Industrial Diversification and Its Impact on Productivity Growth in Taiwan's Electronics Industry*

Show-Ling Jang†

National Taiwan University

Ming-Hung Weng

State University of New York at Stony Brook

Yanzhi Wang

National Taiwan University

The present study attempts to link plant-level production diversification to productivity growth in Taiwan's electronics industry. An account of the role of the Taiwanese government over the last 2 decades leading to the take-off of its electronics industry is briefly discussed. We reviewed production activities of more than 20 000 Taiwanese electronics plants during the period 1992–1999. In an inter-industry comparison, we find that at the four-digit and seven-digit industry levels, Taiwanese electronics production plants exhibit a significantly higher degree of product diversification than plants in the manufacturing sector as a whole. Econometric results positively identify diversification as a source of significant productivity growth across all electronics plants classified in the related industry groups.

Keywords: plant-level diversification, productivity growth, electronics industry.

JEL classification codes: O12, L63.

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† Corresponding author. Department of Economics, National Taiwan University, 21 Hsu-chow Road, Taipei 100, Taiwan. Email: sljang@ntu.edu.tw

I. Introduction

The exceptional capability of Asian manufacturing firms to mass produce standardized products has become widely recognized as a major source of their competitive advantage. Published empirical literature (Ferguson and Morris, 1993) has attributed the success of Asian companies to their learning of superb production skills, which in turn has facilitated the mass production of various commodities to well-defined standards.

Over the past 2 decades, profit margins have been growing thin in markets where most of the products are considered mature. Correspondingly, many multinational corporations, such as IBM, Dell and Hewlett-Packard, have switched from in-house production to outsourcing to their Asian partners, enabling the multinationals to focus more on R&D and marketing. The outsourcing has benefited Taiwanese electronics firms to a rapid growth, a growth that has outpaced Taiwan's international competitors. In year 2000, Taiwan became the world's third largest supplier of information products after the USA and Japan.

In an effort to accelerate the technological catching-up process, most of Taiwan's public R&D resources over the past 2 decades have been systematically allocated to the electronics industry, allowing great expansions in its technological capability. Aside from the widely-recognized strength in mass production, many electronics plants that traditionally concentrated on the production of computer-related goods have now diversified into the rapidly-growing telecommunications industry. Taiwan's electronics plants exhibit a significantly higher degree of diversification than that achieved by Taiwan's manufacturing plants, because technological know-how and production skills in electronic assembly have many related applications.

The present study examines the extent of plant-level diversification in Taiwan's electronics industry and analyzes its impact on productivity growth.[1] We use a pooled dataset of more than 20 000 electronics plants from the *Registered Firm Survey Report*, covering the period from 1992 to 1999.[2] The sample includes plants involved in data storage and processing products (SIC314), consumer electronics products (SIC315), communications equipment and apparatus (SIC316) and electronics parts and components (SIC317); these industries are then disaggregated at the seven-digit level.[3]

1. A 'plant' is defined as a physical location under single ownership engaging in one of the categories of industrial activity contained within the Taiwan Standard Commodity Classification.
2. This survey is conducted annually between census years by the Department of Statistics at the Ministry of Economic Affairs (MOEA), Taiwan. All manufacturing firms that are registered with the MOEA must provide annual plant-level operating data for this survey. The survey report can be purchased at http://2k3dmz2.moea.gov.tw/gwweb. The census year 1996 is excluded from the sample period in the present paper.
3. The coding numbers are identified in the Taiwan Standard Commodity Classification, which is similar to the US Standard Industry Classification. In terms of monetary value, the electronics plants in the above listed four three-digit industries that have produced more than 80 percent of the total production in the SIC31 (Electrical & Electronic Machinery). Our sample excludes the plants in the other five three-digit industries under SIC31 because they are not producers of major products in the semiconductor, computer and communications equipment industries.

The question we address in the present paper is whether product diversification has added to Taiwan's global manufacturing competitiveness in the electronics area. Our analysis begins with an overview of Taiwan's manufacturing sector over the past 2 decades, with a focus on its electronics industry. We then examine the way in which Taiwanese plants both in electronics and in overall manufacturing, diversify their product lines. Finally, we test the effect of diversification on the productivity growth of Taiwan's electronics plants. We found that productivity growth was significantly higher in plants with greater diversification across related industry groups.

The remainder of this paper is organized as follows. Section II provides background on Taiwan's manufacturing sector and electronics industry. Section III follows with a comparison of the extent of plant-level diversification in the electronics industry and manufacturing as a whole. Then Section IV discusses the econometric models used in the study and reports the findings. Section V concludes the paper.

II. Taiwan's Manufacturing Sector and Electronics Industry

Given that more than 90 percent of all manufacturing firms in Taiwan are private small and medium-sized enterprises (SME), very little high-technology build-up has been achieved on the island from the natural market mechanism. Since the early 1970s, the Taiwanese government has been the force behind the push for enhanced technological capability in a business environment dominated by a drive to export. One major step was the provision of government support for the island's attempt to transform itself into a high-technology-oriented economy. Pursuing this goal has resulted in the establishment of two institutions: (i) the Industrial Technology Research Institute (ITRI); and (ii) the Hsinchu Science-based Industrial Park.

At the same time, dramatic growth in the investment of industrial R&D (in the form of subsidies) rose from US$0.25bn in 1982, to US$2.24bn in 1999. These R&D resources have, on the whole, been unevenly distributed across industries, with the electronics industry taking a big bite before all others in research funding and personnel. The emphasis of the state to realize rapid 'catch-up' has led to a succession of collaborative R&D ventures that have emerged between public institutions and private firms. ITRI, for example, has acted as a prime vehicle for the leveraging of advanced technologies from abroad, and was responsible for the diffusion of the various technologies to local firms. Based upon these acquired technologies and their own R&D efforts, private firms were able to expand their technological base in the 20 years since ITRI was first established in 1973. Furthermore, because ITRI was first established in 1973, more than 15 000 skilled personnel have been subsequently spun-off from ITRI into the private sector, a move that has significantly contributed to improving the core competencies of private firms.

