity by subtracting each plant's mean level of its regressors from the respective regressors during the sample years. In order to use fixed effect regression, we need to drop plants which only appear once during the sample periods. This step eliminated 25% of observations in the Computer & Data Storage industry, 16% of observations in the Consumer Electronics industry, 20% of observations in the Telecommunications Equipment industry and 13% of observations in the Parts & Components industry.

3.5.2 Estimation Results

Tables 3.8-3.11 present the parameter estimates of the cost function for the Computer & Data Storage, Consumer Electronics, Telecommunications Equipment and Parts & Components industries, respectively.

From the translog cost function in equation (3.6), the elasticity of cost with

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[15] We also tried random effect estimation and used a Hausman specification test to compare it with the fixed effect regression. If the time-invariant plant level heterogeneity is correlated to the regressors, the estimated parameters from the random effect regression will be inconsistent but efficient. If this statement is true, there will be systematic difference in the parameters between random and fixed effect model. We test the null hypothesis that the difference of parameters is not systematic and a Hausman specification test rejects the null hypothesis under a 1% level. This suggests that fixed effect regression is better for the cost function estimation.

respect to output q_i can be calculated by

$$\begin{aligned} e_i &= \frac{\partial lnC}{\partial lnq_i} \\ &= \alpha_i + 2\beta_{ii}\tilde{q}_i + \sum_{\substack{j \in M_{pt} \\ j \neq i}} \beta_{ij}\tilde{q}_j + \delta_{kq_i}k + \delta_{wq_i}w + \delta_{rdq_i}D_{rd} \qquad (3.7) \end{aligned}$$

where e_i presents the percentage change in costs if a plant increases its output level of product i by 1 %. β_{ii} is positive and significant in all industries, which indicates that an increase in its own output q_i will raise the elasticity of a plant's cost, e_i[16].

The negative and significant coefficients on the interaction terms between a multi-product plant's output pairs, β_{ij} indicates that raising the amount of another output q_j will decrease a plant's cost sensitivity to q_i. That is, an increase in q_j will shift down the e_i curve[17].

Negative δ_{kq_i} reflects that, conditional on a plant's output levels, large plants (in terms of capital stock) are less sensitive in terms of their cost increment. δ_{wq_i} are negative in the Computer & Data Storage, Consumer Electronics and Parts & Components industries[18]. The negative sign indicates that high-wage plants have lower cost elasticity. If wage acts as a signal of the quality of a plant's labor, then

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[16] Since we use the translog cost equation, $MC_i = e_i \frac{C}{q_i}$ and an increase in q_i raises e_i ($\beta_{ii} > 0$), total costs, C and q_i. The effect of increasing in q_i on MC_i depends on the scale of increments in C and q_i. If we look at the second-order differentiable cost function, $MC_{ii} = \frac{\partial MC_i}{\partial q_i} = \frac{C}{q_i^2}[2\beta_{ii} + e_i(e_i - 1)]$, then it is clear the sign of MC_{ii} is positive, i.e. marginal cost is increasing in its own output level, if $e_i > \frac{1+\sqrt{1-8\beta_{ii}}}{2}$. For example, e_i is the inverse of the degree of return to scale for a single-product plant and if $e_i > 1$, i.e. decreasing return to scale, then MC_i is increasing in q_i.

[17] In order to understand the relationship between MC_i and q_j, we can calculate $MC_{ij} = \frac{\partial MC_i}{\partial q_j} = \frac{C}{q_i q_j}[\beta_{ij} + e_i e_j]$. An increases in q_j will decrease e_i (negative β_{ij}) and raise the total costs, C. The effect of increasing the total costs will depend on the cost sensitivity to increments of q_j (e_j), which affects MC_i through interacting with e_i. Since $\beta_{ij} < 0$ and $e_i > 0 \; \forall i$, the sign of MC_{ij} depends on the scale of the absolute value of β_{ij} and $e_i e_j$.

[18] One exception is δ_{wq_2} in the Computer & Data Storage industry but it is statistically insignificant.

high-quality labor can elevate a plant's productivity, so that its total cost is less sensitive to output increases relative to plants with lower quality workers.

The coefficients on the interaction terms between output and the R&D dummy δ_{rdq_i} are negative and significant in thirteen out of seventeen parameters in all four industries, which indicates that R&D decreases the cost elasticity with respect to output level q_i. By investing in R&D, a plant can improve its production technology and becomes less sensitive to cost increment as it produces more.

Since R&D expenditures are excluded from total costs in the cost equation (3.6), negative δ_{rdq_i} also suggests that multi-product plants that perform R&D enjoy a cost advantage. This supports the idea that R&D is a shared public assets across different products within a multi-product plant.

3.5.3 Scope Economies

Economies of scope for a two-product plant[19] exist if the cost of producing two products jointly is less than the cost of producing the same products separately. That is, if

$$C(q_1, q_2) < C(q_1, 0) + C(0, q_2)$$

where q_1 is the output level of product 1 and q_2 is the output level for product 2.

Baumol et al. (1982) introduce a natural measure of the degree of economies of scope (SC), which is defined as the proportion of the cost saving from joint production:

$$SC = \frac{C(q_1, 0) + C(0, q_2) - C(q_1, q_2)}{C(q_1, q_2)} \tag{3.8}$$

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[19] We report the degree of scope economies for 3-product plants in Appendix E.

Where

$$SC \begin{cases} > 0 & \text{Scope Economies,} \\ < 0 & \text{Scope Diseconomies.} \end{cases}$$

We calculate the index SC from the estimated cost function given by:

$$\begin{aligned} ln\hat{C}(q_1, 0) &= (\alpha_1 \tilde{q_1} + \beta_{11} \tilde{q_1}^2 + \delta_{kq_1} k\tilde{q_1} + \delta_{wq_1} w\tilde{q_1} + \delta_{rdq_1} D_{rd}\tilde{q_1}) \\ &+ (\delta_k k + \delta_w w + \delta_{ww} w^2 + \delta_{rd} D_{rd}) \\ &\equiv A_1 + C \\ ln\hat{C}(0, q_2) &= (\alpha_2 \tilde{q_2} + \beta_{22} \tilde{q_2}^2 + \delta_{kq_2} k\tilde{q_2} + \delta_{wq_2} w\tilde{q_2} + \delta_{rdq_2} D_{rd}\tilde{q_2}) \\ &+ (\delta_k k + \delta_w w + \delta_{ww} w^2 + \delta_{rd} D_{rd}) \\ &\equiv A_2 + C \\ ln\hat{C}(q_1, q_2) &= (\alpha_1 \tilde{q_1} + \beta_{11} \tilde{q_1}^2 + \delta_{kq_1} k\tilde{q_1} + \delta_{wq_1} w\tilde{q_1} + \delta_{rdq_1} D_{rd}\tilde{q_1}) + \beta_{12}\tilde{q_1}\tilde{q_2} \\ &+ (\alpha_2 \tilde{q_2} + \beta_{22} \tilde{q_2}^2 + \delta_{kq_2} k\tilde{q_2} + \delta_{wq_2} w\tilde{q_2} + \delta_{rdq_2} D_{rd}\tilde{q_2}) \\ &+ (\delta_k k + \delta_w w + \delta_{ww} w^2 + \delta_{rd} D_{rd}) \\ &\equiv A_1 + A_2 + B_{12} + C \end{aligned}$$

where $ln\hat{C}(q_i, 0)$ consists of two components: the first, A_i, which is related to q_i and the second, C, which is independent of q_i and associated only with plant characteristics such as w, k and D_{rd}. A two-product plant's cost function incurs an additional interaction term $\beta_{12}\tilde{q_1}\tilde{q_2}$, which is defined as B_{12} in $ln\hat{C}(q_1, q_2)$. The index of scope economies SC is calculated by

$$SC = \frac{\hat{C}(q_1, 0) + \hat{C}(0, q_2) - \hat{C}(q_1, q_2)}{\hat{C}(q_1, q_2)} = \frac{e^{A_1 + C} + e^{A_2 + C} - e^{A_1 + A_2 + B_{12} + C}}{e^{A_1 + A_2 + B_{12} + C}}$$

$$= \frac{e^{A_1} + e^{A_2} - e^{A_1+A_2+B_{12}}}{e^{A_1+A_2+B_{12}}}$$

We calculate SC for every two-product plant in the sample and present the number of plants with scope economies and scope diseconomies in Table 3.12. Every two-product plant is assigned into a type category based on the components of its product mix: a plant producing product 1 and product 2 belongs to type 12. The gray shaded types are those that have significantly high or low frequencies of co-production in Tables 3.4-3.7[20]. Column 2 shows plants with $SC < 0$, i.e. scope diseconomies in joint production, and column 3 shows plants with scope economies ($SC > 0$). Column 4 indicates the share of 2-product plants with scope economies for each type category.

In the Computer & Data Storage industry no plant in type 12, 15 or 24 has scope economies from joint production. Most plants have scope diseconomies from joint production in each type category. The only type with over half of plants with scope economies is type 25, but there are only 2 plants in this category, which is not enough to be representative. Overall, only 28% of 2-product plants enjoy a cost efficiency from joint production in the Computer & Data Storage industry.

In the Consumer Electronics industry plants with scope economies are less than one-fourth in all type categories and only 21% of 2-product plants operate under scope economies. From Table 3.5 we know that types 12 and 23 have significantly high frequencies relative to type 13. Types 12 and 23 are composed of around one-fourth of plants with scope economies in contrast with zero plants with scope

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[20] In Tables 3.4-3.7, we calculated the expected frequencies for each product pairs under the assumption that plants choose their production mixes randomly. If the observed frequency is significantly higher than the expected frequency in one product pair in Tables 3.4-3.7, then plants are more likely to produce these two products together. This implies possible existence of cost complementarities between these two specific products. On the other hand, if the observed frequency is significantly lower than the expected frequency in one product pair in those tables, then producing these two products together may have scope diseconomies.

economies in type 13. This disadvantage of joint production of type 13 may explain the relatively fewer plants producing products 1 and 3 together.

Plants with scope economies are concentrated in type 35 in the Parts & Components industry, even if over half (61%) of plants within this type show scope diseconomies. Type 35 is also with high frequency in Table 3.7 (182 observed plants against 90 expected plants). However, 2-product plants within this industry predominantly (70%) show scope diseconomies.

In contrast to all the above industries, over half of 2-product plants (around 67%) enjoy scope economies in the Telecommunications Equipment industry. In types 12 and 23, approximately two-thirds of plants have a positive SC. Moreover, all type 13 plants enjoy scope economies. This may explain the observed significant portion of co-production of “Switch & Transmission Devices” and “Telephone, Fax and Answer Machines”, and “Telephone, Fax and Answer Machines” and “Wireless Telecommunications Equipment”.

In summary, except for the Telecommunications Equipment industry, the majority of plants in the other industries appear to have diseconomies of scope. One of the practical difficulty in implementing the formula used to measure scope economies is that the cost estimation involves many zero values for some outputs under the current production technology for multi-product plants. Table 3.2 indicates that multi-product plants on average have higher capital-labor ratios than single-product plants, which implies that single-product and multi-product plants adopt different production technologies. Using formula (3.6) to estimate the cost function parameters requires extrapolation to potential observations outside the sample range. Hence, estimates of incremental costs $C(q_1, q_2) - C(q_1, 0)$ can be negative even though this contradicts theory. Over 60% of plants associated with scope economies face this problem. To fix this problem, we utilize the concept of quasi-scope economies which is explained in the next section.

