The impact of IT investment on productivity of Taiwanese manufacturing firms

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Abstract

This paper employs the manufacturing sampling survey data from the industry, commerce, and service census of Taiwan in 1991 to explore the issue of whether IT investment brings about the productivity paradox. In order to take the improvement of product quality caused by IT investment into account, a proper computer price index is used to deflate the IT variable. This paper applies the Translog production function to construct an empirical framework. We use the Translog production function to jointly estimate marginal product, output, and substitution elasticities. Empirical results show that IT investment provides a significant contribution to productivity as indicated in the study of both full sample and subsamples, suggesting that there is no productivity paradox. We also find that IT capital is a net substitute for non-IT capital, implying that when IT prices change, the flow of the input to substitute for the others will occur.

Keywords: Information technology; Productivity paradox; Productivity; Hedonic price index

1. Introduction

The progression of information technology (IT) has brought about the so-called third industrial revolution for the world’s population. With the application of Internet and E-commerce, the function and efficiency of IT have diffused rapidly. In the past two decades, most industrial countries have invested a huge amount into IT in order to create, accumulate, storage, and transfer knowledge and also to improve competition and profit. For example, the share of IT in a firm’s total investment in equipment has jumped from 7% in 1970 to 40% in 1996 (Economist, 1996). Dewan and Kraemer (2000) quoted a statistical survey by the International Data Corporation (IDC) in 1997, showing that global IT expenditure has increased from $162 billion in 1985 to $630 billion in 1996 and with a continuing, rising trend. Jorgenson (2001) found that the decline in IT price provides enterprises powerful economic incentives for the substitution of IT investment for other forms of inputs. The value of the net stock of IT capital equipment approached $900 billion by the end of 1999 in the U.S. (Stiroh, 2001). Pakko (2002) analysed official statistics from the U.S. Bureau of Economic Analysis (BEA) and wrote that IT expenditure has risen to account for over one-third of a business’ total fixed investment by the year 2000.

Taiwan plays a key position in the production and manufacturing of IT equipment for the world. Taiwan has an important role in producing IT-related equipment such as that in the semiconductor, computer, and telecommunications fields. In addition to the IT manufacturing industry, other industries in Taiwan also have made massive investment in IT so as to face the competition in this age of the knowledge-based economy. Taiwan’s IT expenditure approached NT$118.4 billion in 2000. According to the survey that was conducted by the electronic data-processing center of the Directorate General of Budget, Accounting & Statistics (DGBAS). The share of the manufacturing industry’s IT expenditure to the overall industrial sector amounted to 85%. Furthermore, the IT expenditure of the manufacturing industry rose from NT$20.1 billion in 2000 to NT$20.6 billion in 2001.

Some economists have discovered that the IT revolution does not necessarily result in productivity growth. They also point out that the increase in IT investment does not necessarily help to promote productivity. Solow (1987) called this phenomenon the “Productivity Paradox”. Morrison and Berndt

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1 The survey method regards the questionnaire as the main mode, effectively having a total number of observations at 7,225. The sample data is used to figure out total population, and so the value is an estimated value and is not a physical observation number.
(1995) explored relationships between industry performance measures and investments in high-tech office and IT capital for two-digit manufacturing industries from 1968 through 1986, and they found that increases in IT are negatively correlated with multi-factor productivity. Loveman (1994) exploited business unit level data for U.S. and Western Europe manufacturing companies from 1978 to 1984 to explore the productivity impact of IT investment, writing that no matter whether having full sample or subsamples, the output elasticity for IT ranges from −0.12 to 0. This shows the result that the value of marginal product (MP) is not only zero, but also negative. Therefore, the above empirical studies display the phenomenon of the productivity paradox.

The empirical studies of later scholars present entirely different conclusions. Brynjolfsson and Hitt (1996) used firm-level data for 1987-1991, which included 367 U.S. large firms, to explore the contribution of output from IT. Their results indicate that IT spending has a substantial and statistically significant contribution to firm output. They also found that the gross MP for IT capital averaged 81%. Lehr and Lichtenberg (1998) examined the impact of IT on productivity in the public sector, showing that there is a strong positive relationship across federal agencies between productivity growth and computer-intensity growth during the period 1978-1992. Therefore, according to the above studies the productivity paradox phenomenon is non-existent. Barua and Lee (1997), Dewan and Min (1997), Stiroh (1998), Gera, et al. (1999), Matt and Oliver (2001), and Jorgenson (2001) all showed that firms investing into IT will not bring about the phenomenon of productivity paradox. Therefore, opinions of productivity paradox are mixed among those in the literatures above.