Given the strong public R&D policy stimulus for the electronics industry, R&D intensity (defined as the ratio of R&D expenditure to total sales) has been much higher within the electronics industry than in other manufacturing industries. The R&D intensity ratio of the electronics industry went from 1.46 percent in 1984, to 2.05 percent in 1992, subsequently reaching 2.41 percent in 1999. In contrast, the overall manufacturing sector was much less R&D intensive; the average ratio in this sector was only 0.79 in 1984, rising slightly to 0.92 in 1992, and 1.31 percent in 1999.[4]

In addition to the widely recognized entrepreneurial flexibility of SME in Taiwan, the accumulation of professional knowledge, of both a managerial and technological nature that is derived from long-term industrial R&D, has helped Taiwanese electronics firms to integrate into a fiercely competitive global supply chain with their numerous partners in the developed countries under a model of original equipment manufacturing. The buyers in the developed countries, who usually initiate the development and design of the product, provide detailed specifications to their subcontractors when placing a production order for an intermediate input or a finished product. The Taiwanese subcontractors then have to ensure that they maintain high output rates to achieve economies of scale and scope, thereby meeting the buyers' requirements of low costs, timely delivery and consistent quality.

In 1980, the high-technology manufacturing industry, dominated by the semiconductor, computer and communications equipment segments, accounted for less than 12 percent of Taiwan's total manufacturing output. By 1992, this proportion had climbed steadily to 17 percent, and leapt to 25.6 percent by 1998. By year 2000, Taiwan had even succeeded in establishing itself as the world's third largest production center for information and electronics products, behind only the USA and Japan. The manufacturing of IC foundry and packaging, notebook computers and components had gained considerable market recognition.[5] To maintain the growth rate achieved over recent years, many of Taiwan's electronics plants, which had traditionally been recognized as producers of computer-related products, have now noticeably diversified into the rapidly growing telecommunications industry, providing products such as cellular phones, personal digital assistants and information appliances. Our objective here is to test the significance of such production diversification in explaining the manufacturing competitiveness of electronics production plants.

III. The Extent of Plant-level Diversification

Previous studies by Dunne et al. (1988); and Gollop and Monahan (1991) suggest that increased specialization appears to be a common trend in the manufacturing sector of industrialized countries. Dunne et al. (1988) points to

4. Data source: Statistics on Science and Technology Indicators, National Science Council, Taiwan, 2001.

5. According to a market survey by the Market Intelligence Center, Institute for Information Industry, Taiwan, in 1999 14 of Taiwan's information product items had secured the highest global market share and, of these, 9 items had more than 50 percent of the market.

the decreasing number of product lines in US manufacturing industries between 1963 and 1982. Gollop and Monahan (1991) note that product specialization in individual plants in the USA increased in 17 out of 20 two-digit industries over the same period. Furthermore, according to the findings of their multi-industry studies, there were no discernible differences in the degree of diversification between plants in the electrical equipment manufacturing industry and other manufacturing industries.

Streitwieser's study (1991) of US manufacturing industries from 1972 to 1982 finds that firms in the high technology sector had tended to produce a greater number of different products than firms in the lower technological strata. The present study compares the diversification behavior between the electronics industry in Taiwan and Taiwan's manufacturing sector as a whole, using plant-level data from the Taiwanese Registered Firm Survey Report, covering the period from 1992 to 1999 (with the exception of the 1996 census year)

Several measures of plant-level diversification are constructed in the present study. We use commodity sales profiles at the four-digit and seven-digit levels of the Taiwan Standard Commodity Classification. Two criteria were adopted for the screening of plants within the sample. First, those plants at the seven-digit level whose sales of individual product lines were either missing or incomplete were excluded from the sample. Second, all plants in the tobacco industry were excluded because of their small number. The resulting sample comprised of 480 957 manufacturing plants in 21 two-digit manufacturing industries. The electronics industry was singled out from the sample for further regression analysis. There were a total of 21 224 electronics plants.[6]

Because our data are taken from the Registered Firm Survey Report, the sample naturally excludes the plants of non-registered firms. However, our final sample does include more than half of all plants economy-wide (Table 1). The data are representative of more than 65 percent of all employees in both the manufacturing sector and electronics industry in Taiwan, respectively.

Table 2 provides some details of the extent of plant-level diversification at the four-digit and seven-digit levels for the whole sample period. Plant-level diversification is measured in terms of the percentage of both the number of multi-product plants and their shipment value in the electronics industry. This measure was repeated for overall manufacturing. Some trend effects are clearly evident; the first of which is a common decline in diversification over time (i.e. increased specialization) for all plants.

There are also considerable disparities in the share of the number of multi-product plants between the electronics industry and the manufacturing sector. More specifically, at the four-digit level, the share of multi-product plants attributable to manufacturing was 8 percent in 1992, and just 6 percent in 1999.

6. The 1994 sample sizes for both the electronics industry and the manufacturing sector were much smaller than those in the other years because some of the firms in that year contained data that did not meet our criterion for inclusion.