3.5.3.1 Quasi-Scope Economies

In order to avoid the problem arising from using observed multi-product plants to extrapolate the costs of producing a single product, we implement a technique from Humphrey and Pulley (1993) where zero values are replaced by εq_i in the calculation of hypothetical single-product plants.

We calculate quasi-scope economies index (QSC) defined by Humphrey and Pulley[21] (1993) by the formula:

$$QSC = \frac{C[(1-\varepsilon)q_1, \varepsilon q_2] + C[\varepsilon q_1, (1-\varepsilon)q_2] - C(q_1, q_2)}{C(q_1, q_2)} \tag{3.9}$$

where ε is a small number, close to zero, measuring the fraction of non-specialized output produced. When $\varepsilon = 0$, QSC measures coincide with the original scope economies index SC.

We use four values of ε, 0.001, 0.01, 0.05 and 0.1, and report the number of plants with scope economies and the mean value of QSC in Tables 3.13-3.16.

Compared to the original definition of scope economies, the number of plants enjoying the benefit of scope economies falls substantially in all industries even when $\varepsilon = 0.001$. As ε increases to 0.01, there are virtually no plants with scope economies; positive values of QSC, indicating economies of scope, are found only in type 13 ("Switch and Transmission Devices" and "Wireless Telecommunications Equipment") in the Telecommunications Equipment industry. As we increase ε from 0.001 to 0.1, QSC approaches zero with the mean values approaching zero

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[21] In their case, almost all observations are multi-product firms. Zero output potential firms are outside of their sample so they suggest using a quasi-scope economies index to solve the extrapolation problem.

and the standard deviation becoming smaller. Small ε solves the unusual negative incremental cost problem[22]; and the mean values of QSC become more negative when we increase ε from 0 to 0.001. However, the quasi-scope economies index reveals more plants with scope diseconomies in these industries.

It should be noticed that we calculate scope economies based on the short-run cost function, which basically examines whether there exist cost efficiencies of variable production costs from producing different products together rather than producing them separately. There are many other possible factors, not reflected in the data sets, which contribute to the benefit of joint production. For example, knowledge of producing one product may help to produce another products. Products may share a common marketing channel, another source of scope economies.

Moreover, there may be some demand-side incentives for a plant to produce multiple products. For example, a multi-product plant uses its profit from one market to support predatory pricing activities in another market to deter new entrants.

Nevertheless, the absence of evidence of scope economies may be a key explanation for the small fraction of multi-product plants in the Taiwanese electronics sector. From Figure 3.1 we also see that the share of multi-product plants has decreased over time. In Section 3.6, we will explore the trend of specialization in the Taiwanese electronics industry during the 1990s.

3.6 Specialization

Figures 3.1 and 3.2 demonstrates the importance of multi-product plants in the electronics sector over the 1990s. Figure 3.1 plots the fraction of the number of

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[22] The problem of negative incremental costs vanishes in all industries when $\varepsilon = 0.1$.

multi-product plants in each industry and with fractions declining or stagnant in three of the four industries: the Computer & Data Storage, Consumer Electronics and Parts & Components industries. Figure 3.2 presents the total output share of multi-product plants and, except for short spells, the contribution by multi-product plants followed a downward trend since 1992. Taken together, Figures 3.1 and 3.2 suggest that plants within the electronics sector became less diversified during the 1990s.

One possible explanation for the declining share of multi-product plants in Taiwan is the increased competition from other low-wage Asian countries in the international market during the 1990s. Figure 3.3 displays the import- and export-output ratios in the electronics sector. Export-output ratio decreased over the 1990s and import-output ratio increased except between 1995 and 1996[23]. During the same period, Taiwan's foreign direct investment in Southeast Asia and China expanded rapidly as a result of the dismantling of foreign exchange and investment controls by the Taiwanese government. Many Taiwanese firms, attracted by lower costs overseas, moved part or all of their production overseas to serve their foreign and domestic consumers. Figure 3.4 provides more information on the trend in the share of imports by countries of origin. The fraction of imports from high-income countries (the U.S. and Japan) fell over time, while that from low-income countries (China and Association of Southeast Nations (ASEAN)[24]) rose[25]. In the face of

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[23] There were two events which caused Taiwanese Dollars to depreciate during the 1990s. The first one is the military exercises of China in the water around Taiwan in the late 1995, which caused US$7 billions flee from Taiwan. The depreciation may explain the decreases in import-output ratios between 1995 and 1996. The second is the 1997 Asian financial crisis. Comparing with other Asian countries such as South Korea and Southeastern Asian countries, Taiwan had smaller changes in its exchange rate and these Asian countries were important importing origins of Taiwan. Therefore, the effect on imports was insignificant.

[24] ASEAN consists of ten countries: Indonesia, Malaysia, the Philippines, Singapore, Thailand, Brunei Darussalam, Vietnam, Lao People's Democratic Republic, Myanmar and Cambodia.

[25] Imports from those countries accounted for over 70% of global imports in the Taiwanese electronics sector.

more intense competition from these countries, multi-product firms are potentially more likely to respond by restructuring their product lines.

Table 3.17 shows some patterns of specialization of multi-product plants across the four industries in the Taiwanese electronics sector. The second column presents the change in the share of total sales of multi-product plant's primary product between two adjacent years. We focus on plants producing multiple products in both years t and (t+1) and calculate the share of their primary product in their total sales in both years, s_t and s_{t+1}. For example, a two-product plant that sells \$70 of its primary product and \$30 of its second product in year t has $s_t = \frac{70}{(70+30)}$. Positive $(s_{t+1} - s_t)$ indicates that multi-product plants increased concentration on their primary product. We find some variation across industries; the degree of concentration is the highest in the Computer & Data Storage industry and the mean value of $(s_{t+1} - s_t)$ is negative in the Consumer Electronics industry. This may reflect differences in strategies in a growing industry (the Computer & Data Storage) compared to a declining industry (the Consumer Electronics) during the 1990s[26]. We calculate the fraction of number of continuing plants that switch from multi-product to single-product plants in the third column. On average, there are over 25% of multi-product plants in each industry that switched to specializing in a single product. Table 3.17 reveals that overtime a significant fraction of multi-product plants switched to producing a single product and others became specialized in their primary products.

We introduce the concept of core competence by creating a plant-product relatedness measure between plants' core and peripheral products in order to examine

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[26] Table 3.18 reports the total real value of production in each industry in 1991, 1996 and 2001. Within the electronics sector, the output value increased in the Computer & Data Storage, Telecommunications Equipment and Parts & Components industries, but declined in the Consumer Electronics industry.

the restructuring behaviors of multi-product plants in the Taiwanese electronics sector. The rest of this section is organized as follows. First, we construct plants' status in each product market and discuss the relatedness across products within a multi-product plant. Second, we study if multi-product plants diversifying into unrelated products are more likely to drop products. Finally, we test the hypothesis that a multi-product plant reduces its business activities by dropping products unrelated to the plant's core product.

3.6.1 Restructuring within a Multi-product Plant

3.6.1.1 Plant Status

To identify the plants that remain in or drop from each of the product markets we use information from the entire product-level data set before any data cleaning. We define a plant's operating status in each 4-digit product market for two adjacent sample years. A plant is defined as exiting product market i in year t if this plant is active in product market i in the current year t but not in the next sample year $(t + 1)$. A continuing plant operates in both years t and $(t + 1)$. A plant that produces product i in year t but not in year $(t - 1)$ is categorized as an entrant in product market i. We then combine these operating statuses for a plant in each market in the Taiwanese electronics industry within a single year. This definition recognizes a multi-product plant restructuring its operating activities by adding or dropping some of its product lines. Since our interest is in restructuring within a multi-product plant, we first focus on plants diversifying into multiple products in year t and surviving into year (t+1). Then, we include all plants that produce more than one product in the first year of any two consecutive sample years.

3.6.1.2 Relatedness Measure

Researchers classify relatedness between products using the SIC coding system. If two products do not share the same two-, three- or four-digit SIC code, then these two products are defined as unrelated. This SIC-based measure of relatedness has some disadvantages, however. It is a weak indicator of the relationships among products, because it is based on a variety of considerations ranging from similarities in material usages to product-market linkages. Further, SIC classification is discrete and therefore does not measure the degree of relatedness.

Recently, Fan and Lang (2000) developed two relatedness measures: vertical relatedness and complementarity from Input-Output tables (IO tables). Based on their definition, two industries are vertically related if one can employ the other's output as input for its own production or one can offer its output as the other's input. If two industries can procure inputs jointly or share the same marketing and distribution channel, then these two industries are complementary. For each pair of industries, Fan and Lang construct a coefficient a_{ij} that presents the dollar value of industry i required to produce one dollar of industry j's output, and a coefficient b_{kj} that represents the percentage of industry k's output supplied to industry j. The vertical relatedness index between industries i and j, V_{ij}, is defined as the average of $(a_{ij} + a_{ji})$. Complementarity between industries i and j is calculated by the average of $(Corr(a_{ik}, a_{jk}) + Corr(b_{ki}, b_{kj}))$. The index of complementarity captures common linkages between input suppliers and output destinations. Fan and Lang's relatedness indices measure the overlap of input flows or output destination between any industry pair. However, their definition ignores firm heterogeneity of production technology by using industry-wide information in the IO tables.

In contrast with Fan and Lang's industry-wide relatedness measures, Gollop and Monahan (1991) offer a product dissimilarity index, which assesses if a product is relatively similar to or different from other products of a multi-product firm. They define a dissimilarity between products i and k as $\sigma_{ik} = \left(\sum_j \frac{|\omega_{kj}-\omega_{ij}|}{2}\right)^2$, where ω_{kj} is the input share of the j^{th} input in the k^{th} product. This index is based on a Cobb-Douglas production technology $y_k = \Pi_j x_{kj}^{\beta_{kj}}$, where x_{kj} is the amount of the j^{th} input used for the k^{th} product and β_{kj} represents the technology parameter for the j^{th} input. Based on the Cobb-Douglas production technology, the input cost shares w_{kj} serve as estimates of β_{kj}. The dissimilarity index captures the difference of the technology parameter β that relies on the premise that two products requiring the same inputs in nearly identical proportions are likely to be less heterogeneous than two products having dissimilar input requirements. By using the cost information of each product for multi-product firms, Gollop and Monahan's dissimilarity index captures firm-specific production technologies.

In the absence of product-level input usages information, we use the second-order differentiable cost function, MC_{ij}, as a dissimilarity measure for every product pair within a multi-product firm. $MC_{ij} = \frac{\partial MC_i}{\partial q_j}$ indicates the increment on the marginal cost of product i (MC_i) if a multi-product plant increase its production of product j. High values of MC_{ij} indicate that products i and j are more dissimilar in terms of firms' production technologies since the production of product j elevates the production costs of product i. We calculate MC_{ij} from the estimated cost function:

$$MC_{ij} = \frac{\partial MC_i}{\partial q_j} = \frac{\tilde{C}}{q_i q_j}[\beta_{ij} + e_i e_j] \tag{3.10}$$

where $e_i = \frac{\partial lnC}{\partial lnq_i}$ is the cost elasticity with respect to output i and $\tilde{C}$ is the total cost deflated by industry-level intermediate price index.