Therefore, some economists have tried to find out the rational reasons and explanations behind these mixed empirical findings. Belleflamme (1999) pointed out that the productivity paradox might result from oligopolistic competition and product differentiation, but not from pursuing efficiency. Thatcher and Oliver (2001) suggested that these mixed empirical findings might result from incorrect methodology, data error, or not reflect the real IT contribution, especially from the ability of IT to improve product quality as indicated by Brynjolfsson and Hitt (1996), Barua and Lee (1997), and Lehr and Lichtenberg (1998). They indicated that quality improvements are realized when a technology investment leads to the creation of new products, new features, or existing products, which directly increase human desire to consume those products. For example, patient-tracking systems, data mining tools, interaction television technologies, and decision support systems all help IT equipment to promote product quality. Furthermore, Chun and Nadiri (2002) mentioned that productivity growth could take place in the improvement of output quality (product innovation). In particular, improvement in output quality is one of the most prevailing characteristics in the IT production such as microprocessor speed, the capacity of storage devices and memory, etc. They noted that an increase in product variety and quality should properly be counted as part of the value of output, and then the contribution to output will not be underestimated. Hence, IT plays an important role in improving and promoting product and service quality.

When the issue of whether IT investment brings about a productivity paradox has been debated in the academic circle, we fail to find any study about the impact of IT on productivity in Taiwan, except Yang (1998), due to a lack of full and integrity-related data. Suffering from the restriction of the available data, Yang’s paper can only study the relationship between IT investment and financial revenue and does not really reflect the contribution of IT on productivity. This paper also faces the problem of acquiring empirical data in the early stage, and the difficulty of matching a firm’s IT investment, output, and other variables. We finally were able to acquire computer equipment quantity survey data and other related variables from a manufacturing sampling survey data of industry, commerce, and service census in Taiwan by the DGBAS in 1991. According to the studies of Brynjolfsson and Hitt (1996) and Lehr and Lichtenberg (1998) we can define personal computer and terminal equipment as the IT investment variable. According to the theories of production and the model of previous literature, we use the Translog production function to construct an empirical model and appraise the impact of IT on productivity and the phenomenon of the productivity paradox. In order to take the improvement of product quality caused by IT investment into account, this paper not only uses firm-level data to reflect the impact of IT on product quality (Hitt and Brynjolfsson, 1996), but also adopts a deflator to deflate IT variables. The quality-adjusted price index used in our paper

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3 See Christen et al. (1971), and Berndt and Christensen (1973a, 1973b) for details.
4 Loveman (1994), Barua and Lee (1997) and Gera, Gu, and Lee (1999) indicated that each variable’s real term can be derived from deflating using the by proper price indices, and this can be used as the method of reflecting the product quality recondition.
is a computer hedonic price index. It can be free from the problem of too much deflation by deflating PC variables and turning IT variables from nominal terms to real terms. The computer hedonic price index adopted by this paper considers the character variable of quality, such as brand, CPU, screen, memory, hard drive, and time, etc. The computer hedonic price index is estimated by the hedonic regression method to reflect the improvement of output quality.

Although the related literature classifies the capital input into IT capital and non-IT capital, only Dewan and Min (1997) estimated substitution elasticity between IT capital and non-IT capital. Since substitution elasticity can be regarded as liquidity between two factors (as shown by the study of Stiroh, 1998 whereby out of 35 sectors, 33 sectors used IT investment to substitute for traditional inputs), this paper applies the flexible Translog production function to jointly estimate output and substitution elasticity between IT investment and other inputs. The subsample analysis in existing literature is always based on sectors and there are not many studies concerning the productivity paradox aim at industry. Jorgenson and Stiroh (2000a, 2000b) investigated the contribution of each industry and used the data of U.S. economic growth at the industry level for the period 1958-1996. They found that high-tech industries grew rapidly in both output and productivity in the 37 industries. This paper thus considers whether high-tech industries that produce IT equipment invest and make use of the IT capital in order to generate higher productivity than other industries.