Table 1 Sample size, by number of plants

	Sample years							*Census year*
	1992	*1993*	*1994*	*1995*	*1997*	*1998*	*1999*	*1996*
Manufacturing sector								
Number of plants	71 990	73 457	51 906	71 350	66 891	70 171	75 192	158 609
Number of employees	1 697 527	1 791 241	1 816 455	1 830 942	1 760 705	1 741 852	2 252 991	2 474 638
	(2 585 000)	(2 483 000)	(2 485 000)	(2 449 000)	(2 570 000)	(2 611 000)	(2 603 000)	
Electronics industry								
Number of plants	2737	3001	2157	3126	2955	3359	3889	7211
Number of employees	183 222	203 516	148 603	213 850	231 263	227 224	334 203	376 171

Note: Numbers in parentheses are those of employees of the national-wide manufacturing sector from Manpower Surveys, Directorate-General of Budget, Accounting and Statistics, Taiwan.

Table 2 Four-digit and seven-digit plant-level diversification

	Sample Years						
	1992 (%)	*1993 (%)*	*1994 (%)*	*1995 (%)*	*1997 (%)*	*1998 (%)*	*1999 (%)*
Panel A: Four-digit level							
Manufacturing sector							
Plants	0.083	0.069	0.070	0.058	0.071	0.064	0.059
Shipment value	0.366	0.299	0.303	0.412	0.318	0.350	0.330
Electronics industry							
Plants	0.160	0.141	0.158	0.103	0.115	0.103	0.092
Shipment value	0.541	0.437	0.445	0.454	0.489	0.543	0.418
Panel B: Seven–digit level							
Manufacturing sector							
Plants	0.143	0.131	0.124	0.099	0.128	0.105	0.098
Shipment value	0.468	0.456	0.403	0.565	0.318	0.350	0.330
Electronics industry							
Plants	0.238	0.230	0.237	0.158	0.193	0.154	0.138
Shipment value	0.636	0.610	0.639	0.629	0.625	0.650	0.564

The comparative shares in the electronic industry were 14 percent in 1992, and 10 percent in 1999. A similar pattern is registered at the seven-digit level.

Table 2 also indicates that the share of the total value of shipments out of multi-product electronics plants was significantly higher than that of their manufacturing counterparts. At the four-digit level, multi-product plants in electronics contributed 54 percent of the total values of shipments in electronics in 1992 and 42 percent in 1999. Multi-product plants in manufacturing contributed to the manufacturing sector's values of shipment only 37 percent in 1992 and 33 percent in 1999.

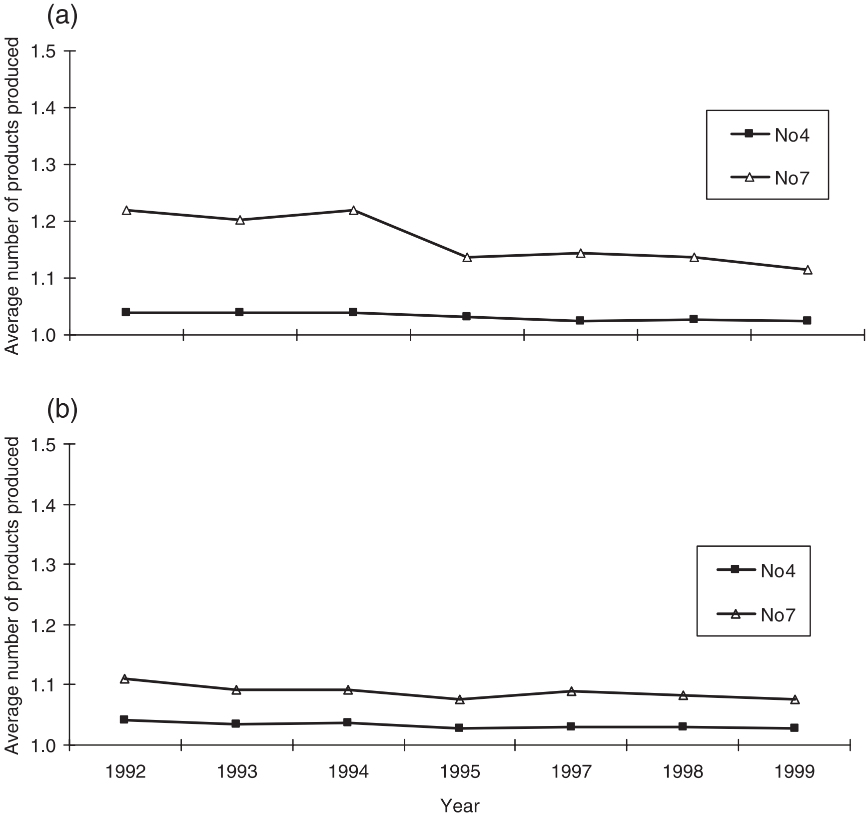
In Figure 1 No4 and No7 denote the respective average numbers of product lines per plant at the four-digit and seven-digit levels. As Figures 1(a) and (b) show, there was a reduction in these levels over time for both electronics and the whole of manufacturing, suggesting that plants were becoming more specialized over time. However, we find that the average numbers of product lines in these plants at both the four-digit and seven-digit levels was significantly greater in electronics than in manufacturing.

We next adopt the Herfindahl index to measure the extent of diversification, as follows:

$$H = 1 - \sum_{i=1}^{n} S_i^2 , \tag{1}$$

where n denotes the total number of product lines of plants across four-digit or seven-digit industry levels, and S_i represents the proportion of the plant's sales accounted for by the ith product line.