In order to analyze the impact of these dissimilarities at the level of the plant, it is necessary to create a summary measure of the product mix for individual plants. We construct an index for a multi-product plant to measure the composite dissimilarity of a plant's product mix. We weight MC_{ij} by the sum of output shares $(s_i + s_j)$ for the combination of products i and j and then sum up all combinations within a plant as the total distance index (TDI):

$$TDI_{pt} = \frac{1}{N_{pt} - 1} \sum_{i \in M_{pt}} \sum_{j \in M_{pt}} (s_{it} + s_{jt}) MC_{ijt} \tag{3.11}$$

where s_{it} is the output share of product i within plant p at time t, N_{pt} is the total number of products plant p has and M_{pt} is the set of products for plant p[27]. We weight the dissimilarity index MC_{ij} by its corresponding output shares in order to capture the contribution of each product within each multi-product plant. Each product's output share s_i will appear a total of $(N_{pt} - 1)$ times in these combinations. A plant with more(less) dissimilar product lines will have a higher(lower) TDI. To avoid getting higher TDI for plants producing more varieties, we re-scale the sum of these combinations by $(N_{pt} - 1)$[28].

3.6.2 Plant Type versus Product Exit

Table 3.19 shows the number of multi-product surviving plants that drop or maintain products during the year t and $(t + 1)$ and the mean level of TDI for each group. It is clear that plants in the dropping groups on average have higher TDI relative to plants that maintain the same number of products over time. An issue

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[27] Since MC_{ij} is undefined for a single-product plant, we only can construct this total distance index for multi-product plants.

[28] The concept of this index is similar to Robins and Wiersema's (1995) firm-level measures of portfolio interrelationship.

of interest here is whether plants with high values of TDI are also the ones that are likely to reduce their product lines the most in response to increased competition.

We use a probit regression model to test the hypothesis that plants with greater unrelated product mixes are more likely to reduce product lines. Each plant compares the expected profit of maintaining its product mix, $EV_{Maintain}$, to the expected profit of dropping some products, EV_{Drop}. The probability of dropping products for multi-product plants is a function of plant characteristics Z_{pt}, industry-wide demand or cost shifters X_I and some macro-environmental shocks which are the same across all industries X_t.

$$\pi^* = EV_{Drop} - EV_{Maintain} = Z_{pt}\beta + X_I + X_t + u_{pt} \tag{3.12}$$

$$y^{Drop} = \begin{cases} 1 & \text{if } \pi^* > 0 \\ 0 & \text{otherwise} \end{cases}$$

We construct a sub-sample of plants that survived in both year t and $(t+1)$ and produce at least two products in year t and use a probit regression[29],

$$Pr(Drop^p_{t:t+1}|Survial) = \Phi(Z_{pt}\beta + \alpha_t + \alpha_I) \tag{3.13}$$

where α_t is time dummies and α_I is industry dummies.

Since multi-product plants are few in number in the Taiwanese electronics sector, we pool plants in these four industries together and add industry dummies to control for the industry fixed effect in the following regression models. We propose two specifications of the regression model. In the first specification, we

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[29] We tried a random probit model but did not get any significant difference from pooled probit model. In addition, the proportion of the total variance contributed by the plant-heterogeneity is not significant. Therefore, we use pooled probit model here.

include only TDI in Z_{pt} as the baseline regression and add age and capital in the second specification. TDI indicates the total degree of unrelated diversification for a multi-product plant. Higher TDI indicates a higher level of unrelatedness for a plant's product spectrum.

Age presents the effect of a plant's production experience on its product scope. Mitchell (2000) introduced a Bayesian-learning model which is similar to Jovanovic's (1982) learning model, where a plant's age is an important variable for its scope decision. In Mitchell's model, firms are endowed with an efficiency level θ which is unknown by firms and fixed over time. The firm chooses the scope of the tasks it will undertake at a point in time, learns from that experience, and then chooses a new set of tasks to operate on in the following period. The tasks differ in terms of their most efficient technique and the firm chooses its scope based on the perception of its efficiency level. There is an exogenous shock that affects firms' profitability every year. The exogenous shock and the firm's uncertainty of its true efficiency level affect the firm's profit on each task and hence the firm's choices of tasks to undertake. As the firm becomes older, learning enhances the firm's knowledge about its production technology θ and it therefore becomes less likely to drop products under a bad exogenous shock.

Another important factor for a plant's decision on its product portfolio is its capacity level. We choose capital stock as the proxy for a plant's capacity measure. Different industries may have different capital intensive production technologies so we normalize each plant's capital value to the industry mean value for each year. If there are scale economies for production activities, plants with small capacity are more likely to narrow down their businesses in order to overcome competitive pressure. Moreover, capital also could be a public input which can be shared by different varieties within a plant.

Since we only focus on survivors' behaviors, the coefficients from the estimation may be biased if the factors affecting a plant's survival decision also affect the plant's decision to drop products. Following Heckman's selection model, we estimate a survival equation. That is, a multi-product plant in year t first chooses to exit or continue its production in year (t+1). Conditional on continuing its business activities, this plant chooses to drop products or not. The regression model becomes

$$\begin{aligned} y^{Drop} &= 1(Z_{pt}\beta + X_t + X_I + u_{1pt}) \\ y^{survival} &= 1(\tilde{Z_{pt}}\gamma + X_I + X_t + u_{2pt}) \qquad (3.14) \\ \text{where } \; Corr(u_{1pt}, u_{2pt}) &= \rho \end{aligned}$$

Jovanovic's (1982) learning model specifies that a plant's size and age are important determinants associated with its expected operating profit. Plants will choose to stay in production or shutdown based on these profitability factors, which include size and age. Therefore, we include ln(age) and ln(employment) as $\tilde{Z_{pt}}$ in the survival equation. Year dummies and industry dummies capture the demand and cost shifters which affect a plant's profitability.

We present the regression results in Table 3.20. The coefficients for TDI in all regression models are positive and statistically significant. The positive coefficients on TDI indicate that plants with greater unrelatedness product index are more likely to drop products.

The negative coefficients for ln(age) in the second and third specifications support the learning model although the coefficient is not statistically significant in the third specification. A plant understands its true efficiency value from its production experience, so it is less likely for an old plant to drop products. While capital is an important variable for a plant's scope decision, it plays a statistically insignificant role in the regression equation.

Negative and significant coefficients on ln(age) in the survival equation imply that old plants are more likely to shut down their plants in the Taiwanese electronics sector. This may imply that new plants are protected from failure by their endowment and initial choices to compete in the market, and their initial sources become less adequate to new environment so that older plants are more likely to shut down. Taken together with the impact of age on the product-dropping equation, old plants are more likely to shut down entirely but less likely to adjust their product mix if they choose to continue their operation in the industry. The coefficients on ln(employment) are positive and statistically significant indicating that large plants are more likely to survive in the sector. The size effect on survival decisions is consistent with Jovanovic's (1982) learning model and some empirical literature, such as Bernard and Jensen (2005) for U.S. manufacturing firms.

The unexplained shocks that increase the probability of survival are negatively correlated with the unobservable shocks that lead to dropping products ($\rho = -0.02$). However, the likelihood ratio test cannot reject the hypothesis of independence of the dropping equation and the survival equation. Therefore, the endogenous shutdown decision has a weak effect on a plant's product-dropping decision.

In summary, multi-product plants with high values of TDI (i.e. unrelatedness) are more likely to drop some of their products. Older plants have low probabilities of giving up some of their products conditional on survival, but are more likely to shut down their whole operating activities. An increase in plant size (measured by total employment) raises the probability of surviving, but plant capacity (measured in capital stock) does not play an important role in the adjustment in the plant's product spectrum. These results are consistent with recent empirical research on the relationship between the degree of unrelatedness of diversification and firms' performance. For example, Robins and Wiersema (1995) and Fan and Lang (2000) find negative correlation between unrelated diversification and firm performance.

3.6.3 Product Type versus Product Exit

In addition to analyzing the relationship between the degree of unrelated diversification and the probability of dropping products for a multi-product plant, our data also allows us to examine which product a multi-product plant drops. In this subsection, we test the hypothesis that multi-product plants restructure their business by reallocating resources to concentrate production in their core product. In other words, over time, multi-product plants may drop products that are technologically far from their core product in response to increasing competition in the marketplace.

Multi-product plants decide if they want to continue producing product i or dropping it based on their expected present net value of operating in the product market i. Let π_{ipt} be the net profit of plant p from producing product i in year t, that is, $\pi_{ipt} = TR_{ipt} - [C_{pt}(q_i, q_{-i}) - C_{pt}(0, q_{-i})]$, where TR_{ipt} represents the total revenue for selling product i, $C_{pt}(q_i, q_{-i})$ represents the total costs of producing product i, q_i, and other products, q_{-i}, and $C_{pt}(0, q_{-i})$ represents the total costs without producing product i[30].

A plant's net profit from operating in product market i, $\pi_{ipt}(X_{ipt}, Z_{pt}, X_i, X_t)$, is a function of its production technology of product i, X_{ipt}, which captures the extra

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[30] Here we assume that product markets are independent in the demand side. That is, the price of product i does not affect the price of product j, but we allow the competition across plants within the same product market.

costs of keeping product i rather than dropping it, a set of plant characteristics Z_{pt}, time-invariant demand and cost shocks specific to product market X_i and time-variant macro-environmental shocks X_t. A Herfindahl index (HHI) is used to represent the product market concentration level that a plant faces. HHI is constructed by the sum of squared values of each plant's market share within a product market.

We assume that there is a scrap value, S_{ip} for plant p to exit market i. A plant will exit market i if the expected present net value in market i, $EV_{ip(t+1)} = \sum_{s=(t+1)}^{\infty} \beta^{s-t}\pi_{ips}$ is smaller than its scrap value S_{ip}. If plants make their exiting decisions before observing their current values of X_{ipt} and Z_{pt} and X_{ipt} and Z_{pt} follow a first order Markov process, then $EV_{ip(t+1)}$ can be represented by a function of plant p's X_{ipt} and Z_{pt}. We use a reduced form to represent the net expected profit $(EV_{ip(t+1)} - S_{ip})$ such that

$$EV_{ip(t+1)} - S_{ip} = X_{ipt}\gamma + Z_{pt}\beta + X_t + X_I + v_p + \varepsilon_{ipt} \tag{3.15}$$

where v_p is unobservable plant heterogeneity where the density function f(v) and ε_{ipt} are drawn from an i.i.d. standard normal distribution. We then model the plant's choice of dropping products using a random probit regression equation where the decision to drop a product is categorized as one and the choice to continue producing a product as zero. The likelihood of dropping a product between years t and (t+1) is a function of product-plant characteristics, plant characteristics and some controls for demand and cost shocks:

$$Pr(Drop_{t:t+1}^{ip}) = \int \Phi(X_{ipt}\gamma + Z_{pt}\beta + \alpha_t + HHI_{it} + \alpha_i + v_p)f(v)dv \tag{3.16}$$

where HHI_{it} is a Herfindahl index capturing the level of competition in each product market i in year t, α_t and α_i represent time and product market dummies, respectively.

