African Journal of Business Management Vol. 5(14), pp. 5895-5899, 18 July, 2011
Available online at http://www.academicjournals.org/AJBM
DOI: 10.5897/AJBM11.188
ISSN 1993-8233 ©2011 Academic Journals

Full Length Research Paper

Information technology and total factor productivity

Ting-Kun Liu[1]* and Wen-Cheng Lu[2]

[1]Department of Finance, Chaoyang University of Technology, 168, Jifeng E. Rd., Wufeng District, Taichung, 41349, Taiwan, R.O.C.
[2]Department of Economics, Ming Chuan University, Taiwan, R.O.C.

Accepted 28 April, 2011

This paper employs the manufacturing firm-level data of Taiwan to explore the issue of whether information technology investment brings about the Solow productivity paradox. In order to take into account the improvement of product quality caused by information technology investment, a hedonic price index is used to deflate the information technology variable. Besides the general specification of Cobb-Douglas production function, this paper considers the impact of information technology on total factor productivity, capital and labor productivity through substitution by applying a non-neutral production function.

Key words: Information technology, total factor productivity, hedonic price index.

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, store, 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). 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. According to OECD (2008), the IT spending of the whole word in 2007 reached US$ 1,473 billion.

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 have also made massive investment in IT so as to face the competition in this age of the knowledge-based economy. According to the survey that was conducted by the electronic data-processing center of the Directorate General of Budget, Accounting and Statistics (DGBAS), the IT expenditure rose from NT$ 165 billion in 2005 to NT$ 193 billion in 2007.

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". The studies of Berndt and Morrison (1995) and Loveman (1994) displayed the phenomenon of the productivity paradox. However, the empirical studies of later scholars present entirely different conclusions. Brynjolfsson and Hitt (1996), Gunasekaran and Nathb (1997), Barua and Lee (1997), Dewan and Min (1997), Lehr and Lichtenberg (1998), Stiroh (1998), Gera et al. (1999), Thatcher 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.

The Solow productivity paradox: what do computers do to productivity? Asking the question of why TFP is not an increasing function of IT. As Triplett (1999) states that "Growth accounting answers the question: Why is growth not higher?" The paradox says: "Why is productivity not higher?" This implies that some papers use growth accounting method to compute the IT's contribution to

*Corresponding author. E-mail: tkliu@cyut.edu.tw. Tel: +886+423323000/4881. Fax: +886+423742333.

growth not to TFP. Furthermore, intensive use of computer is likely to raise the labor and nonIT capital productivity through input substitution. In Dewan and Mins' (1997) empirical findings, IT capital is a net substitute for both ordinary capital and labor. Stiroh (1998) also finds that noncomputer input growth decrease as the use of computer capital services increased in these computer intensive sectors, and cheap computers substituted for other inputs, including labor. Therefore, a suitable production function is needed to answer the Solow productivity paradox.

Besides incorrect methodologies and measurement errors, some economists have tried to find out the rational explanations for these mixed empirical findings. Thatcher and Oliver (2001) suggested that these mixed empirical findings might result from incorrect methodology, data error, but not reflect the real IT contribution, especially from the ability of IT to improve product quality 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. 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. Hence, IT plays an important role in improving and promoting product and service quality.

According to the studies of Brynjolfsson and Hitt (1996) and Lehr and Lichtenberg (1998), personal computer and terminal equipment can be defined as the IT investment variable. Due to the findings from Dewan and Mins' (1997) and Stiroh (1998), except the general specification of Cobb-Douglas production function, this paper considers the impact of IT on TFP, capital and labor productivity through substitution by applying a non-neutral production function to construct an empirical model and appraise the impact of IT on productivity and the phenomenon of the productivity paradox. Therefore, the end result of this on production is a non-neutral shift in the observed output. Not only will the productivity of inputs change, but also, the marginal rate of technical substitution (Huang and Liu, 1994).

In order to take into account the improvement of product quality caused by IT investment, 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 the paper is a computer hedonic price index. Thus, people can be free from the problem of too much deflation due to deflate the PC related variables, and turn IT variables from nominal terms to real terms. The computer hedonic price index adopted by this paper considers the character variables of quality, such as brand, CPU, screen, memory, hard drive, and time dummy variables, etc. Furthermore, the computer hedonic price index index is estimated by the hedonic regression method to reflect the improvement of output quality.