Figure 1 Plant level diversification within the (a) electronics industry and (b) manufacturing sector

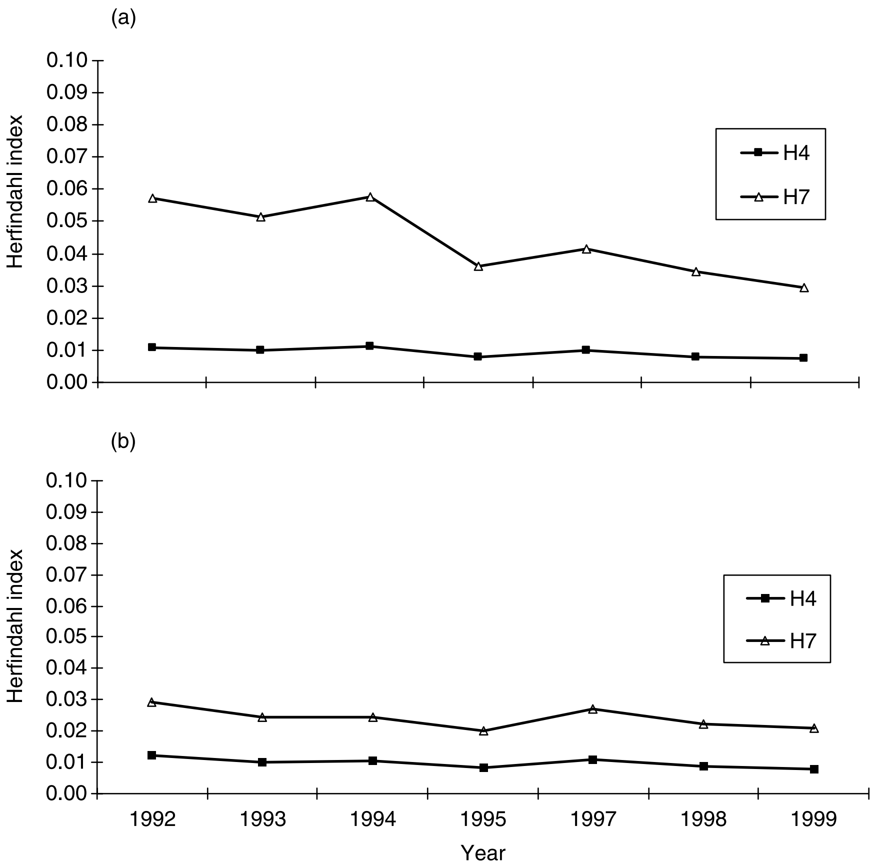


Note: No4 and No7 denote the average numbers of product lines per plant at the four-digit and seven-digit levels, respectively.
Source: Registered Firm Survey Report, 1992–1999.

The Herfindahl index takes into account not only the number of product lines in each plant, but also the distribution of sales over all production lines. A greater index value indicates a higher degree of diversification. The Herfindahl index for the plants are, respectively, denoted as *H4* and *H7* for the four-digit and seven-digit industry groups. As Figures 2(a) and (b) indicate, the average magnitude of *H4* and *H7* in electronics was almost twice the level observed in the manufacturing sector.

The three measures of diversification outlined above; namely, No4, No7 and H, suggest that at both the four-digit and seven-digit industry levels, there is a significantly higher degree of diversification within plants in the electronics industry than that which is present in total manufacturing. This is a ubiquitous trend. The electronics industries also have higher R&D intensity and higher technological

Figure 2 Plant level diversification in the (a) electronics industry and (b) manufacturing sector



Note: H4 and H7 denote the Herfindahl index for the plants for the four-digit and seven-digit industry groups, respectively.
Source: Registered Firm Survey Report, 1992–1999.

capability. It is apparent that in addition to pursuing the high-volume production of homogeneous products, an alternative strategy for maintaining competitiveness within the electronics industry has been to produce a wider scope of products at the lowest possible prices using plants' internally-generated proprietary production skills, technological know-how and managerial experience.

Streitwieser (1991) suggests that economies of scope might exist as a result of joint production, whereas Teece (1980, 1982) argues that although the achievement of economies of scope can explain joint production, it does not explain why joint production must be organized within a single multi-product organization. Teece emphasizes that even in the absence of a multi-product organization, joint production can proceed if contractual mechanisms can be devised to share those inputs that yield such scope economies. However, if difficulties arise in the transactions surrounding the sharing of a common input, such as technological know-how, managerial expertise, or certain specialized physical assets, then compelling efficiencies are likely to be yielded by a multi-product organization. Diversification can, therefore, represent a very effective and efficient mechanism that enables a plant to secure integration economies associated with the simultaneous supply of inputs common to several production processes that are geared to distinct final product markets.

Chandler (1990) also recognizes that manufacturing enterprises tended to produce multi-products because such additional new product lines allowed them to maintain long-term rates of return on their investment through a reduction in the overall costs of production, and through the transfer of facilities and skills to meet the challenges of the market. Such a process of diversification has provided these firms with the internal dynamics that has enabled them to maintain their competitive position. Therefore, holding constant all other control variables, from a supply-side perspective the diversification of production within a plant can lead to improved productivity performance as a direct result of the cost advantages of joint production.

In contrast, Scherer et al. (1975) view multi-plant operations as a form of hedging against demand volatility, because they argue that diversification across product lines has the potential of reducing fluctuations in returns, or indeed, the probability of failure resulting from instability of demand as a result of either the withdrawal of orders by buyers or the rapid pace of product maturation. Demand dynamics has been a critical problem for producers in the high-technology industries. As noted by Fraser (1990), those manufacturers with greater risk awareness might well experience some conflict between product complementary and risk aversion at a given level of diversification. This implies that any attempt by manufacturers to diversify their production activities, under a leading consideration of demand instability, might well lead to cost disadvantages.

We believe that the motivations that drove the production diversification activities probably included factors on both the supply side and the demand side. The net correlation between plant-level diversification and productivity growth, however, might not be predicted. In the following section, we test for the presence of this correlation.