We are interested in whether multi-product plants refocus on their core products by giving up operation in some markets where the product-plant specific production technologies are most dissimilar from the plants' core competence. For this purpose, we identify the core product as the product with the maximum output share within a multi-product plant. Based on the definition used by Eaton and Schmitt (1994) and Teece et al. (1994), a multi-product plant is most efficient at producing its core product. Therefore, a multi-product plant may produce a larger amount of its core product because of this large cost advantage[31].

We use MC_{ijpt} constructed from the estimated cost function in Section 3.5 as the proxy for plant p's extra costs from producing product i, X_{ipt}. MC_{ijpt} is the increment on marginal cost of its core product j for plant p if this plant increases its production of product i. If a multi-product plant's production technology for product i is more unrelated to its core product j, then we will expect a higher value of MC_{ijpt}. Since we are interested in the dissimilarity of production techniques between peripheral and core products, we define $X_{ipt} = 0$ for each plant's core product.

Plant characteristics Z_{pt} include ln(age) and ln(capital) which are determinants of a plant's profitability following Jovanovic's (1982) and Hopenhayn's (1992) theoretical models. Similar to the previous subsection, ln(capital) is normalized to the industry mean value. Time dummies and product market dummies are used as cost and demand shifters of plants' profits.

In contrast to the previous subsection, we include all multi-product plants that

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[31] Liu (2006) also uses this definition of core product for a multi-product plant.

survive or shut down in the next year. We try two regression models and the estimated results are reported in Tables 3.21 and 3.22. In Table 3.21, we introduce a dummy variable which equals to one if the product is the core product. The negative coefficient on this dummy variable indicates that core products are less likely to be dropped for a multi-product plant. In Table 3.22, the positive and statistically significant coefficient for MC_{ijpt} indicates that plants are more likely to drop products with a higher dissimilarity index. This result offers evidence that multi-product plants use resources more efficiently by moving their operations away from unrelated products and moving into their core products.

As expected, we get negative and statistically significant coefficients on capital. This supports the idea that large plants are usually more productive so that it is less likely for a large plant to drop products. This is consistent with Aw and Batra's (1998) empirical results for some Taiwanese manufacturing sectors. They find the positive correlation between firm size and diversification[32].

The coefficients on age are negative which is consistent with Jovanovic's (1982) learning model. Older plants have more operating experience so that they are likely able to overcome the bad economic shocks. However, they are both statistically insignificant. The negative and statistically significant coefficients on HHI (high HHI represents low competition) indicates that higher competitive pressure in a product market increases the probability that some multi-product plants will exit some product markets.

Tables 3.17 and 3.18 indicate multi-product plants may have different response in growing and declining industries. Plants are likely to drop their core products if the core is no longer lucrative. To address this problem, we drop the Consumer

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[32] Aw and Batra use a Herfindahl index, $1 - \sum_i s_i$ where s_i is the value of the i^{th} product in the total value of sales of the firm, as the measure of diversification.

Electronics (a declining) industry and re-estimate the model. The estimation results are in Table 3.23. The coefficients on the dummy of primary product and the dissimilarity index assume greater absolute values. More interestingly, the coefficients on age become positive and statistically significant after we drop the Consumer Electronics industry. This possibly captures the fact that new entrants bring new technologies in industries where technology is changing quickly.

Using the result of this subsection, we can characterize the type of product that a multi-product plant chooses to drop. First, plants are less likely to drop their core products than their peripheral ones. We also find that production dissimilarity from a plant's core product, in terms of the increment on marginal cost of the core product by increasing the amount of the peripheral product, is an important determinant for a multi-product plant's restructuring. Plants are much more likely to drop products using a technology that is very different from that used in producing their core products. In addition, large plants have small probabilities of giving up any of their business activities. The size effect supports Jovanovic's (1982) and Hopenhayn's (1992) firm dynamics theoretical models. Competitive pressure within a product market increases the probability that a multi-product plant exits that market. After we drop the declining industry (the Consumer Electronics), age is positively correlated to plants' decision to drop.

3.7 Summary and Conclusions

This chapter examines the product choices of multi-product plants in four industries within the Taiwanese electronics sector. In contrast to the U.S. manufacturing sector, the Taiwanese manufacturing sector is dominated by small-and medium-sized plants that do not readily undertake product diversification. Within all manufacturing sectors, the share of multi-product plants is highest in the electronics sector. While multi-product plants account for less than 10% of the total number of plants in the electronics sector (compared to 49% in the U.S. manufacturing sector), these plants still have characteristics in common with U.S. multi-product firms: they are relatively large in size and produce a significant share of the total industry output.

Using plant-level and product-level data, we analyze the frequency distribution of every product pair where multi-product plants co-manufacture these products in a given year. We find the probability that a pair of products are produced together within a plant is not equally distributed, implying the presence of cost complementarities in joint production.

In order to understand if the uneven frequency in the co-production pattern reflects complementarities between products, we first estimate cost functions for plants in each industry and then calculate the degree of economies of scope. Our results indicate some variation in the fraction of plants with economies of scope across different co-production types. These results only weakly explain the uneven frequency of co-production observed in data. A practical difficulty in implementing formulae of scope economies is that they involve estimating costs when some outputs are zero under the current production technology for multi-product plants. Following Humphrey and Pulley (1993), we calculated quasi-scope economies index. Our results provide virtually no scope economies of any product combination. Overall, our findings suggest that the Taiwanese electronics multi-product plants do not appear to enjoy any advantage of joint production in the 1990s. This could explain why less than 10% of plants are multi-product plants and could also explain the trends towards increased product specialization over the period from 1992 to

1999[33].

In order to analyze how multi-product plants restructure their product mix, we construct a dissimilarity index based on the increment of marginal cost of the core products resulting from an additional amount of the peripheral product. Higher indices of dissimilarity indicates less relatedness between the peripheral and the core products. This measure, in contrast to other measure in the literature, is able to capture plant heterogeneity by accounting for the technological gaps between any two products produced by a plant. After controlling for plant attributes as well as industry and time fixed effects, we find that: (1) Multi-product plants with greater unrelatedness index (TDI) are more likely to drop some of their products; (2) Plants choose to exit from product markets that are technologically far from their core competence. Our findings about the way multi-product plants restructure under intensified competition are consistent with other empirical studies, where multi-product firms are shown to refocus on their core competence when facing stiffer international competition.

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[33] However, it should be noted that our measure of economies of scope only takes into account production variable costs. It is possible that the incentive for plants to produce multiple products may arise from other common inputs such as managerial knowledge, shared marketing channels or demand-side considerations.

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Table 3.1. Product Definition, by 3-digit Industry

4-digit SIC / 3-digit SIC	Computer & Data storage	Consumer Electronics	Telecommunications Equipment	Parts & Components
Product 1	Computers Calculators	Record Players Radios Cable Equipment	Switch and Transmission Devices	Semi-Conductors
Product 2	Monitors Terminal	Video, Radio and Stereo Parts	Telephones Faxes Answer Machines	Opto Devices
Product 3	Disk Drivers Printers Keyboards and Mice Card Readers	Security Systems	Wireless Telecommunication Equipment	Passive Components
Product 4	Interface Cards		Other	Printed Circuits
Product 5	Numerical Controllers and Other			Other

Notes: We define 3-digit SIC as an industry and 4-digit as a product. SIC= 3142 and SIC=3151 are excluded from our product definition. In the telecommunications equipment and parts & components industries, we made separate some 5-digit products within the same 4-digit SIC category into different product groups.

Table 3.2. Summary Statistics of Single- and Multi-product Plants, 1992-1999

	Computer & Data Storage		Consumer Electronics		Telecommunications Equipment		Parts & Components	
	SP	MP	SP	MP	SP	MP	SP	MP
Plants (no.)	2807	251	3113	100	1258	75	10084	304
Products (no.)	1	2.33	1	2.1	1	2.04	1	2.03
Employment (no.)	41.82	188.86	26.12	60.87	38.62	85.36	50.49	244.08
TFP	.060	.172	-.033	.059	.025	.112	-.048	.059
Age (years)	4.3	5.1	7.6	8.4	6.3	7.8	6.8	8.9
ln(K/L)	6.12	6.57	5.99	6.12	6.10	6.46	6.17	6.37
ln(Per Product Sales)	10.50	11.48	9.79	10.14	10.04	10.38	10.16	11.00
R&D Participation (%)	26.1	69.3	15.6	39	26.1	54.7	15.2	42.8

Notes: SP represents single-product plants and MP represents multi-product plants. Total factor productivity (TFP) is constructed by Good et al.'s (1997) index which is adopted by Aw et al. (2001) and TFP is normalized by industry mean level in 1993. There is no TFP information for 1992. Per-Product Sales is the ratio of total sales over total number of products within a plant. R&D Participation is the share of plants practicing R&D in a given year.

Table 3.3. Share of Multi-product Plants (%), by Size

	Small	Medium	Large
Computer & Data Storage	4.75	8.25	25.17
Consumer Electronics	2.11	3.58	16.82
Telecommunications Equipment	3.86	5.56	21.84
Parts & Components	1	3.24	10.48

Notes: Size is defined into three categories: plants with total employment less than or equal to twenty are small, plants with total employment between twenty-one and 100 are medium and plants with total employment over 100 are large.

Table 3.4. Product Co-production Within Plants, Computer & Data Storage Industry (1992-1999)

	Product 1	Product 2	Product 3	Product 4	Product 5
Product 1	–	30 (25.3)	58 (43.9)	65 (50)	43 (38.4)
Product 2	30 (25.3)	–	45 (28.9)	31 (32.9)	23 (25.3)
Product 3	58 (43.9)	45 (28.9)	–	75 (57.1)	46 (43.9)
Product 4	65 (50)	31 (32.9)	75 (57.1)	–	84 (50)
Product 5	43 (38.4)	23 (25.3)	46 (43.9)	84 (50)	–

Notes: There are 192, 179, 744, 692 and 1166 single-product plants for product 1, product 2, product 3, product 4 and product 5 in the pooled sample, respectively. The Pearson χ^2 test rejects the hypothesis that each cell is independent. Expected values are in parentheses. Light gray cells indicate significant difference from expected values.

Table 3.5. Product Co-production Within Plants, Consumer Electronics Industry (1992-1999)

	Product 1	Product 2	Product 3
Product 1	–	67 (36.7)	20 (20.7)
Product 2	67 (36.7)	–	41 (25.7)
Product 3	20 (20.7)	41 (25.7)	–

Notes: There are 315, 1510 and 1401 single-product plants for product 1, product 2 and product 3 in the pooled sample, respectively. The Pearson χ^2 test rejects the hypothesis that each cell is independent. Expected values are in parentheses. Light gray cells indicate significant difference from expected values.