EMPIRICAL FRAMEWORK AND MEASUREMENT OF TFP

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 et al., 1999) adopt the Cobb-Douglas production function as an empirical model. Hence, the study applies the Cobb-Douglas production function as the basic model. This paper assumes that the production function can be approximated by a Cobb-Douglas function:

$$Y_i = A \cdot NONIT_i^{\alpha} LAB_i^{\beta} IT_i^{\gamma} e^{\varepsilon_i}, \tag{1}$$

Where Y is value added, *nonIT*, *LAB*, and *IT* are the non-IT physical capital, labor input, and IT capital, respectively. The subscripts i refer to firm i, and ε is the error term reflecting the effect of unknown factors and other disturbances.

The study can take the logarithms of Equation (1) and obtain a linear regression in order to implement the estimation of the Cobb-Douglas function as shown thus:

$$y_i = a + \alpha nonit_i + \beta lab_i + \gamma it_i + \varepsilon_i, \tag{2}$$

Where the lower-case letters denote the logarithms of the variables, and α, β and especially γ (the elasticities of value added with respect to IT capital) are the parameters in which we are particularly interested.

We can use the results of Equation (2) to verify and compare with the results of Brynjolfsson and Hitt (1996), Hitt and Brynjolfsson (1996) and Dewan and Min (1997), whether marginal product (MP) could be a proper productivity indicator of the contribution of IT to output.

This paper uses the estimated coefficients of Equation (2) to calculate MP in the following way:

$$MP_i = \frac{\partial Y}{\partial X_i} = \frac{\partial Y}{\partial X_i}\frac{X_i \cdot Y}{Y \cdot X_i} = \delta_i \frac{Y}{X_i}, \tag{3}$$

Where X_i through X_n are the variables that measure *NONIT*, *LAB* and *IT*, and δ_i is the output elasticity of X_i. The MP of X_i (MP_i) is simply the elasticity multiplied by the ratio of output to X_i input as shown in Equation (3).

Owing to the Solow productivity paradox: what do computers do to productivity? that asks the question of why TFP is not an increasing function of IT, therefore, Triplett (1999) states that "Growth accounting answers the question: Why is growth not higher?" The paradox says: "Why is productivity not higher?"
This implies that some papers use growth accounting method to compute the IT contribution to growth but not to TFP. Most analyses are based on Equation (1):

$$Y = F(NONIT, LAB, IT), \tag{4}$$

Taking the total differential, we have:

$$dY = F_N dNONIT + F_L dLAB + F_I dIT \,, \quad (5)$$

Where the F_i are the MP of *NONIT*, *LAB* and *IT*, respectively. And the growth accounting identity becomes:

$$\frac{dY}{Y} = \frac{NONIT \cdot F_N}{Y} \cdot \frac{dNONIT}{NONIT} + \frac{LAB \cdot F_L}{Y} \cdot \frac{dLAB}{LAB} + \frac{IT \cdot F_I}{Y} \cdot \frac{dIT}{IT} \quad (6)$$

The problem with this type of analysis is that the production function does not measure the TFP, and its decompositions, dY and dY/Y, do not indicate the change of TFP.

The Solow paradox asks the question of why TFP is not an increasing function of IT. Furthermore, intensive use of computer is likely to raise the labor and nonIT capital productivity through input substitution as shown in the empirical finding of Dewan and Mins (1997) and Stiroh (1998).

Therefore, one suitable reformulation of the non-neutral production function is:

$$Y = F(g(IT)NONIT, h(IT)LAB, IT) \cdot TFP(IT) \,, \quad (7)$$

Where g(.), h(.) and TFP(.) are function of IT. The reformulation of the non-neutral production function gives rise to the following equation:

$$Y_i = AIT_i^{\gamma} NONIT_i^{\alpha_1 + \alpha_2 IT_i} LAB_i^{\beta_1 + \beta_2 IT_i} TFP_i^{\lambda_1 + \lambda_2 IT_i} e^{\varepsilon_i} \quad (8)$$

By taking the logarithms of Equation (8), the study obtain Equation (9), which can be used to implement the relationship between IT and TFP, and IT and other traditional inputs:

$$y_i = a + \gamma it_i + \alpha_1 nonit_i + \alpha_2 IT \cdot nonit_i + \beta_1 lab_i + \beta_2 IT \cdot_i lab_i + \lambda_1 tfp + \lambda_2 IT \cdot tfp + \varepsilon_i \,, \quad (9)$$