IV. The Impact of Plant-level Diversification on Productivity

IV.1 Theoretical modeling

In their examinations of the relationship between production diversification and productivity growth, many of the prior published studies have focused on the developed countries. Gollop (1997), for example, found that between 1963 and 1987, the reduction in product heterogeneity was a major determinant of manufacturing productivity growth in the USA. Lichtenberg (1992) also shows that when holding constant the number of parent-firm plants, the greater the number of industries within which the parent firm operates, the lower the productivity of its plants. The present paper examines the relationship between production diversification and productivity growth within Taiwan's electronics industry at the plant level. To our knowledge, no prior research has estimated the contribution of product diversification to the manufacturing strength of Asian firms.

We apply a multilateral index to measure total factor productivity growth (ln *TFP*) for each plant in the electronics industry over the sample period, and then go on to develop a set of regression models to examine the impact of production diversification on productivity growth for these plants. The multilateral index method, developed by Caves et al. (1982), has been used to measure productivity in several empirical studies (e.g. Caves et al., 1982; Aw et al., 2001). This index relies upon a single reference point, constructed as a hypothetical plant, with the input cost share (or output revenue share) equal to the arithmetical means of shares over all observations and input levels (or output levels) equal to the geometric means of the inputs (or outputs) over all observations. The input, output and/or productivity level of each plant is measured for each year relative to the hypothetical plant, with the multilateral index providing transitive comparisons between any of the observation subsets.

According to Caves et al. (1982), the derivation of the multilateral index is based upon a constant returns-to-scale translog transformation function, upon which no further constraint of the elasticity of substitution is imposed. The same assumptions are applied in our model.[7] We also use the extended multilateral index proposed by Good et al. (1996) to chain-link all the separate hypothetical plant reference points in each year over the sample period.

Let an electronics plant i produces a set of outputs $Y_{m,i,t}$, where $m = 1, 2, \ldots, n$ in time t. The plant uses a set of inputs, $X_{j,i,t}$, with j = labor (L), materials (M) and capital (K). The TFP growth index for electronics plant i in year t is defined as:

$$\begin{aligned}\ln TFP_{i,t} = {} & \frac{1}{2}\sum_{j}(r_{m,i,t} + \overline{r_{m,t}})(\ln Y_{m,i,t} - \overline{\ln Y_{m,t}}) + \frac{1}{2}\sum_{s=93}^{t}\sum_{m}(\overline{r_{m,s}} + \overline{r_{m,s-1}}) \\ & \sum_{s=93}^{t}(\overline{\ln Y_{m,s}} - \overline{\ln Y_{m,s-1}}) - \frac{1}{2}\sum_{j}(s_{j,i,t} + \overline{s_{j,t}})(\ln X_{j,i,t} - \overline{\ln X_{j,t}}) \\ & - \frac{1}{2}\sum_{s=93}^{t}\sum_{j}(\overline{s_{j,s}} + \overline{s_{j,s-1}})(\overline{\ln X_{j,s}} - \overline{\ln X_{j,s-1}}) \quad s, t = 93, \ldots, 97,\end{aligned} \tag{2}$$

7. The growth of TFP could be theoretically decomposed into pure technical change and scale effect by incorporating the cost elasticity of output, which might be obtained from the estimation of the cost function for firms that exhibit homogeneous production behaviors (Denny et al., 1981). It is not likely that production behavior of the electronics plants in our sample would have first degree homogeneity in their production technology and scale. Therefore, we apply a multilateral index to measure TFP growth (ln TFP) for each plant directly without adjusting the scale effect or the elasticity of substitution through cost function estimation.

where the output weight, $r_{m,i,t}$, is the revenue share of plant i attributable to output Y_m, and the input weight, $S_{j,i,t}$, is the cost share of plant i attributable to input X_j. The over-bars denote the average value of all electronics plants in year t, and the index measures the percentage deviation in TFP relative to the hypothetical plant, for plant i, in year t, in the base time period which in this study, is 1992.

A multilateral TFP growth index captures many factors contributing to the differences in efficiency between plants, such as differences in technology, age, labor quality, quality of capital stock, managerial ability or scale economies. It is a more comprehensive measure of productivity growth than a multilateral single-input productivity growth index such as the ln *LP*, ln *KP* and ln *MP*.[8]

The Registered Firm Survey Report dataset provides information on detailed input and output variables of the plants necessary to measure plant-level TFP growth. Plant output is defined as the real value of plant sales net of subcontractors' services. The net plant sales are deflated by the industry-specific output price deflator obtained from the *Monthly Price Index Statistics* published by the Directorate-General of Budget, Accounting and Statistics.

We assume that each electronics plant uses three production inputs: labor (L), materials (M) and capital (K), where L is simply the number of employees. Total wage bill is the sum of worker salaries (non-wage benefits are excluded because of data shortage). The material input M includes expenditure for all raw materials, water and electricity. Payments for raw materials are deflated by the price deflator of intermediate electronics goods at the two-digit level. Expenditure on water and electricity is deflated by water and electricity price indices, which are universal for all industries.

The quantitative indices of raw materials, water and electricity are aggregated to obtain a cost-share weighted average of the quantitative index of materials. Because our data sample is insufficient for directly estimating the price and quantity of capital inputs, these are taken as the plant's book value of capital stock deflated by the price deflator of fixed capital formation. The capital input price ($P_{K,t}$) is derived from an adaptation of the model utilized by Hall and Jorgenson (1967), and is measured as:

$$P_{K,t} = P_{I,t-1}\gamma_t + \delta P_{I,t-1} - (P_{I,t} - P_{I,t-1}), \tag{3}$$

where $P_{K,t}$ is the price of capital K in year t; $P_{I,t}$ is the replacement price of capital K in year t proxied by the price deflator of fixed capital formation in that year; γ_t is the average interest rate on time deposits offered by Taiwan Bank in year t; and δ is the average depreciation rate calculated from total depreciation expenditure divided by the book value of capital stock for each plant. The plant's expenditure on capital is equal to the quantity of capital multiplied by the price of capital. The sum of labor, materials and capital expenditure represents the plant's total production costs.