Table 3.6. Product Co-production Within Plants, Telecommunications Equipment (1992-1999)

	Product 1	Product 2	Product 3	Product 4
Product 1	–	33 (19.2)	13 (14.1)	7 (5.4)
Product 2	33 (19.2)	–	32 (18.8)	6 (7.2)
Product 3	13 (14.1)	32 (18.8)	–	7 (5.3)
Product 4	7 (5.4)	6 (7.2)	7 (5.3)	–

Notes: There are 303, 351, 563 and 130 single-product plants for product 1, product 2, product 3 and product 4 in the pooled sample, respectively. The Pearson χ^2 test rejects the hypothesis that each cell is independent. Expected values are in parentheses. Light gray cells indicate significant difference from expected values.

Table 3.7. Product Co-production Within Plants, Parts & Components Industry (1992-1999)

	Product 1	Product 2	Product 3	Product 4	Product 5
Product 1	–	24 (8.5)	24 (29.8)	5 (5.8)	41 (37.5)
Product 2	24 (8.5)	–	9 (20.3)	0 (4)	31 (25.5)
Product 3	24 (29.8)	9 (20.3)	–	10 (13.9)	182 (89.7)
Product 4	5 (5.8)	0 (4)	10 (13.9)	–	29 (17.5)
Product 5	41 (37.5)	31 (25.5)	182 (89.7)	29 (17.5)	–

Notes: There are 448, 208, 3533, 1416 and 5751 single-product plants for product 1, product 2, product 3, product 4 and product 5 in the pooled sample, respectively. The Pearson χ^2 test rejects the hypothesis that each cell is independent. Expected values are in parentheses. Light gray cells indicate significant difference from expected values.

Table 3.8. Cost Function Estimation, Computer & Data Storage Industry

Parameter	Estimation	Parameter	Estimation	Parameter	Estimation	Parameter	Estimation	Parameter	Estimation
α_1	0.232	β_{13}	-0.016	δ_{kq2}	-0.018	δ_{rd}	-0.025	Year 1998	-0.242
	(0.047)***		(0.001)***		(0.002)***		(0.285)		(0.030)***
α_2	-0.113	β_{14}	-0.013	δ_{kq3}	-0.035	δ_{rdq1}	-0.006	Year 1999	-0.458
	(0.044)**		(0.001)***		(0.002)***		(0.011)		(0.032)***
α_3	0.179	β_{15}	-0.014	δ_{kq4}	-0.037	δ_{rdq2}	0.007	Constant	0.376
	(0.040)***		(0.001)***		(0.002)***		(0.011)		(0.515)
α_4	0.233	β_{23}	-0.015	δ_{kq5}	-0.037	δ_{rdq3}	-0.013		
	(0.039)***		(0.001)***		(0.002)***		(0.009)**		
α_5	0.190	β_{24}	-0.012	δ_w	0.875	δ_{rdq4}	-0.020		
	(0.037)***		(0.001)***		(0.170)***		(0.009)**		
β_{11}	0.045	β_{25}	-0.012	δ_{ww}	-0.045	δ_{rdq5}	-0.018		
	(0.003)***		(0.001)***		(0.016)***		(0.009)**		
β_{22}	0.041	β_{34}	-0.013	δ_{wq1}	-0.010	δ_{rdk}	0.084		
	(0.003)***		(0.001)***		(0.007)		(0.018)***		
β_{33}	0.054	β_{35}	-0.015	δ_{wq2}	0.006	δ_{rdw}	-0.101		
	(0.002)***		(0.001)***		(0.007)		(0.042)**		
β_{44}	0.052	β_{45}	-0.017	δ_{wq3}	-0.016	Year 1993	0.132		
	(0.002)***		(0.001)***		(0.006)**		(0.022)***		
β_{55}	0.062	δ_k	0.365	δ_{wq4}	-0.02	Year 1995	-0.021		
	(0.002)***		(0.022)***		(0.006)***		(0.028)		
β_{12}	-0.005	δ_{kq1}	-0.034	δ_{wq5}	-0.030	Year 1997	-0.116		
	(0.001)***		(0.003)***		(0.006)***		(0.030)***		
Observation	2221	Plant	849	R-squared	0.87				

Standard errors in parentheses

* Significant at 10%; ** Significant at 5%; *** Significant at 1%

Table 3.9. Cost Function Estimation, Consumer Electronics Industry

Parameter	Estimation	Parameter	Estimation	Parameter	Estimation
α_1	0.266	δ_{kq2}	-0.010	δ_{rdk}	0.015
	(0.038)***		(0.002)***		(0.010)
α_2	0.303	δ_{kq3}	-0.009	δ_{rdw}	0.035
	(0.036)***		(0.002)***		(0.026)
α_3	0.392	δ_w	0.406	Year 1993	0.060
	(0.040)***		(0.099)***		(0.011)***
β_{11}	0.044	δ_{ww}	-0.014	Year 1995	0.069
	(0.002)***		(0.011)		(0..012)***
β_{22}	0.045	δ_{wq1}	-0.018	Year 1997	0.121
	(0.001)***		(0.005)***		(0.013)***
β_{33}	0.043	δ_{wq2}	-0.023	Year 1998	0.197
	(0.002)***		(0.005)***		(0.014)***
β_{12}	-0.039	δ_{wq3}	-0.02	Year 1999	0.139
	(0.001)***		(0.005)***		(0.014)***
β_{13}	-0.024	δ_{rd}	-0.004	Constant	1.522
	(0.001)***		(0.156)		(0.306)***
β_{23}	-0.039	δ_{rdq1}	-0.026		
	(0.002)***		(0.006)***		
δ_k	0.094	δ_{rdq2}	-0.027		
	(0.015)***		(0.006)***		
δ_{kq1}	-0.009	δ_{rdq3}	-0.031		
	(0.002)***		(0.006)***		
Observation	2660	Plant	853	R-squared	0.94

Standard errors in parentheses
* Significant at 10%; ** Significant at 5%; *** Significant at 1%

Table 3.10. Cost Function Estimation, Telecommunications Equipment Industry

Parameter	Estimation	Parameter	Estimation	Parameter	Estimation	Parameter	Estimation
α_1	0.048	β_{23}	-0.044	δ_{wq2}	0.001	Year 1995	-0.008
	(0.051)		(0.002)***		(0.009)		(0.023)
α_2	0.127	β_{24}	-0.028	δ_{wq3}	0.001	Year 1997	0.010
	(0.051)**		(0.003)***		(0.009)		(0.024)
α_3	0.149	β_{34}	-0.044	δ_{wq4}	0.0001	Year 1998	0.009
	(0.050)***		(0.003)***		(0.011)		(0.026)
α_4	0.068	δ_k	-0.007	δ_{rd}	0.294	Year 1999	-0.111
	(0.059)		(0.027)		(0.274)		(0.027)***
β_{11}	0.044	δ_{kq1}	0.003	δ_{rdq1}	-0.082	Constant	4.158
	(0.003)***		(0.003)		(0.011)***		(0.549)***
β_{22}	0.044	δ_{kq2}	-0.002	δ_{rdq2}	-0.076		
	(0.002)***		(0.003)		(0.011)***		
β_{33}	0.043	δ_{kq3}	-0.002	δ_{rdq3}	-0.079		
	(0.002)***		(0.003)		(0.011)***		
β_{44}	0.052	δ_{kq4}	-0.003	δ_{rdq4}	-0.099		
	(0.003)***		(0.004)		(0.014)***		
β_{12}	-0.046	δ_w	0.043	δ_{rdk}	0.034		
	(0.002)***		(0.184)		(0.018)*		
β_{13}	-0.069	δ_{ww}	-0.004	δ_{rdw}	0.05		
	(0.007)***		(0.019)		(0.047)		
β_{14}	-0.042	δ_{wq1}	0.010	Year 1993	0.032		
	(0.003)***		(0.009)		(0.023)		
Observation	1030	Plant	357	R-squared	0.93		

Standard errors in parentheses

* Significant at 10%; ** Significant at 5%; *** Significant at 1%

Table 3.11. Cost Function Estimation, Electronic Components & Parts Industry

Parameter	Estimation	Parameter	Estimation	Parameter	Estimation	Parameter	Estimation	Parameter	Estimation
α_1	0.520	β_{13}	-0.033	δ_{kq3}	-0.012	δ_{rdq1}	-0.003	Year 1999	-0.096
	(0.020)***		(0.001)***		(0.001)***		(0.006)		(0.008)***
α_2	0.488	β_{14}	-0.037	δ_{kq4}	-0.011	δ_{rdq2}	-0.015	Constant	1.171
	(0.028)***		(0.001)***		(0.001)***		(0.007)**		(0.174)***
α_3	0.375	β_{15}	-0.033	δ_{kq5}	-0.014	δ_{rdq3}	-0.020		
	(0.018)***		(0.001)***		(0.001)***		(0.005)***		
α_4	0.333	β_{23}	-0.028	δ_w	0.416	δ_{rdq4}	-0.018		
	(0.019)***		(0.002)***		(0.056)***		(0.005)***		
α_5	0.407	β_{25}	-0.046	δ_{ww}	-0.013	δ_{rdq5}	-0.021		
	(0.018)***		(0.001)***		(0.006)**		(0.005)***		
β_{11}	0.027	β_{34}	-0.041	δ_{wq1}	-0.018	δ_{rdk}	-0.005		
	(0.002)***		(0.001)***		(0.004)***		(0.006)		
β_{22}	0.030	β_{35}	-0.045	δ_{wq2}	-0.025	δ_{rdw}	-0.003		
	(0.002)***		(0.001)***		(0.004)***		(0.017)		
β_{33}	0.040	β_{45}	-0.033	δ_{wq3}	-0.021	Year 1993	0.044		
	(0.001)***		(0.001)***		(0.003)***		(0.007)***		
β_{44}	0.039	β_k	0.130	δ_{wq4}	-0.017	Year 1995	0.001		
	(0.001)***		(0.011)***		(0.003)***		(0.007)		
β_{55}	0.042	δ_{kq1}	-0.012	δ_{wq5}	-0.024	Year 1997	0.018		
	(0.001)***		(0.001)***		(0.003)***		(0.008)**		
β_{12}	-0.039	δ_{kq2}	-0.010	δ_{rd}	0.295	Year 1998	0.015		
	(0.001)***		(0.002)***		(0.100)***		(0.008)*		
Observation	9560	Plant	3025	R-squared	0.92				

Standard errors in parentheses

* Significant at 10%; ** Significant at 5%; *** Significant at 1%

Table 3.12. Number of Plants with Scope Diseconomies and Economies, by Product Mix Type

Type	Scope Diseconomies (D)	Scope Economies (E)	Share of Scope Economies (%)
1. Computer & Data Storage			
12	2	0	0
13	17	5	22.73
14	12	1	7.69
15	7	0	0
23	11	4	26.67
24	2	0	0
25	0	2	100
34	13	6	31.58
35	7	6	46.15
45	12	8	40
Overall	83	32	27.83
2. Consumer Electronics			
12	34	10	22.73
13	5	0	0
23	17	5	22.73
Overall	56	15	21.13
3. Telecommunications Equipment			
12	6	11	64.71
13	0	7	100
14	2	1	33.33
23	4	9	69.23
24	1	0	0
34	2	2	50
Overall	15	30	66.67
4. Parts & Components			
12	14	2	12.5
13	13	0	0
14	1	2	66.67
15	25	0	0
23	5	0	0
25	9	14	60.87
34	5	5	50
35	80	51	38.93
45	20	0	0
Overall	172	74	30.08