The rest of the paper is organized as follows. In section 2 we discuss our empirical model. Section 3 describes the data sources and the selection of variables used in this study. The analyses of empirical results are presented in section 4. The conclusion is presented in section 5.

2. Empirical Model

Although the empirical models of existing literature have different samples and periods, most of them (Loveman, 1994; Berndt and Morrison, 1995; Hitt and Brynjolfsson, 1996; Lehr and Lichtenberg, 1998; Gera, Gu, and Lee, 1999) adopt the Cobb-Douglas production function as an empirical model. However, the Cobb-Douglas production function assumes that the elasticity of substitution between factors is unity (Healthfield and Wibe, 1987; Varian, 1992). To further study the level of substitution between IT capital and other inputs, this paper applies the flexible Translog production function to jointly estimate output and substitution elasticity between IT investment and other inputs. To estimate the contribution of IT toward output, constructing the production function is the first step.

The Translog production function is given by the estimation equation:

$$Y = F (ITc, nonITc, Lab)$$

$$\log Y_i = \alpha_0 + \alpha_1 \log ITc_i + \alpha_2 \log nonITc_i + \alpha_3 \log Lab_i$$

$$+ 1/2 \beta_{11} (\log ITc_i)^2 + 1/2 \beta_{22} (\log nonITc_i)^2 + 1/2 \beta_{33} (\log Lab_i)^2$$

$$+ \beta_{12} (\log ITc_i) (\log nonITc_i) + \beta_{13} (\log ITc_i) (\log Lab_i)$$

$$+ \beta_{23} (\log nonITc_i) (\log Lab_i) + \epsilon_i$$

Here, $Y_i$ denotes output produced by firm $i$; $ITc$ and $nonITc$ denote respectively the value of IT capital and non-IT capital; $Lab$ denotes the expenditure of workers; $\epsilon$ is an error term; $\alpha_0$ is a Hicks-neutral efficiency parameter, and the parameters $\alpha_1$, $\alpha_2$, $\alpha_3$, $\beta_{11}$, $\beta_{22}$, $\beta_{33}$, $\beta_{12}$, $\beta_{13}$, and $\beta_{23}$ are typical Translog parameters.

Differentiating equation (2) and setting factor prices equal to the adjusted marginal products, we can derive the factor shares equation:

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6 Loveman (1994) used a BEA quality-adjusted price index to the deflator IT variable. However, Loveman’s IT data contained not only computers, but also: 1. Computers and peripheral equipment, 2. Office, computing, and accounting, 3. Other office computing equipment, 4. Communication equipment, 5. Instruments, science and engineering, 6. Photocopy and related equipment. Barua and Lee (1997) used the same data and indicated that the study of Loveman (1994) results in too much deflation and will cause a productivity paradox.
7 The high-tech industry includes computer, semiconductor, and communication equipment industries.
The error terms in equations (2) and (3) account for other omitted factors, which affect the factor shares. Share equations when added up to one result in singularity of the disturbance covariance matrix. Therefore, one of them must be eliminated in each group and the efficient estimators can be derived from the remaining two. The factor shares must sum to 1, which requires, in addition to the symmetry restrictions already imposed, that the following restrictions on the parameters imply linear homogeneity:

\[ \sum i \alpha_i = 1, \sum j \beta_{ij} = \sum \beta_j = 0, \quad i = 1, 2, 3, \quad \beta_{ij} = \beta_{ji}, \quad i \neq j. \]  

(4)

Zellner’s (1962) seemingly unrelated regression (SUR) method provides a set of efficient estimators to the share equations. Therefore, Chung (1987), Sveikauskas et al. (1988), and Wang (1998) all apply SUR to estimate the set of coefficients of parameters for the empirical study of the Translog form function. However, Kmenta and Gilbert (1968) indicated that the estimation results are not invariant to the equation deleted from the system. By iterating the estimation procedure until the estimated coefficients and residual covariance matrix have been converged, the invariance can then be attained. They also found that the converged estimates by using the iterative seemingly unrelated regression (ISUR) method are equivalent to the maximum likelihood estimates and thus are the best linear unbiased estimates. (e.g., Kumbhakar and Heshmati 1996; Okunade, 2001).