8. To measure the multilateral single-input productivity growth, we set j = L (or M or K) in Equation (2).

To estimate the relationship between production diversification and productivity growth within Taiwanese electronics plants, we use the following estimation model:

$$\ln TFP_i = f(DIV_i, Z_i) + e_i, \tag{4}$$

where $\ln TFP_i$ is the chained multilateral TFP growth index of plant i, calculated by Equation (2); DIV is a measure of the degree of plant diversification; Z is a set of control variables for each electronics plant i; and e_i is an error term.

We construct four regression models, each with a different plant-level diversification index and a common set of control variables. *MULTI 4* and *MULTI 7* are two dummy variables of diversification used in Models 1 and 2, respectively. *MULTI 4* has a value of 1 if the plant exhibits production diversification at the four-digit industry level, otherwise zero. *MULTI 7* has a value of 1 if there is production diversity at the 7-digit level, otherwise zero. The extent of diversification in Models 3 and 4 is, respectively, measured by *H4* and *H7*.

The set of control variables in Z_i includes plant size and age, along with four other industry-specific variables, following Caves and Barton (1990), to determine the productivity growth of industrial groups in Taiwan's electronics industry. These variables are R&D intensity (*RD*); new capital intensity (*IK*); the annual rate of output growth (*GR*); and market concentration (*CR8*). The summary statistics and correlation matrix of the control variables in Z_i are provided in Tables A2 and A3, respectively.

III.1 Size of plant

Differences in productivity growth relating to plant size are controlled by the variable *SIZE*, defined as the logarithmic value of total net plant sales. This is obtained by deducting from total plant sales the subcontracting services provided by other plants. Larger plants might possess more specialized assets than smaller ones, such as technological know-how and human capital; hence, the impact of plant size could be positive. In contrast, larger plants might also suffer from managerial inefficiency, which would impede their overall productivity. For these reasons, we determined that there not be an a priori relationship posited between plant size and productivity growth.

III.2 Age of plant

A plant's age, *AGE*, is measured in terms of the number of years from the plant's establishment to the end of the study year. New plants are traditionally regarded as the bearers of new technology and, therefore, are expected to be more effective. However, the analysis of the productivity growth of large US manufacturing plants in Bartelsman and Dhrymes (1998), covering the period from 1972 to 1986, found that new plants were not uniformly more productive than old plants, insofar as new plants were faced with greater uncertainty in their evolution and, therefore, had a lower probability of maintaining their productivity gain. Aw et al. (2001), in contrast, determine that the entry and exit of firms had been a significant source of productivity growth in Taiwan, and that exiting firms were less productive than the survivors. Therefore, we let the empirical findings of the present study speak to the nature of the relationship between age and productivity growth.

III.3 R&D intensity

The intensity of sectoral R&D activities reflects the technological opportunities that are available as well as the chance experienced within each sector. Innovative efforts are expected to deliver payoffs over time in terms of the achievement of new technological processes, new product introductions and improvements to existing product lines. Therefore, R&D intensity (*RD*), measured as the ratio of R&D expenditure to sales at the four-digit industry level, is expected to have a positive effect on plants' productivity performance (Lichtenberg and Siegel, 1991; Hall and Mairesse, 1995).

III.4 IK ratio

Because much of the new technology is embodied in new vintages of capital, an increase in capital formation effectively accelerates the rate of new technology introduction and, therefore, improvements in productivity growth. We use the ratio of new capital investment to total fixed assets (*IK*) at the four-digit industry level to indicate the extent to which new technology is flowing into an industry group, thereby broadening the spectrum of technologies used in that industry. The *IK* ratio is expected to relate positively to the productivity growth of plants.

III.5 Growth rate

The annual growth rate of sales at the four-digit industry level (*GR*) is used to describe the industry-specific characteristics of demand. Plants in a rapidly growing industry clearly have a greater capacity for investment of their windfall profits into new equipment and technologies than plants in an industry faced with diminishing demand. Production growth develops abilities, thereby encouraging experimentation in an effort to identify, combine and exploit production factors. The variable (*GR*) is, therefore, expected to have a positive correlation with productivity growth. However, any unanticipated increase in demand will lead to disparities between expected and actual demand, affecting existing production capacity. Furthermore, any unanticipated intensive use of existing production capacity will delay the retirement of older plants, which can lead to lowering productivity growth. Therefore, the sign of *GR* cannot be predicted.

III.6 CR8

We use a concentration variable, *CR8*, measured as the sales ratio of the eight largest plants at the four-digit industry level, to reflect the degree of competition within the market. Caves and Barton (1990) suggest that when production was concentrated in the hands of a few large producers, then: (i) the absence of strong competition between sellers will allow inefficient production units to survive; and (ii) imperfect competition generates its own forms of inefficiency when partially collusive bargains in oligopoly induce rent-seeking forms of non-price competition. Therefore, the higher the concentration level, the lower the level of productivity growth. In contrast, Scherer (1984) argue that concentration could lead to greater R&D intensity, which in turn would increase productivity growth. The present study does not suggest an a priori direction of the impact of market concentration.

III.7 TIME

Finally, a dummy variable, *TIME*, is used to describe the productivity changes during the time periods in question.