Table 3.13. Quasi-Scope Economies, Computer & Data Storage Industry

Type	$\varepsilon = 0$		$\varepsilon = 0.001$		$\varepsilon = 0.01$		$\varepsilon = 0.05$		$\varepsilon = 0.1$	
	Plant	QSC	Plant	QSC	Plant	QSC	Plant	QSC	Plant	QSC
12	0	-0.733	0	-0.805	0	-0.738	0	-0.584	0	-0.466
		(0.110)		(0.078)		(0.076)		(0.084)		(0.087)
13	5	-0.239	1	-0.631	1	-0.69	1	-0.580	1	-0.480
		(0.416)		(0.718)		(0.291)		(0.194)		(0.170)
14	1	-0.515	0	-0.785	0	-0.750	0	-0.617	0	-0.509
		(0.254)		(0.129)		(0.100)		(0.105)		(0.107)
15	0	-0.550	0	-0.849	0	-0.814	0	-0.693	0	-0.592
		(0.174)		(0.084)		(0.078)		(0.092)		(0.099)
23	4	-0.196	0	-0.735	0	-0.709	0	-0.573	0	-0.464
		(0.339)		(0.143)		(0.110)		(0.113)		(0.114)
24	0	-0.588	0	-0.855	0	-0.804	0	-0.668	0	-0.559
		(0.217)		(0.047)		(0.029)		(0.022)		(0.018)
25	2	0.375	1	0.168	1	-0.373	0	-0.358	1	-0.283
		(0.482)		(1.452)		(0.633)		(0.475)		(0.433)
34	6	-0.046	4	-0.161	1	-0.466	1	-0.408	1	-0.323
		(0.517)		(1.091)		(0.384)		(0.245)		(0.210)
35	6	0.092	3	-0.435	0	-0.607	0	-0.529	0	-0.441
		(0.647)		(0.491)		(0.214)		(0.157)		(0.143)
45	8	0.246	0	-0.572	0	-0.655	0	-0.556	0	-0.462
		(0.825)		(0.254)		(0.142)		(0.126)		(0.123)

Note: Standard Deviation of QSC in parentheses.

Table 3.14. Quasi-Scope Economies, Consumer Electronics Industry

Type	$\varepsilon = 0$		$\varepsilon = 0.001$		$\varepsilon = 0.01$		$\varepsilon = 0.05$		$\varepsilon = 0.1$	
	Plant	QSC	Plant	QSC	Plant	QSC	Plant	QSC	Plant	QSC
12	10	-0.212	4	-0.488	1	-0.562	1	-0.449	1	-0.349
		(0.351)		(0.540)		(0.229)		(0.154)		(0.131)
13	0	-0.798	0	-0.842	0	-0.791	0	-0.658	0	-0.552
		(0.096)		(0.072)		(0.054)		(0.050)		(0.047)
23	5	-0.115	4	-0.178	2	-0.426	2	-0.355	2	-0.268
		(0.431)		(0.984)		(0.352)		(0.194)		(0.146)

Note: Standard Deviation of QSC in parentheses.

Table 3.15. Quasi-Scope Economies, Telecommunications Equipment Industry

Type	$\varepsilon = 0$		$\varepsilon = 0.001$		$\varepsilon = 0.01$		$\varepsilon = 0.05$		$\varepsilon = 0.1$	
	Plant	QSC	Plant	QSC	Plant	QSC	Plant	QSC	Plant	QSC
12	11	0.021	4	-0.183	0	-0.360	0	-0.276	0	-0.188
		(1.123)		(0.361)		(0.168)		(0.116)		(0.101)
13	7	8.06	7	1.44	7	0.356	7	0.204	7	0.218
		(2.55)		(1.258)		(0.356)		(0.163)		(0.114)
14	1	-0.022	0	-0.327	0	-0.458	0	-0.357	0	-0.262
		(0.491)		(0.278)		(0.167)		(0.144)		(0.137)
23	9	0.332	3	-0.141	1	-0.398	1	-0.326	1	-0.239
		(0.607)		(1.020)		(0.379)		(0.221)		(0.175)
24	0	-0.153	0	-0.668	0	-0.646	0	-0.509	0	-0.402
		–		–		–		–		–
34	2	0.365	2	0.818	1	-0.093	1	-0.154	1	-0.103
		(0.320)		(2.05)		(0.569)		(0.275)		(0.201)

Note: Standard Deviation of QSC in parentheses. There is only one plant in type 24 so standard deviation is undefined.

Table 3.16. Quasi-Scope Economies, Parts & Components Industry

Type	$\varepsilon = 0$		$\varepsilon = 0.001$		$\varepsilon = 0.01$		$\varepsilon = 0.05$		$\varepsilon = 0.1$	
	Plant	QSC	Plant	QSC	Plant	QSC	Plant	QSC	Plant	QSC
12	2	0.07	0	-0.45	0	-0.48	0	-0.31	0	-0.19
		(0.213)		(0.145)		(0.087)		(0.063)		(0.05)
13	0	-0.63	0	-0.74	0	-0.67	0	-0.5	0	-0.38
		(0.117)		(0.123)		(0.099)		(0.094)		(0.090)
14	2	-0.21	0	-0.59	0	-0.55	0	-0.42	0	-0.32
		(0.529)		(0.182)		(0.122)		(0.086)		(0.066)
15	0	-0.55	0	-0.80	0	-0.71	0	-0.54	0	-0.42
		(0.107)		(0.064)		(0.055)		(0.054)		(0.055)
23	0	-0.84	0	-0.84	0	-0.75	0	-0.59	0	-0.47
		(0.064)		(0.042)		(0.035)		(0.029)		(0.024)
25	14	0.96	1	-0.41	0	-0.43	0	-0.28	0	-0.18
		(1.38)		(0.247)		(0.104)		(0.066)		(0.056)
34	5	0.02	0	-0.56	0	-0.57	0	-0.44	0	-0.33
		(0.329)		(0.266)		(0.153)		(0.117)		(0.1)
35	51	0.12	23	-0.29	4	-0.42	3	-0.32	3	-0.22
		(0.545)		(0.508)		(0.205)		(0.122)		(0.097)
45	0	-0.61	0	-0.74	0	-0.70	0	-0.55	0	-0.44
		(0.156)		(0.139)		(0.097)		(0.084)		(0.077)

Note: Standard Deviation of QSC in parentheses.

Table 3.17. Specialization Patterns within Multi-product Plants (1992-1999)

Industry	Change in the Sales Share of Primary Product (mean)	Share of Number of Multi-product Plants Switch to Single-product (%)
Computer & Data Storage	0.030	27
Consumer Electronics	-0.025	39
Telecommunications Equipment	0.004	37
Parts & Components	0.017	27

Notes: Change in the share of primary product is calculate by $(s_{t+1} - s_t)$, where s_t is the sales share of the primary product within a multi-product plant. We show the mean value within plants producing multiple products in both years t and (t+1).

Table 3.18. Production Value, by Industry

Year	Computer & Data Storage	Consumer Electronics	Telecommunications Equipment	Parts & Components
1991	137,287	98,916	45,740	167,178
1996	380,094	80,562	68,646	489,179
2001	917,817	73,504	177,174	1,367,763

Data Source: Industry, Commerce and Service Census (DGBAS) (1991, 1996 and 2001)

Notes: Production value is deflated by industry-wide wholesales price indices.

Table 3.19. Total Distance Index and the Number of Plants that Drop Products within Surviving Multi-product Plants, by Industry (1992-1999)

Year	Computer Data Storage		Consumer Electronics		Telecommunications Equipment		Parts & Components	
	M	D	M	D	M	D	M	D
1992-1993	22	16	11	2	1	1	36	6
1993-1995	9	15	8	8	4	3	23	16
1995-1997	5	4	3	5	2	4	24	10
1997-1998	9	7	5	3	1	2	26	8
1998-1999	8	17	10	2	8	4	34	14
TDI ($\times 10^{-5}$)	3.81	4.96	2.18	2.60	2.64	5.27	2.59	3.51

Notes: D(Drop) group: Plants in year t are multi-product plants, and drop some varieties without adding any new products in year (t+1).

M(Maintain) Group: Plants in year t are multi-product plants, and produce exactly the same product mix in year (t+1) as in year t.

Total Distance Index (TDI) is the measure of unrelatedness of a plant's product mix. $TDI_{pt} = \frac{1}{N_{pt}-1}\sum_{i \in M_{pt}}\sum_{j \in M_{pt}}(s_{it} + s_{jt})MC_{ijt}$, where s_{it} is the output share of product i within plant p at time t, N_{pt} is the total number of products plant p has and M_{pt} is the set of products for plant p.

There are fourteen, four, three and five multi-product plants shut down their whole operations between years t and (t+1) in the Computer & Data Storage industry, Consumer Electronics industry, Telecommunications Equipment industry and Parts & Components industry, respectively. Moreover, we exclude twenty-seven multi-product plants which both add and drop (switch) some of their products between years t and (t+1).

Table 3.20. Probit Regression of the Probability of Dropping Products (1992-1999)

Parameters	(1) (Baseline)	(2)	(3)	Survival Equation
TDI	4418.69	3873.89	3881.965	
	(1761.91)**	(2005.04)*	(2068.894)*	
Consumer Electronics	-0.420	-0.343	-0.346	0.886
	(0.228)*	(0.236)	(0.306)	(0.386)**
Telecommunications Equipment	-0.201	-0.135	-0.138	0.926
	(0.282)	(0.289)	(0.351)	(0.473)**
Parts & Components	-0.638	-0.582	-0.586	1.219
	(0.168)***	(0.195)***	(0.338)*	(0.308)**
Year 1993	0.646	0.676	0.677	-0.571
	(0.213)***	(0.215)***	(0.236)***	(0.403)
Year 1995	0.474	0.481	0.484	-1.009
	(0.242)*	(0.244)**	(0.317)	(0.456)**
Year 1997	0.282	0.275	0.276	-0.435
	(0.235)	(0.238)	(0.250)	(0.485)
Year 1998	0.292	0.308	0.309	-0.332
	(0.211)	(0.215)	(0.222)	(0.405)
ln(Age)		-0.164	-0.162	-0.654
		(0.089)*	(0.153)	(0.196)***
ln(Capital)		-0.004	-0.004	
		(0.053)	(0.052)	
$(ln(Capital))^2$		0.008	0.008	
		(0.015)	(0.147)	
ln(Employment)				0.181
				(0.103)*
Constant	-0.399	-0.199	-0.201	2.641
	(0.185)**	(0.215)	(0.215)	(0.477)***
ρ				-0.02
				(1.34)
Observations	354	354	377	
Log Likelihood	-217.941	-215.90	-286.21	

Standard errors in parentheses

* Significant at 10%; ** Significant at 5%; *** Significant at 1%

We drop plants with TDI less than 5% or more than 95% in all regression models.

ln(Capital), ln(Employment) are normalized to the industry mean in each year.