Where the lower-case letters denote the logarithms of the variables, and the TFP index is measured using the approach initially proposed by Solow (1957) and also adopted by Jefferson et al. (2000) and Huang (2004). This paper estimates the TFP index in the following steps from Equations (10) to (13):

$$Y_i = A\left(\prod_{j=1}^{2} X_{ij}^{\phi_i}\right)\varepsilon_i \quad (10)$$

$$\theta_j = \frac{\phi_j}{\sum_{j=2}^{2} \phi_j} \quad (11)$$

$$u_i = \log Y_i - \sum_{j=1}^{2} \theta_j \log X_{ij} \quad (12)$$

$$TFP_i = \exp(u_i - u_{\max}) \quad (13)$$

Where *Y* is value added, and X is the vector of input, including capital and labor for each firm in Equation (10), ϕ is the output elasticity of input, θ in Equation (11) is the weight measuring factor share to calculate the composite Cobb-Douglas index of TFP. Equations (12) and (13) are used to calculate TFP of each firm in this specific year. Equation (9) will be explored in this paper, and the general specification of Equation (2) will also be discussed in our study for the purpose comparison.

Finally, in order to measure the magnitude of IT contribution to TFP, the study then evaluates the output elasticity of IT and TFP, respectively to get the estimation by the following definition:

$$\frac{\partial y_i}{\partial it} / \frac{\partial y_i}{\partial tfp} = \frac{\partial tfp}{\partial it} \quad (14)$$

Data sources and definitions of variables

The source of sample data is the manufacturing sampling survey data from the industry, commerce, and service census of Taiwan in 1991 with 1,174 samples of firm-level data.

In Equation (1) of this paper, due to the absence of certain materials in the model, the study uses value-added (*VAL*) as the proxy for the dependent variable. According to the MOEA's (Department of Statistics, Ministry of Economic Affairs) definition, we measure *VAL* based on the following specification: (*VAL*) is equal to total output sales less intermediate inputs. Total output sales are deflated using a wholesale price index and intermediate inputs are deflated using a price index of intermediate inputs. With respect to the explained variables of the right-hand side equation, non-IT capital (*NONIT*) is obtained by subtracting the IT capital from the fixed capital and subtracts accumulated depreciation. We use a capital price index to adjust for inflation, while labor (*LAB*) refers to the number of employees.

According to the search of Hitt and Brynjolfsson (1996) and Lehr and Lichtenberg (1998), PCs and terminals can be defined as IT investment (*IT*) 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. In other words, 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 1 provides sample statistics for our key variables.

EMPIRICAL RESULTS

The previous Equation (2) is regarded as the starting point of the analysis. The OLS estimates coefficients are shown in Table 2. Table 2 shows that the labor coefficient is higher than the capital coefficient, although, both have a significant impact on the level of productivity. The IT capital's parameter (γ) is significantly positive at the 1% statistical level; however, its impact on output is smaller than *NONIT* and *LAB*. Then, the study estimate MP of each input follow the method provided by Brynjolfsson and Hitt (1996) as specified in Equation (3) to verify and compare with the results of Brynjolfsson and Hitt (1996),

Table 1. Statistics on variables (after deflation) (NT$ million).

Variable	Name	Mean (S.E.)
Value added	VAL	992.416 (6406.222)
Non-IT capital	NONIT	162.821(1,791.495)
Number of employees	LAB	554.064 (1,617.800)
IT capital	IT	2.234(6.173)
TFP index	TFP	0.038 (0.039)

The numbers in parentheses are standard errors.

Table 2. Estimates of the Cobb-Douglas production function.

Variable	Parameter estimate	Standard error
constant	7.131[a]	0.281
log NONIT	0.387[a]	0.017
log LAB	0.545[a]	0.027
log IT	0.126[a]	0.020

a, b, and c represent the 1, 5, and 10% significance levels, respectively. R^2=0.841.

Hitt and Brynjolfsson (1996) and Dewan and Min (1997). The results show that MP of each input presents the MP_{IT}> MP_{NONIT} >MP_{LAB} pattern. This estimate pattern is somewhat different from the empirical results in Brynjolfsson and Hitt (1996), Hitt and Brynjolfsson (1996), and Dewan and Min (1997), which have MP_{LAB}> MP_{IT}> MP_{NONIT} pattern. All these studies reflect a contradiction between the magnitude of output elasticity and MP of IT even smaller than labor, although, its MP is larger than non-IT capital. Owing to the fact the small share of IT to output, by applying Equation (3), the estimation of MP would be larger. This implies that MP could not be a proper productivity indicator, and MP is not the same as TFP. Thus, it could not be used to explicitly evaluate productivity paradox.