The detailed definitions of these control variables are listed in the appendix tables. Data covering the period from 1993 to 1999 are pooled (with the exception of the 1996 census year). However, because the output growth rate, GR, is incorporated into the regression model, the time period of the dataset used in the regression analysis covers only 6 years instead of seven.

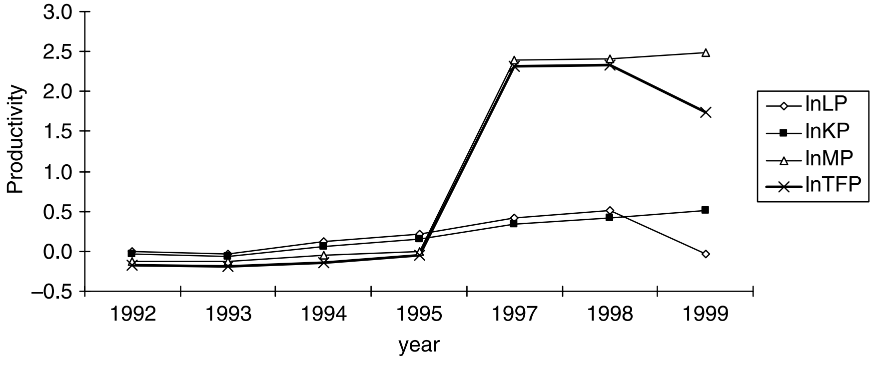
IV.2 Empirical results

Figure 3 illustrates the trends of the four multilateral productivity growth indices: ln *LP*, ln *KP*, ln *MP* and ln *TFP* over the 1992–1999 period. Both ln *LP* and ln *KP* have slightly increased through time. However, ln *MP* increased dramatically between 1997 and 1999, clearly as a result of the fact that material prices generally declined since the 1997 Asian financial crisis. Because TFP growth captures all the factors leading to efficiency differences across plants, we use the multilateral ln *TFP* for our empirical analysis.

The impact on productivity growth from production diversification within Taiwan's electronics plants is explored through four OLS regression models. The overall estimation results, which are presented in Table 3, indicate that most of the explanatory variables have significant impacts on plant level productivity growth, with the adjusted R^2 being approximately 0.21 for each of the four models.

The overall effect of the degree of diversification is the primary concern of the present study. We see that in Models 1 and 2, the respective estimated coefficients

Figure 3 Productivity growth in the electronics industry



Source: Registered Firm Survey Report, 1992–1999.

Table 3 Plant productivity growth (ln TFP) regression results on diversification in Taiwan's electronics industry

	Model 1	*Model 2*	*Model 3*	*Model 4*
MULTI 4	0.250*	—	—	—
	(10.95)	—	—	—
MULTI 7	—	0.274*	—	—
	—	(14.05)	—	—
H4	—	—	0.456*	—
	—	—	(8.33)	—
H7	—	—	—	0.510*
	—	—	—	(11.64)
SIZE	−0.037*	−0.038*	−0.037*	−0.038*
	(−3.71)	(−3.87)	(−3.71)	(−3.87)
AGE	−0.012*	−0.013*	−0.012*	−0.012*
	(−9.61)	(−9.96)	(−9.17)	(−9.55)
RD	−0.118*	−0.117*	−0.120*	−0.118*
	(−12.52)	(−12.48)	(−12.69)	(−12.60)
IK	0.104*	0.107*	0.103*	0.105*
	(6.54)	(6.75)	(6.46)	(6.64)
GR	−0.492*	−0.489*	−0.492*	−0.490*
	(−23.800)	(−23.79)	(−23.83)	(−23.81)
CR8	0.028*	0.027*	0.029*	0.027*
	(6.34)	(6.14)	(6.54)	(6.31)
TIME	0.988*	0.990*	0.987*	0.989*
	(35.68)	(35.82)	(35.61)	(35.73)
CONST	−0.002	−0.029	0.011	−0.011
	(−0.08)	(−1.06)	(0.42)	(−0.40)
R^2	0.214	0.217	0.212	0.215
Number of observations	20 800	20 800	20 800	20 800

Notes: Dependent variable is ln *TFP* defined in Equation (2). * Indicates significance at the 5% level. *MULTI 4* and *MULTI 7* are two dummy variables of diversification for the plants at four-digit and seven-digit industry level, respectively. *H4* and *H7* are the extent of diversification for the plants at four-digit and seven-digit industry level, respectively. The definitions of *SIZE*, *AGE*, *RD*, *IK*, *GR*, *CR8*, *TIME* are described in Table A1. *CONST* denotes the constant term. —, variable that is not estimated in the regression model.

of diversification (*MULTI 4* and *MULTI 7*) have significantly positive effects on TFP gain. This finding suggests that, consistent with the theory, holding constant all other control variables, plants that diversify across related products defined either as the four-digit or seven-digit industrial groups, have had better productivity growth than plants that have refrained from diversification. Another interesting finding is the relative magnitude of the coefficients of *MULTI 7* (0.27) and *MULTI 4* (0.25). It appears that plants that have diversified across more related products (*MULTI 7*) have enjoyed higher productivity, albeit not by much.

In Models 3 and 4 of Table 3, the dummy variables *MULTI 4* and *MULTI 7* are replaced by the Herfindal indices, *H4* and *H7*. As stated before, the Herfindahl indices represent the degree of plant-level diversification. The empirical findings reinforce what we have learned from Models 1 and 2 in that the coefficients of *H4* and *H7* are also both positive and significant. The finding is consistent with the proposition that an increase in the extent of a plant's diversification into related products leads to an improvement in the plant's technical efficiency.