Table 3.21. Random Probit Regression of the Probability of Dropping Primary Products (1992-1999)

Parameters	Estimation	Parameters	Estimation
Primary	-0.386	Product 11	-0.270
	(0.097)***		(0.357)
ln(Age)	-0.004	Product 12	0.482
	(0.069)		(0.604)
ln(Capital)	-0.069	Product 13	-1.077
	(0.029)**		(0.330)***
HHI	-3.464	Product 14	-1.055
	(1.792)*		(0.361)***
Product 2	0.101	Product 15	-0.895
	(0.296)		(0.252)***
Product 3	-0.310	Product 16	-1.019
	(0.244)		(0.373)***
Product 4	-0.268	Product 17	-1.003
	(0.243)		(0.243)***
Product 5	0.099	Year 1993	0.742
	(0.259)		(0.160)***
Product 6	-0.248	Year 1995	0.717
	(0.281)		(0.187)***
Product 7	-0.814	Year 1997	0.600
	(0.277)***		(0.173)***
Product 8	-0.625	Year 1998	0.385
	(0.337)*		(0.174)**
Product 9	-0.597	Constant	-0.126
	(0.473)		(0.270)
Product 10	-0.315	ρ	0.13
	(0.337)		(0.067)**
Observation	952	log-Likelihood	-518.128
Plants	267		

Standard error in parentheses. * Significant at 10%; ** Significant at 5%; *** Significant at 1%.

Notes: Primary is a dummy equal to 1 if the product is the plant's core product. HHI is the industry concentration ratio, which is calculated by $\sum_p s_{pt}^2$, where s_{pt} is the market share for plant p in year t. Products 2-5 represent products 2 to 5 in the Computer & Data Storage industry, Products 6-8 represent products 1 to 3 in the Consumer Electronics industry, Products 9-12 represent products 1 to 4 in the Telecommunications Equipment industry and Products 13-17 represent products 1 to 5 in the Parts & Components industry.

ρ is the fraction of total variance contributed by unobservable plant-specific error.

Table 3.22. Random Probit Regression of the Probability of Dropping Inefficient Products (1992-1999)

Parameters	Estimation	Parameters	Estimation
MC_{ijpt}	1702.965	Product 11	-0.195
	(907.733)*		(0.353)
ln(Age)	-0.008	Product 12	0.497
	(0.068)		(0.599)
ln(Capital)	-0.049	Product 13	-1.025
	(0.029)*		(0.326)***
HHI	-3.467	Product 14	-0.927
	(1.789)*		(0.353)***
Product 2	0.145	Product 15	-0.800
	(0.292)		(0.249)***
Product 3	-0.250	Product 16	-0.977
	(0.242)		(0.366)***
Product 4	-0.219	Product 17	-0.920
	(0.240)		(0.241)***
Product 5	0.178	Year 1993	0.731
	(0.257)		(0.158)***
Product 6	-0.273	Year 1995	0.699
	(0.278)		(0.183)***
Product 7	-0.694	Year 1997	0.596
	(0.271)***		(0.171)***
Product 8	-0.536	Year 1998	0.378
	(0.336)		(0.171)***
Product 9	-0.443	Constant	-0.380
	(0.459)		(0.270)
Product 10	-0.293	ρ	0.12
	(0.334)		(0.065)**
Observation	952	log-Likelihood	-524.512
Plants	267		

Standard error in parentheses. * Significant at 10%; ** Significant at 5%; *** Significant at 1%.

Notes: Primary is a dummy equal to 1 if the product is the plant's core product. HHI is the industry concentration ratio, which is calculated by $\sum_p s_{pt}^2$, where s_{pt} is the market share for plant p in year t. Products 2-5 represent products 2 to 5 in the Computer & Data Storage industry, Products 6-8 represent products 1 to 3 in the Consumer Electronics industry, Products 9-12 represent products 1 to 4 in the Telecommunications Equipment industry and Products 13-17 represent products 1 to 5 in the Parts & Components industry.

ρ is the fraction of total variance contributed by unobservable plant-specific error.

Table 3.23. Random Probit Regression of the Probability of Dropping Products, exclude the Consumer Electronics industry (1992-1999)

Parameters	Estimation	Parameters	Estimation
Primary	-0.457	MC_{ijpt}	1942.193
	(0.110)***		(1023.908)*
ln(Age)	0.176	ln(Age)	0.159
	(0.096)*		(0.093)*
ln(Capital)	-0.082	ln(Capital)	-0.057
	(0.035)**		(0.035)*
HHI	-4.413	HHI	-4.722
	(2.157)**		(2.149)**
Constant	-0.392	Constant	-0.643
	(0.317)		(0.317)**
ρ	0.269	ρ	0.250
	(0.082)***		(0.080)***
Product Dummy	Yes	Product Dummy	Yes
Year Dummy	Yes	Year Dummy	Yes
log-Likelihood	-432.941	log-Likelihood	-440.086
Observation	815	Plants	228

Standard error in parentheses. * Significant at 10%; ** Significant at 5%; *** Significant at 1%.

Notes: Primary is a dummy equal to 1 if the product is the plant's core product. HHI is the industry concentration ratio, which is calculated by $\sum_p s_{pt}^2$, where s_{pt} is the market share for plant p in year t.

ρ is the fraction of total variance contributed by unobservable plant-specific error.