Since one of the share equations must be deleted to deal with the singularity problem, we eliminate the share equation for labor. Whichever one is eliminated should not have any effect on the results. The parameters associated with the equation that is deleted can be recovered through the parameter restrictions implied by the homogeneity, symmetry, and conservation properties. We then use the ISUR method to jointly estimate equations (2) through (3), and the restrictions of equation (4) also join the consideration.

\[ M_{ij} = \frac{\partial Y}{\partial X_i} \cdot \frac{\partial Y}{\partial X_j} = \frac{\partial Y}{X_i} \cdot \frac{\partial Y}{X_j} = \varepsilon_i, \]  

(5)

where \( X_i \) through \( X_n \) are the variables that measure \( ITc, nonITc \) and \( Lab \), and \( \varepsilon_i \) is the output elasticity of \( X_i \). The marginal product of \( X_i \) \((M_{ij})\) is simply the elasticity multiplied by the ratio of output to \( X_i \) input as shown in equation (4). Equation (4) is used to estimate the contribution of each variable to output, which is productivity.

We adopt the Allen-Uzawa partial elasticity of substitution (AES) (Allen, 1938; Chung, 1994) to assess the elasticity of substitution between factors of the Translog production function.

\[ \sigma_{ij} = \sum_{j} \frac{\partial f_{i,j}}{F} \cdot \frac{F_{i,j}}{F} \quad (i \neq j), \]  

(6)

where \( \sigma_{ij} \) denotes the elasticity of substitution between factors \( i \) and \( j \); \( F \) denotes the bordered Hessian determinant; \( F_{i,j} \) is a co-factor of \( F \); \( f_{i,j} = \partial f/\partial x_i = M_{ij} \).

\[ F = \begin{bmatrix} 0 & f_{11} & \cdots & f_{1n} \\ f_{11} & f_{111} & \cdots & f_{11n} \\ \vdots & \vdots & \ddots & \vdots \\ f_{1n} & f_{11n} & \cdots & f_{nn} \end{bmatrix}. \]  

(7)

The Translog production function must satisfy the following regularity conditions: monotonicity and convexity so as to correspond to a well-behaved production structure. Monotonicity requires that the marginal product of input be positive, i.e. \( M_{ij} > 0 \) for each input. Convexity of the Translog production function requires that its bordered Hessian must be negative semi-definite i.e. \((-1)^n F_{ii} > 0\). Therefore, we will test the two regularity conditions in accordance with the above criteria.

3. Data Sources and Variables
Our source of sample data is the manufacturing sampling survey data from the industry, commerce, and service census of Taiwan in 1991. We select a total of 1,194 samples of firm-level data, which own both terminal and PC equipment. According to the characteristics of the data, we measure the variables in dollars not in quantity so as to construct the production function.

### Table 1: The sample statistics of firms that own computer equipment (Unit: set)

<table>
<thead>
<tr>
<th>Computer equipment</th>
<th>Average</th>
<th>Standard error</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-large system computer</td>
<td>0.12</td>
<td>0.61</td>
<td>0.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Small-scaled system computer</td>
<td>0.76</td>
<td>6.31</td>
<td>0.00</td>
<td>400.00</td>
</tr>
<tr>
<td>Terminal</td>
<td>8.73</td>
<td>60.73</td>
<td>0.00</td>
<td>2,682.00</td>
</tr>
<tr>
<td>Personal computer</td>
<td>8.87</td>
<td>38.40</td>
<td>0.00</td>
<td>1,208.00</td>
</tr>
</tbody>
</table>

Number of firms that owns computer equipment 4,948
Total number of samples 13,369

| Terminal                          | 32.47  | 120.01        | 1.00    | 2,682.00|
| Personal computer                 | 26.42  | 72.79         | 1.00    | 1,208.00|

Number of firms that owns both terminal and PCs 1,194

### 3.1 Specification of data

Table 1 shows that there are 4,948 firms that own at least one kind of computer equipment and the total number of samples is 13,369. Therefore, the rate that IT equipment is owned by manufacturing is 37%, and each firm owns an average of 8.87 PCs. There are 1,194 firms that own both terminal and PCs. The average number of terminals owned by each firm is 32.47, which is larger than PCs' average of 26.42. The 1,194 firm-level numerical samples are the objective data sources used to construct the production function.