Therefore, this paper adopts the non-neutral production function as our primary empirical model to detect productivity paradox, and also takes into account the impact of IT on TFP, capital and labor productivity through substitution.

In order to observe whether or not IT has an influence on productivity, we use the F-test to test the joint null hypothesis for the parameters in this non-neutral production function model as shown in Equation (9). The joint null hypothesis is H_0: $\alpha_2 = \beta_2 = \gamma_2 = 0$, and the alternative hypothesis is H_1: $\alpha_2 \neq 0$, $\beta_2 \neq 0$, or $\lambda_2 \neq 0$, or all are nonzero. Since F = 6.31 and the P-value < 0.01, the study rejects H_0 and conclude that at least one parameter is not zero, and thus, IT has an effect upon productivity via TFP or other traditional inputs.

Table 3 presents the estimates for the non-neutral production function. The result shows that the coefficient of IT (*logIT)* is 0.370 and positive significance at the 1% statistical level, and the estimated IT contribution to output is more than the Cobb-Douglas functional form. We also find that the interaction terms of IT and non-IT capital, IT and labor, and IT and TFP have statistically significant impacts on productivity. Moreover, the coefficient for the interaction effect between IT and non-IT capital is negative, implying that IT and non-IT capital are substitute in the period of the study. It can be inferred that IT price changes will cause the flow of the input to substitute for other mutually. This is consistent with the finding of Jorgenson (2001) that discovered U.S. IT price decline, triggered by a much sharper acceleration in the price of semiconductors, and found that the rapid price decline for computer investment was 17.1% per year from 1959 to 1995, and since 1995, this decline has almost doubled to 32.1%. His studies show that the price decline of IT investment makes the accelerated accumulation in IT investment for other inputs, and has significant impact on GDP growth.

Besides, the coefficients for the interaction effect between IT and Labor, and IT and TFP have positive and significant impacts on output, this implies that IT and Labor, and IT and TFP have complementary relationships. With this relationship, IT can enhance TFP and then promote productivity, and it can be used to detect the Solow productivity paradox. It can be concluded that, there is no Solow productivity paradox in the study period.

Finally, this paper applies Equation (14) to measure the contribution of IT to TFP, and the result of estimation shows that IT has important positive and significant impacts on TFP of the magnitude approximate 15%. This result could further demonstrate the conclusion of the Solow productivity paradox earlier drawn in this paper.

Table 3. Estimates of the non-neutral production function .

Variable	Parameter estimate	Standard error
constant	4.250[a]	0.045
logIT	0.370[a]	0.135
log NONIT	0.236[a]	0.005
ITlogNONIT	-0.030[a]	0.006
logLAB	0.728[a]	0.003
ITlogLAB	0.019[a]	0.005
logTFP	1.366[a]	0.012
ITlogTFP	0.229[a]	0.079

a, b, and c represent the 1, 5, and 10% significance levels, respectively. R^2 =0.930.

Conclusions

Over the past decade, quite a few studies have discussed and debated the issue of the Solow IT productivity paradox. Nevertheless, few of them focus on the impact of IT on TFP. Some of these studies applied the Cobb-Douglas production function to estimate the MP of IT, and use it as the IT's contribution to productivity. For this reason, this study uses the manufacturing firm-level data of Taiwan in 1991 to explore the issue of whether IT investment brings about the Solow productivity paradox. In order to take the improvement of product quality caused by IT investment into account, a proper hedonic price index is used to deflate the IT variable. Besides the general specification of Cobb-Douglas production function, this paper considers the impact of IT on TFP, capital and labor productivity through substitution by applying a non-neutral production function. Further we evaluate the contribution of IT to TFP.

Empirical results show that that MP could not be a proper productivity indicator, and MP is not the same as TFP. Thus, it could not explicitly evaluate Solow IT productivity paradox. Furthermore, IT investment provides a significant contribution to productivity. The study also finds that IT capital is a complement for TFP and a substitute for non-IT capital. This implies that the price of IT declining would make the accelerated accumulation in IT investment for traditional inputs. With the significant and positive impact of IT on TFP, we conclude that there is no productivity paradox in our study.

ACKNOWLEDGEMENT

Financial support was provided by Taiwan National Science Council through grant NSC 99-2410-H-324-004- and we are grateful.

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