Figure 3.1. Share of Multi-product Plants, by Industry

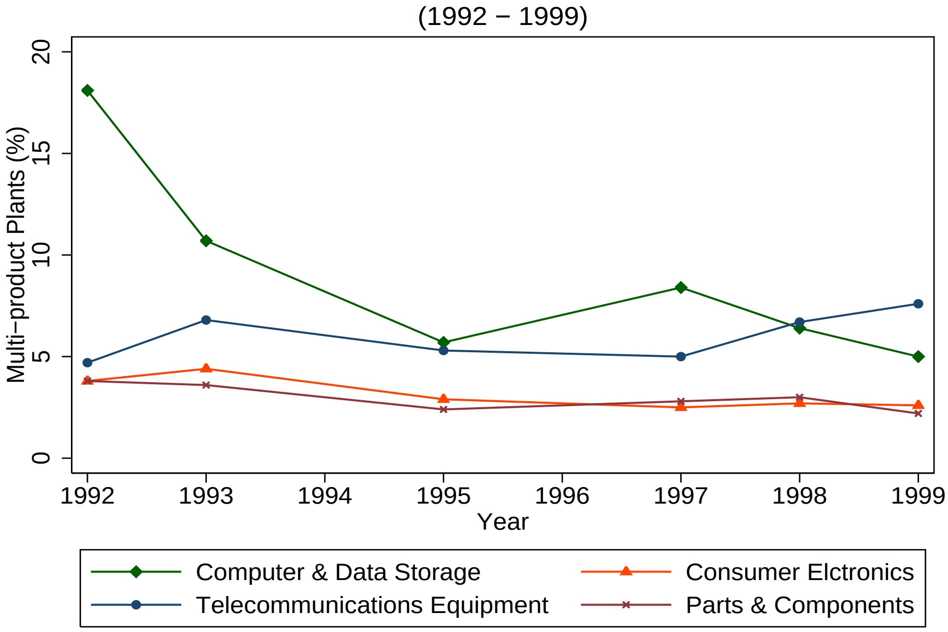


Figure 3.2. Output Share of Multi-product Plants, by Industry

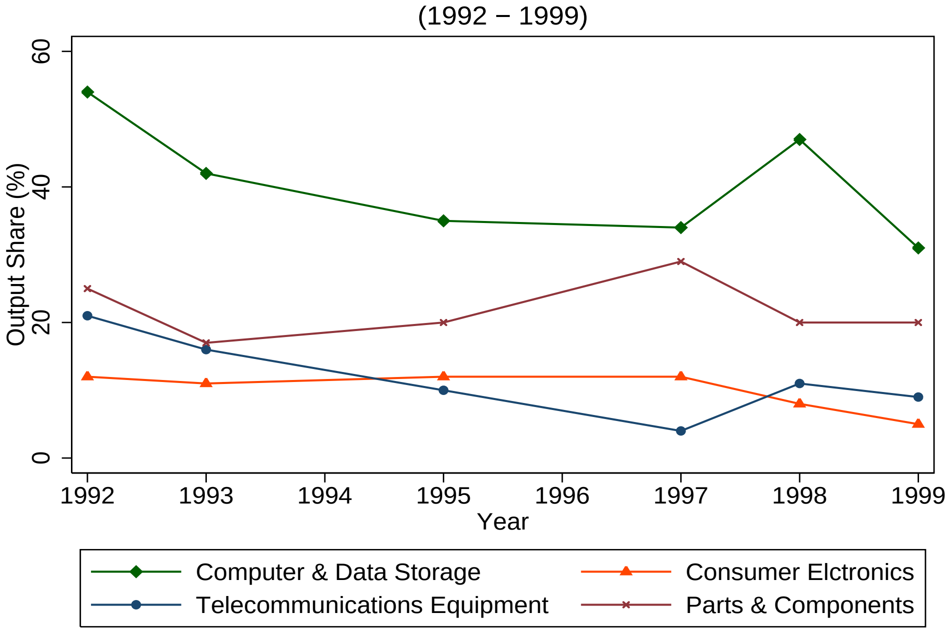


Figure 3.3. Export and Import-Output Ratio

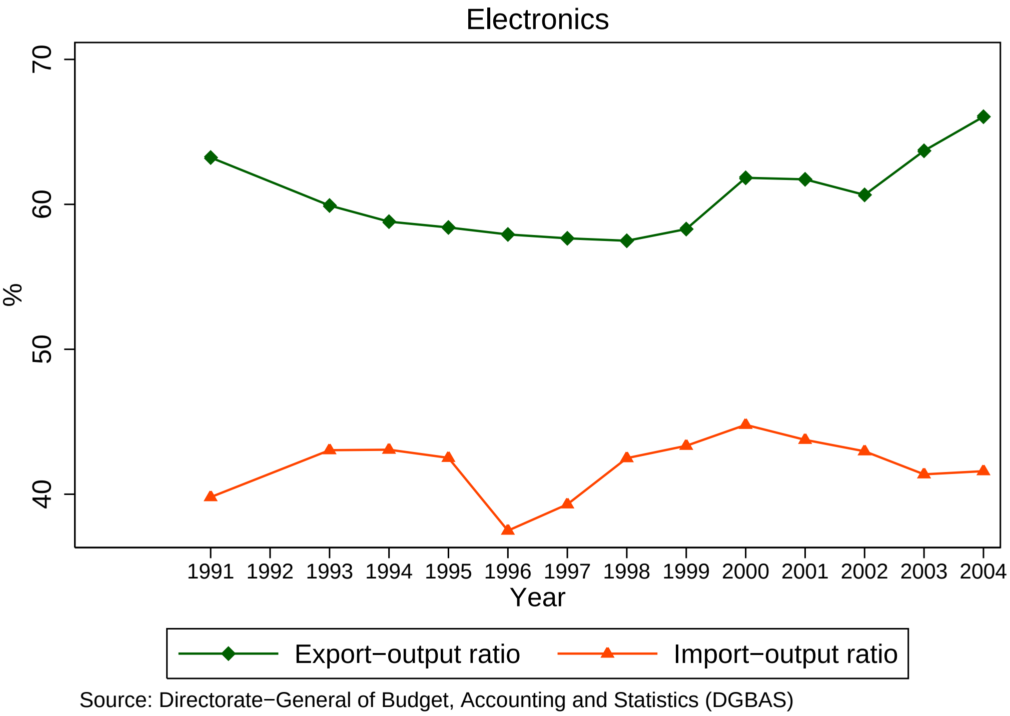
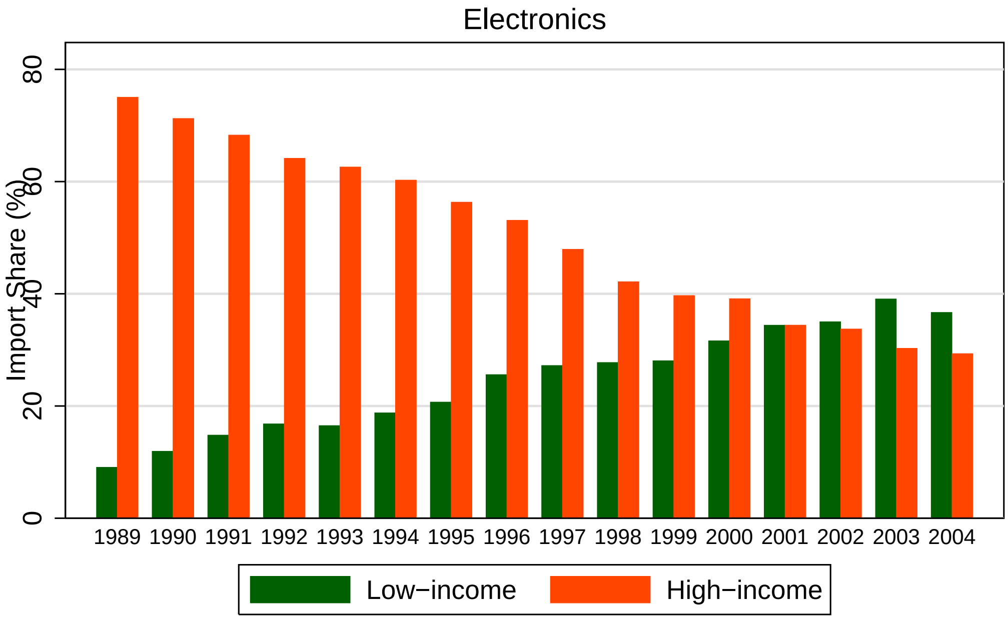


Figure 3.4. Import Share, by Country



Source: Author's calculation based information from Bureau of Foreign Trade.
High−income countries: U.S. and Japan.
Low−income countries: China and ASEAN.
ASEAN: Indonesia, Malaysia, the Philippines, Singapore, Thailand, Vietnam, Brunei, Lao, Myanmar and Cambodia.

Appendix A

Definition of Explanatory Variables

Explanatory Variables	Definition
Labor Productivity	$LP = [(lnQ - \overline{lnQ}) - (lnL - \overline{lnL})]$ where $\overline{lnQ}$ and $\overline{lnL}$ is the industry mean level of lnQ and lnL. Here we construct Q as total revenue plus the net change of the inventory.
Size	ln(total employment)
R&D Intensity	$\frac{\text{R\&D expenditure}}{\text{Total revenue}}$
Tech. Purchasing	The data include the value of technology purchasing from domestic and foreign corporations.
Tech. Pur. Participation	The data include the value of technology purchasing from domestic and foreign corporations. We construct it as a dummy variable equal to 1 if this firm purchases technology from any other enterprise in 2000.
Innovation	It's a dummy variable equal to 1 if this firm had process or product innovations in the past three years.

Appendix B

Pearson χ^2 Test

The sample of n observations in a random sample from a population are classified into one of r different categories according to one criterion and into one of c different categories according to a second criterion. Using the first criterion each observation is associated with one of the r rows and using the second criterion each observation is associated with one of the c columns. Let p_{ij} be the probability of an observation being classified in row i and column j (cell i,j). The null hypothesis is that the joint frequency distribution of the observed numbers n_{ij} follows a multinomial distribution with p_{ij} as probability. Pearson χ^2 index:

$$X^2 = \sum_i \sum_j \frac{[n_{ij} - m_{ij}]^2}{m_{ij}}$$

where n_{ij} is the observed numbers in the cell (i,j) and m_{ij} is the expected frequency in the cell (i,j). As the number of observations become large, $\frac{[n_{ij}-m_{ij}]}{\sqrt{m_{ij}}}$ approach normal distribution.

In a 2 by 2 table:

	$j = 1$	$j = 2$	
$i = 1$	n_{11}	n_{12}	$n_{1.}$
$i = 2$	n_{21}	n_{22}	$n_{2.}$
	$n_{.1}$	$n_{.2}$	n

If each cell is independent, then $p_{ij} = p_{i.}p_{.j}$. We can calculate the expected frequency for cell ij by $\hat{m}_{ij} = np_{ij} = n(\frac{n_{i.}}{n})(\frac{n_{.j}}{n}) = \frac{n_{i.}n_{.j}}{n}$. After we have $\hat{m}_{ij}$ we can calculate $X^2 = \sum_i \sum_j \frac{[n_{ij} - \hat{m}_{ij}]^2}{\hat{m}_{ij}}$ and check if the frequency of each co-production cell is normally independently distributed.

Appendix C

Type Distribution

Table C.1. Number of Plants, by Product Mix Type

Consumer Electronics		Telecommunications Equipment		Parts & Components	
Type	Number	Type	Number	Type	Number
1	243	1	226	1	328
2	1296	2	254	2	163
3	1046	3	412	3	2984
12	45	4	92	4	1176
13	5	12	17	5	4665
23	22	13	7	12	16
123	7	14	3	13	13
		23	13	14	3
		24	1	15	25
		34	4	23	5
		124	1	25	23
				34	10
				35	131
				45	20
				123	1
				145	1
				235	1
Total	2664	Total	1030	Total	9565

Computer & Data Storage	
Type	Number
1	126
2	135
3	528
4	472
5	806
12	2
13	22
14	13
15	7
23	15
24	2
25	2
34	19
35	13
45	20
123	2
124	3
125	4
134	7
135	3
145	5
234	2
235	2
345	8
1234	3
2345	1
Total	2222

Appendix D

Properties of the Cost Function

We check two properties of the short-run cost function:

1. cost elasticity with respect to (w.r.t.) capital, e_k should be negative.
2. cost elasticity w.r.t. wage e_w should be equal to the wage share of total costs.

e_k is expected to be negative; this is shown in Section 5.1 in the discussion of the cost construction. $e_w = \frac{\partial lnC}{\partial lnw} = \frac{\partial C}{\partial w}\frac{w}{C}$ is equal to share of labor costs ($\frac{wL}{C}$) based on Shephard's Lemma. We calculate e_k and e_w from the estimated cost function:

$$\begin{aligned} e_k &= \frac{\partial lnC}{\partial lnK} = \delta_k + \sum_{i \in M_p} \delta_{kq_i} \tilde{q}_i + \delta_{rdk} D_{rd} \\ e_w &= \frac{\partial lnC}{\partial lnw} = \delta_w + 2\ \delta_{ww} w + \sum_{i \in M_p} \delta_{wq_i} \tilde{q}_i + \delta_{rdw} D_{rd} \end{aligned} \tag{D.1}$$

Table D.1 shows the mean values of e_k, e_w, the cost share of labor (S_L) for each of the four industries. A number of plants have e_k which are positive. This may be due to the positive correlation between capital and output.

It is clear that e_w is lower than S_L, suggesting the effect of omitting input prices that vary over time. Large plants pay higher wages and face lower material and energy prices because of bulk purchases. The negative correlation between wages and other input prices puts a downward bias on the coefficient of wages.

Table D.1. Cost Elasticity w.r.t Capital and Wages

Industry	e_k (Mean)	e_w (Mean)	S_L (Mean)
Computer & Data Storage	0.0006	0.11	0.27
Consumer Electronics	-0.003	0.16	0.3
Telecommunications Equipment	-0.008	0.04	0.28
Parts & Components	-0.004	0.05	0.3

Note: S_L is calculated by $\frac{\text{total expenditures on labor}}{\text{total cost}}$. Total cost consists of total expenditures on labor, material, energy, electricity and subcontracting work.

Appendix E

3-Product Plants

When the number of products within a multi-product plant is more than two, there are different ways to synthesize a plant's product portfolio. A three-product plant has two ways to enjoy economies of scope: (1) from a combination of three single-product plants, and (2) from combinations of a two-product and a single-product plants.

$$
\begin{aligned}
SC_1 &= \frac{C(q_1,0,0)+C(0,q_2,0)+C(0,0,q_3)-C(q_1,q_2,q_3)}{C(q_1,q_2,q_3)}\\
SC_2 &= \frac{C(q_1,0,0)+C(0,q_2,q_3)-C(q_1,q_2,q_3)}{C(q_1,q_2,q_3)}\\
SC_3 &= \frac{C(q_1,q_2,0)+C(0,0,q_3)-C(q_1,q_2,q_3)}{C(q_1,q_2,q_3)}\\
SC_4 &= \frac{C(q_1,0,q_3)+C(0,q_2,0)-C(q_1,q_2,q_3)}{C(q_1,q_2,q_3)}
\end{aligned}
$$

Table E.1 shows the degree of economies of scope for 3-product plants in the computer & data storage industry[1]. Generally, we get same results for these dif-

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[1] There are less than nine 3-product plants in each of other three industries and only four 4-product plants in the computer & data storage industry. Therefore, we only show the degree

ferent indices of economies of scope (SC_1 to SC_4) and just small difference across some types. The results suggest most 3-product plants have scope economies, but we have severe problem for negative estimates of incremental costs, $C(q_1, 0, 0) - C(q_1, q_2, q_3)$ and $C(q_1, 0, 0) - C(q_1, q_2, q_3)$. After calculating index of quasi-scope economies, there are less than 8 plants enjoying scope economies even using small $\varepsilon = 0.001$. Therefore, our results suggest that 3-product plants, overall, didn't have cost advantage of joint production in the computer & data storage industry.

Table E.1. Number of 3-Product Plants with Scope Dis(economies), by Type

	SC_1		SC_2		SC_3		SC_4	
Type	D	E	D	E	D	E	D	E
123	1	1		2	1	1	1	1
124	3		1	2	2	1	3	
125	3	1		4	3	1	3	1
134	2	5		7		7		7
135		3		3		3		3
145	1	4	1	4		5	1	4
234	1	1	1	1		2		2
245		2		2		2		2
345		7		7		7		7
Total	11	24	3	32	6	29	8	27

Notes: D represents scope diseconomies and E represents scope economies. We define (q_1, q_2, q_3) by plants' type; taking type 234 as an example, q_1 is for product 2, q_2 for product 3 and q_3 for product 4.

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of scope economies for 3-product plants in the computer & data storage industry.

Vita

Yi Lee

Yi Lee was born in Taipei, Taiwan on February 14, 1978. In 2000 she received a B.A. degree in Economics from National Taiwan University in Taipei, Taiwan. She enrolled in the Department of Economics at the Pennsylvania State University in 2001.