### 3.2 Specification of variables

Output is defined as sales for the firm’s product (including the product sales received domestically and abroad). Non-IT capital subtracts the IT capital from the fixed capital and subtracts accumulated depreciation. Labor expenditure is the payroll of the specialized, skilled workman, chief manager, assistant manager, common worker and physical strength worker (including regular and temporary employees). The above variables are the data in dollar terms. Since we have only the quantitative data of IT capital, we must have the price be expressed into dollar terms. However, computer equipment price data is hard to collect, but we finally were able to acquire the average price of PCs and terminals for that year. According to the search of Hitt and Brynjolfsson (1996) and Lehr and Lichtenberg (1998), PCs and terminals can be defined as IT investment items. In order to take the improvement of product quality caused by IT investment into account, we use firm-level data, and adopt a proper computer hedonic price index to deflate personal computers. The qualitative data on IT capital is adjusted through price and then deflated by the computer hedonic price index for empirical study. In accordance with Hitt and Brynjolfsson (1996), when an increase in product variety and quality is properly counted as part of the value of output, the contribution to output will then not be underestimated.

### Table 2: The sample statistics of each variable (Unit: NT dollars)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average</th>
<th>Standard error</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1,985,365,022</td>
<td>10,153,959,852</td>
<td>0</td>
<td>260,004,699,706</td>
</tr>
<tr>
<td>ITc</td>
<td>2,229,152</td>
<td>6,147,628</td>
<td>80,647</td>
<td>112,747,156</td>
</tr>
<tr>
<td>Non-ITc</td>
<td>1,605,967,251</td>
<td>17,772,610,914</td>
<td>888,133</td>
<td>571,972,234,305</td>
</tr>
<tr>
<td>Lab</td>
<td>222,378,748</td>
<td>949,964,348</td>
<td>946,800</td>
<td>22,784,730,078</td>
</tr>
<tr>
<td>N</td>
<td>1,194</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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8 37% is the ratio of firms that own at least one kind of computer equipment to the total number of the sample.

Table 2 shows the sample statistics of objective variables used to construct a production function. The average value of output amounts to NT$1.98 billion, the IT capital average value is NT$2.2 million, the non-IT capital average value amounts to NT$1.6 billion, and the average value of labor is NT$0.22 billion. Therefore, the share of IT capital in output of that year seems to be smaller than other investments.

4. Empirical Results

4.1 Empirical results of the Translog production function

The ISUR estimate coefficients in Table 3 indicate that all variables are significant at the 1% level, and the system R² is 0.805. The estimation of output elasticity and the marginal product are shown in Table 4. By estimating \( MP_i \) and implementing the bordered Hessian, we find that \( MP_i \) is positive and that a negative semi-definite is satisfied, hence confirming monotonicity and convexity. The empirical results show that the output elasticity of each variable is positive, implying that the marginal product must be positive. The elasticity of output for IT capital is 0.003. The MP of each input presents the \( MP_{lab} > MP_{ITc} > MP_{nonITc} \) pattern. This estimate pattern is identical the empirical results in Brynjolfsson and Hitt (1996), Hitt and Brynjolfsson (1996), and Dewan and Min (1997).

We find that IT investment has a significant influence on output, and its MP is approximately 2.4. In other words, an additional NT dollar of IT investment is associated with an increase in output of NT$2.4. This implies that IT capital does have a significant impact on the productivity level, showing a multiple of 2.4 times contribution toward output. After comparing with the results of Brynjolfsson and Hitt (1996), Hitt and Brynjolfsson (1996) and Dewan and Min (1997) where an additional dollar of IT investment is associated with a contribution on output of 94.9%, 81%, and 1.17 times, respectively, our estimator of MP for IT capital hence has a substantially significant and higher contribution to firm output than the above findings.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coefficient</th>
<th>t-value</th>
<th>Parameter</th>
<th>Coefficient</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_0 )</td>
<td>1.728***</td>
<td>61.60</td>
<td>( \alpha_{11} )</td>
<td>0.007***</td>
<td>9.67</td>
</tr>
<tr>
<td>( \beta_{1} )</td>
<td>0.041***</td>
<td>11.15</td>
<td>( \beta_{22} )</td>
<td>0.127***</td>
<td>6.21</td>
</tr>
<tr>
<td>( \beta_{2} )</td>
<td>0.2489***</td>
<td>8.35</td>
<td>( \beta_{33} )</td>
<td>0.126***</td>
<td>6.07</td>
</tr>
<tr>
<td>( \beta_{3} )</td>
<td>0.711***</td>
<td>23.55</td>
<td>( \beta_{12} )</td>
<td>-0.004***</td>
<td>-5.53</td>
</tr>
<tr>
<td>( \beta_{13} )</td>
<td>0.007***</td>
<td>9.67</td>
<td>( \beta_{13} )</td>
<td>-0.003***</td>
<td>-2.93</td>
</tr>
<tr>
<td>N</td>
<td>1,194</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The system R² is 0.805. *: Significant at the 10% level. **: Significant at the 5% level. ***: Significant at the 1% level.