In addition, the effect of *H7* on ln *TFP* (0.51) in Model 4 is larger than the effect of H4 on the same indicator in Model 3 (0.46), suggesting a direct effect of a plant's higher productivity growth rate stemming from the degree of its diversification. Also, when compared symmetrically to the coefficients of *MULTI 4* and *MULTI 7*, the coefficients of *H4* and *H7* have a much greater magnitude, which would seem to suggest that the degree of diversification is a much more significant variable than the diversification dummy in explaining the TFP gain.

Plant size (*SIZE*) is negative and statistically significant in all four models, showing that larger plants have adversely affected plant productivity growth, possibly as a result of inherent managerial inefficiencies. The *AGE* coefficient, as expected, is negative and significant in all models. The more recently-introduced electronics plants appear to be more productive than those with more vintage. It would appear that as a plant ages, it becomes the bearer of outdated technology and has more limitations in achieving plant efficiency.

With the one exception of the coefficient of R&D intensity, the signs of all other control variables turn out to be consistent with our prior hypotheses. The coefficient of R&D intensity (*RD*) is negative and statistically significant in all models, which is a surprise to us. The reason for that might be that a crucial source of productivity growth within Taiwan's electronics industry has been the use of knowledge transfer through the purchase of know-how (either from the government or from abroad) rather than the development by their own in-house R&D activities. Unfortunately, the lack of availability of data prevents us from carrying out further testing of this issue.

The coefficients of innovation status, *IK*, are positive and significant in all models, suggesting that the embodiment effect of new investment does indeed exert a positive influence on productivity growth. The coefficient of *GR* is negative and statistically significant in all models, indicating that intensive use of existing production capacity, as a result of any unanticipated increase in demand, has tended to delay the scrapping of older plants, which has led to lower productivity growth.

Consistent with the findings of Scherer (1984), concentration ratio (*CR8*) has a positive relationship with productivity growth. The coefficient of the time period dummy variable suggests that the rate of productivity growth in the electronics plants has changed significantly during the period under examination. The average ln *TFP* increased at a growth rate of 10 percent between 1997 and 1999 in all four models, relative to the base period of 1993–1995.

V. Conclusions

The present study has tested the significance of product diversification as a determinant of plant-level productivity growth in Taiwan's electronics industry.

Our empirical models were based on a pooled dataset of more than 20 000 electronics plants, and covered the period from 1992 to 1999.

Empirical results suggest that when all other control variables concerning plant-specific and industry-specific characteristics are neutralized, the productivity growth rates within the electronics plants are greater, the higher the degree of diversification. It appears that Taiwan's electronics production plants have succeeded in making the best use of internally-generated proprietary production skills, shared technological know-how and managerial expertise. As a result, scope economy has helped in significantly enhancing the industry's competitive position worldwide.

Appendix

Table A1 Definitions of regression analysis control variables

Variable	*Definition*
SIZE	The logarithmic value of total net plant sales. Total net plant sales are obtained by deducting the subcontracting services provided by other plants from total plant sales and then deflated by the industry-specific output price deflator from Monthly Statistics of Price Index published by the Directorate-General of Budget, Accounting and Statistics.
AGE	Age of the plant, measured in terms of the number of years from its establishment to the end of the study.
GR	Annual sales growth rate at the four-digit industry level.
IK	The ratio of new capital investment to total fixed assets at the four-digit industry level.
RD	The ratio of R&D expenditure to sales at the four-digit industry level.
CR8	Concentration of the 8 largest plants' sales ratio at the four-digit industry level.
TIME	Time-specific dummy variable, equal to one if it is between 1997–1999, zero if between 1992–1995.

Table A2 Summary statistics of regression variables

	Mean	*Standard deviation*	*Minimum*	*Maximum*
LNTFP	1.0448	1.4172	−7.6956	9.3558
MULTI 4	0.1209	0.3261	0	1
MULTI 7	0.1872	0.3901	0	1
H4	0.0425	0.1323	0	0.8718
H7	0.0724	0.1734	0	0.8782
SIZE	0.8798	1.1948	−2.7545	4.7506
AGE	2.3391	6.0564	−7.7260	38.3996
RD	2.1706	1.2387	0.6312	6.5500
GR	0.3218	0.6613	−1.0351	4.3658
IK	1.8085	0.8188	0.1055	4.2550
CR8	1.6924	2.6192	0.2034	27.0028

Table A3 Correlation matrix

	LNTFP	*MULTI 4*	*MULTI 7*	*H4*	*H7*	*SIZE*	*AGE*	*RD*	*IK*	*GR*	*CR8*
LNTFP	1	—	—	—	—	—	—	—	—	—	—
MULTI 4	0.0528	1	—	—	—	—	—	—	—	—	—
MULTI 7	0.0729	0.7782	1	—	—	—	—	—	—	—	—
H4	0.035	0.8653	0.6753	1	—	—	—	—	—	—	—
H7	0.0597	0.7185	0.8718	0.7843	1	—	—	—	—	—	—
SIZE	0.1811	−0.055	−0.0492	−0.0577	−0.04421	—	—	—	—	—	—
AGE	0.0133	0.0992	0.1015	0.0758	0.0857	0.128	1	—	—	—	—
RD	−0.0086	−0.0525	−0.0524	−0.0469	−0.0457	0.2894	−0.0145	1	—	—	—
IK	0.2724	−0.0663	−0.0758	−0.068	−0.0711	0.5652	0.0787	0.1286	1	—	—
GR	−0.2186	−0.0207	−0.0358	−0.0208	−0.0337	0.0263	−0.0383	0.1924	0.0571	1	—
CR8	0.0352	0.0727	0.0783	0.0661	0.076	−0.0709	0.031	0.3064	−0.0878	0.0564	1

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