<table>
<thead>
<tr>
<th>Output elasticity</th>
<th>Coefficient</th>
<th>Marginal product</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon_{ITc} )</td>
<td>0.003</td>
<td>( MP_{ITc} )</td>
<td>2.390</td>
</tr>
<tr>
<td>( \varepsilon_{nonITc} )</td>
<td>0.406</td>
<td>( MP_{nonITc} )</td>
<td>0.502</td>
</tr>
<tr>
<td>( \varepsilon_{lab} )</td>
<td>0.591</td>
<td>( MP_{lab} )</td>
<td>5.278</td>
</tr>
</tbody>
</table>

The MP for IT investment in this paper is higher than the above estimators and we analyze the reason as follows. First, the statistical information of BEA and the Council of Economic Advisors in 1995 shows that from 1980 to 1994 the IT investment per employee in the service industry sector climbed far higher than the other sectors year by year.10 This implies that the service industry contains higher IT intensity. Second, Hitt and Brynjolfsson (1996) classified the sample into different sectors and further estimate the MP for each sector.11 They found that the MP for computer capital of the non-durable manufacturing, transport and utilities, trade, finance services, and other service industries.

10 BEA and the Council of Economic Advisors in 1995 classified the sectors into non-durable manufacturing, durable manufacturing, transport and utilities, trade, finance services, and other service industries.

11 Hitt and Brynjolfsson (1996) divided the sample into mining, non-durable manufacturing, durable manufacturing, transport and utilities, trade, and other service sectors.
manufacturing sector amounts to $1.25 higher than other sectors.\(^1\) Dewan and Min (1997) split the sample into manufacturing and service sectors and found that the MP for IT in the manufacturing sector is 86 cents higher than the MP for IT in the service sector, which is 67 cents.\(^2\) Third, the service sector has problems of being hard to quantify output can easily be understated (Hitt and Brynjolfsson, 1996 and Lehr and Lichtenberg, 1998), and related studies do not adopt a proper deflator IT investments may underestimate the contribution of IT to output. Finally, the empirical studies show that the service sector has lower productivity and efficiency, Roach (1991) indicated that the service sector is sheltered from competition and has had little incentive to drive out inefficiency. Since the samples of the above studies contain both the manufacturing and service industries and the sample of this paper only includes firm-level data of the manufacturing industry,\(^3\) the estimator of the MP for IT capital in this paper being comparable higher should be quite reasonable.

The labor variable has the most significant influence on output and its MP is approximately 5.3. This implies that an additional NT dollar of labor expenditure is associated with an increase in output of NT$5.3. Brynjolfsson and Hitt (1996) pointed out that human capital is an important resource within a business. In addition, to invest in IT means training operators or establishing an IT department for utilization and operations of IT equipment. In the current knowledge-based economy age, human capital plays an import role in innovation, R&D, and application of information technology, and therefore human capital has a significant impact on productivity. The contribution of non-IT capital is not significant, as an additional NT dollar of non-IT capital is associated with an increase in output of NT$0.5. Consequently, the empirical results indicate that a manufacturing industry investing in IT shows a positive and significant contribution to output. Thus, we can conclude the non-existent phenomenon of the productivity paradox, and we confirm earlier findings of a positive return to IT investment for this data set.\(^4\)

In this subsection we use the Translog production function to estimate the Allen-Uzawa partial elasticity of substitution of each variable. The estimates for AES are all significantly different from one as shown in Table 5. The results show that estimates of AES between IT and non-IT capital are larger than 0, and the AES elasticity estimates are significantly differ from 1. The restriction of the Cobb-Douglas production function that limits the AES of input for 1 is not consistent with our empirical results.

Among all estimates, the substitution elasticity of IT and non-IT capital is 0.441, which implies that IT capital is a net substitute for non-IT capital. Jang et al. (1996) indicated that the average rate of the quality-adjusted price index for a computer has declined about 20% during the period from 1990 to 1995 in Taiwan. Furthermore, Jorgenson (2001) discovered that the decline in U.S. IT prices were triggered by a much sharper acceleration in the price of semiconductors and found that a rapid price decline for computer investment, 17.1% per year from 1959 to 1995, since 1995 this decline has almost doubles to 32.1%. Above studies showed that the price decline in IT investment makes the accelerated accumulation in IT investment of other inputs and has a significant impact on GDP growth. This implies the trend that computer prices have to decline year by year. Therefore, we can conjecture that the factor share of IT investment in production will grow to a more significant level over time. The above empirical evidence can further verify and enhance the textual empirical results. When IT prices change, the flow of the input to substitute for the other will occur.

We can also find that IT capital is a net complementary to labor, meaning that information technologies have higher technicality. As such, when IT investment rises, the related technical personnel will also rise. Labor is slightly complementary to non-IT capital, suggesting that a labor force that is higher educated and more technical is not easily replaced by capital input.

<table>
<thead>
<tr>
<th>AES elasticity</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{12}$</td>
<td>0.441</td>
</tr>
<tr>
<td>$\sigma_{13}$</td>
<td>-0.912</td>
</tr>
</tbody>
</table>

\(^1\) Dewan and Min (1997) did not take into account the estimated value of each segment to justification in their paper, indicating only by use of a histogram. Using this chart we can definitely discover the amount of each sector’s value of MP.

\(^2\) The MP of 86 cents and 67 cents are estimated according to Dewan and Min (1997) their research, and they can be estimated by using equation (5) in this paper.

\(^3\) Brynjolfsson and Hitt (1996) have a search sample of 367 large firms’ data during 1987-1991 (including the manufacturing and service industries). Hitt and Brynjolfsson (1996) have a search sample of 370 large firms’ data during 1988-1992 (including the manufacturing and service industries). Dewan and Min (1997) have a sample from very large Fortune 500 companies during 1988-1992 (about two-third of the firms are from the manufacturing sector, while the remaining are mainly service firms).

\[ \sigma_{23} = -4.844 \times 10^{-11} \]

\( \sigma_{22}, \sigma_{13}, \) and \( \sigma_{23} \) represent the AES elasticity of IT and non-IT capital, IT capital and labor, and non-IT capital and labor, respectively.

### 4.2 Analysis of sample splits

In this subsection we conduct an analysis of the following data grouping: high-tech and traditional industry. Before conducting the analysis of the two data groupings, we first apply the standard industrial classification (SIC) of Taiwan for two-digit manufacturing industries to divide the sample into eight industries. This paper splits the sample according to the sample characteristic into high-tech and traditional industry groupings. The subsamples’ statistics of industry of each variable are presented in Table 6. We can find that the average of IT capital of the high-tech industry is greater than the traditional industry about 6 times. But the traditional industry invests more average non-IT capital than the high-tech industry. This implies that the traditional industry still relies on traditional inputs for production. Table 7 shows results of estimation of the output elasticity, the MP and AES of each variable.

### 4.3 High-tech industry vs. Traditional industry

The elasticity of output for IT capital \( \varepsilon_{ITc} \) of the high-tech industry is 0.007 and is higher compared to \( \varepsilon_{ITc} \) of the traditional industry, which is 0.001. The result shows that the high-tech industry invests and makes use of IT capital that generates higher productivity than the traditional industry. An additional NT dollar in IT investment is associated with an increase in output of NTS$3.0 by the high-tech industry, and the MP of other inputs in the high-tech industry all are larger than the traditional industry and higher than the magnitude of the full sample study. It could be that the high-tech industry can cut the learning time and costs that employees search for, because of having to get acquainted with the IT equipment’s applications and functions. Moreover, the high-tech industry has the style of vertical separation; whereby these firms interact persistently through technology and information and help supply each other's needs. Therefore, we can conclude that the high-tech industry that invests and applies IT capital indeed has higher productivity than the traditional industry.

#### Table 6: The subsamples’ statistics of industry of each variable (Unit: NT$ average)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Industry</th>
<th>High-tech</th>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITc</td>
<td></td>
<td>11833.359</td>
<td>1970.186</td>
</tr>
<tr>
<td>Non-ITc</td>
<td></td>
<td>2035425.052</td>
<td>2190031.041</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td>5171209.997</td>
<td>2392148.589</td>
</tr>
<tr>
<td>Lab</td>
<td></td>
<td>620409.922</td>
<td>263051.297</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>306</td>
<td>888</td>
</tr>
</tbody>
</table>

#### Table 7: Estimates of subsamples of industry

<table>
<thead>
<tr>
<th>( \varepsilon )</th>
<th>Industry</th>
<th>High-tech</th>
<th>Traditional</th>
<th>Industry</th>
<th>High-tech</th>
<th>Traditional</th>
<th>Industry</th>
<th>High-tech</th>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon_{ITc} )</td>
<td></td>
<td>0.007</td>
<td>0.001</td>
<td></td>
<td>MP(_{ITc})</td>
<td>3.037</td>
<td>1.473</td>
<td>( \sigma_{12} )</td>
<td>0.540</td>
</tr>
<tr>
<td>( \varepsilon_{nontI} )</td>
<td></td>
<td>0.364</td>
<td>0.421</td>
<td></td>
<td>MP(_{nontI} )</td>
<td>0.924</td>
<td>0.459</td>
<td>( \sigma_{13} )</td>
<td>-1.506</td>
</tr>
<tr>
<td>( \varepsilon_{Lab} )</td>
<td></td>
<td>0.629</td>
<td>0.578</td>
<td></td>
<td>MP(_{Lab})</td>
<td>5.245</td>
<td>5.257</td>
<td>( \sigma_{23} )</td>
<td>-1.30514E-10</td>
</tr>
</tbody>
</table>

16 Food and beverage manufacturing industry; spinning, ready-to-wear clothes, leather manufacturing industry; the bamboo of wood, furniture, paper manufactured articles’ manufacturing industry, chemistry spoilage, chemistry products manufacturing industry; the petroleum, rubber, plastics products’ manufacturing industry, metal industry, metal manufactured articles, machine equipment manufacturing industry, the electron and electric machinery devices, and other industries

17 The high-tech industry regards the two-digit SIC-31 industry as representing the 7th industry classified above by this paper, containing the electron and electric machinery devices. The remaining 7 industries we categorize into the traditional industry. The high-tech industry domain has the following three digits: The electronic machinery devices, household appliance, lighting equipment, data storage and data processing equipment, video and audio electronic products, communication equipment, electronic components, and battery manufacturing.
In respect of the AES estimation, we find that results of the subsamples are the same with a full sample study. The results also show that IT capital is a net substitute for non-IT capital, IT capital is a net complementary to labor, and labor is slightly complementary to non-IT capital. The substitution of IT capital for non-IT capital in the traditional industry is highest among all subsamples, implying their attempt so as to prevent the risk of becoming a twilight industry.

5. Conclusion

This paper employs the manufacturing sampling survey data from the industry, commerce, and service census of Taiwan in 1991 to assess the impact of IT investment on the manufacturing industry’s productivity. Empirical results show that an additional NT dollar of IT investment is associated with an increase in output of NT$2.4. This implies that IT capital does have a significant impact on productivity level, and contributes 2.4 times to output, which is an outstanding contribution for output in comparison to the other research studies on the advanced countries. Therefore, the conclusion drawn by this paper is that firms investing into IT will not cause the phenomenon of productivity paradox, and confirms earlier findings of a positive return to IT investment.

The results show that estimates of AES between IT and non-IT capital are larger than 0. Among all estimates, the substitution elasticity of IT and non-IT capital is 0.4, implying that IT capital is a net substitute for non-IT capital, such that when IT prices change, the flow of input to substitute for the other will occur. We suggest that in order to achieve reasonable calculations, a more flexible production function should be adopted if the AES must be estimated.

In this paper we find that a high-tech industry investing and making use of IT capital generates higher productivity than a traditional industry and higher than the magnitude of the full-sample study, which is correspondence with the investigation by Jorgenson and Stiroh (2000a, 2000b). The results of subsamples have the same trend on MP and AES to compare with full sample.

The results of this paper would be better, if a time-series or panel data were available, and a complete IT equipment hedonic price index could be constructed. Future research in this area could focus on IT investment that promotes output quality, and IT spillover and diffusion.

References


