# IT INDUCED PRODUCTIVITY GAINS AT NATIONAL LEVELS: CHARACTERISTICS OF AN APPROPRIATE THEORETICAL MODEL

Anandi P. Sahu, Oakland University, Michigan
Ronal L. Tracy, Oakland University, Michigan*

***Abstract***

*Numerous studies in recent years have examined the productivity impact of information technology (IT). The IT impact has been studied both at the macro and micro level. This paper confines to the studies at the national level in the U.S. Evidence varies from unqualified support for IT as the source of U.S. productivity resurgence in the 1990s to skepticism and doubt. One possible explanation for widely divergent results for the impact of IT on productivity is the wide variation in both theoretical and empirical methodologies utilized in studying the impact of IT on productivity. Therefore, our study closely examines the appropriateness of theoretical models employed in studying the IT impact at the national level, with a view to determine the attributes of the most appropriate model. Our findings suggest that a model based on the Cobb-Douglas production function allows the introduction of IT (in its different forms) to estimate the effect of IT on productivity both from the point of view of capital deepening and total factor productivity (technical change). However, all differences are not due to model differences – differences in the scope of the data are also important. Finally, we offer a process to resolve the identified discrepancies.*

## INTRODUCTION

Numerous studies in recent years have examined the productivity impact of information technology (IT). The IT impact has been studied both at the macro (economy wide) and micro (firm, business unit and industry) level – some examining adoption of IT across countries. The focus of this study is to examine the appropriateness of theoretical models employed in studying the impact of IT on productivity at the national level.

A large number of studies have examined the IT impact on economic growth in the United States. Examples of such studies include Jorgensen and Stiroh (2000); Oliner and Sichel (2000, 2002); Baily and Lawrence (2001); Stiroh (2002); Basu, *et al.* (2003); Jorgenson *et al.* (2005, 2006); and Stiroh and Botsch (2007). Evidence varies from unqualified support for IT as the source of U.S. productivity resurgence in the 1990s to skepticism and doubt (induced by the fact that the productivity growth strengthened after September 2001 despite a massive slowdown in investment in IT). In comparing the national-level IT impact across countries, Shih, Kraemer and Dedrick (2007) observed that while IT is an important driver of economic growth in developed countries, it is not yet a significant force in developing countries. Even among developed countries, IT was not always seen as the savior. Basu, *et al.* (2003), for example, questioned why IT accelerated productivity in the U.S., but not in the United Kingdom.

One possible explanation for widely divergent results for the impact of IT on productivity is the wide variation in both theoretical and empirical methodologies utilized in studying the impact of IT on productivity. Therefore, our study proposes to closely examine the appropriateness of theoretical models employed in studying the IT impact at the national level, with a view to determine the attributes of the most appropriate model.

**Input Substitution or Technical Change?**

Our study starts out with the examination of the appropriateness of Solow methodology to measure "technical change." Utilizing Solow's (1957) seminal work, many economists consider greater investment in IT as a substitution of IT for other forms of labor and capital. This implies that greater IT investment is merely a *movement* along a given production function, rather than a *shift* implying a technical change. As this initial step indicates, our task is a rather difficult one: reconciling the popular notion of productivity (defined mainly by the “growth of output per unit of labor”), characteristics of IT as an input, and theoretical models that can identify the contribution to labor productivity attributable to IT investment.

Once an appropriate theoretical model for use at the national level is identified, we will utilize it in future studies to determine the magnitude of IT impact on productivity empirically, based on macroeconomic data from the U.S. and other countries.

## THEORETICAL MODELS EMPLOYED

**The Basic Underlying Model**

The basic underlying model in most studies of the impact of IT on productivity utilize the neoclassical Cobb-Douglas Production function:

$$Y = A\,K^{\alpha}\,L^{\beta} \qquad (1)$$

where $K$ = the capital input
$L$ = the labor input
$A$ = the technological level, and
$(\alpha + \beta) = 1$ to reflect the constant returns to scale assumption.

Equation (1) is the simplest form of the Cobb-Douglas production function. Moreover, it the simplifying assumption of constant returns to scale.

**IT and Non-IT Capital**

One approach simply modifies the neo-classical Cobb-Douglas production function approach to include IT based capital stock explicitly in the production function and retains the constant returns to scale assumption. This approach was followed by Dewan and Kraemer (2000), and Park, Shin and Shin (2007), and their model is presented as follows:

$$Y(t) = A\, e^{ct}\, K_N(t)^{\beta_N}\, K_{IT}(t)^{\beta_{IT}}\, L(t)^{1-\beta_N-\beta_{IT}} \quad (2)$$

where $Y(t)$ = the output at time t,
$K_N(t)$ = the non-IT related physical capital,
$K_{IT}(t)$ = the IT related physical capital,
$L(t)$ = the labor input at time t,
$A$ = the technological level
$c$ = the constant rate of technological advancement in production technology

The coefficients satisfy the constant returns to scale assumption as follows:

$0<\beta_N, <\beta_{IT} <1$
$(\beta_N + \beta_{IT}) <1$ and assuming that $(\gamma_L = 1- \beta_N, - \beta_{IT})$, we have
$\beta_N, + \beta_{IT} + \gamma_L = 1$.

Normalizing equation (2) by dividing both sides by $L(t)$, (2) can be rewritten in terms of both output and capital per labor unit:

$$y(t) = A\, e^{ct}\, k_N(t)^{\beta_N}\, k_{IT}(t)^{\beta_{IT}} \quad (3)$$

*In the preceding equation, y(t), output per unit of labor is the typical productivity measure*. Taking logs of both sides, we have:

$$\log y(t) = \log A + c \times t + \beta_N \log k_N(t) + \beta_{IT} \log k_{IT}(t) \quad (4)$$

In order to avoid, spurious relationships and to achieve stationarity, the first difference of variables in (4) is utilized:

$$d \log y(t) = c + \beta_N\, d \log k_N(t) + \beta_{IT} \log k_{IT}(t) \quad (5)$$

First differences of logs are equivalent to the variables being expressed in growth rate terms. Equation (5) essentially provides a regression model, whose coefficients can be estimated using time series data. The estimate of coefficient $\beta_{IT}$ provides the effect of IT investment on productivity.

**Capital Intensity and Spillover**

Park, Shin and Shin (2007) investigate the impact of both *IT intensity* (captured by the $k_{IT}$ term), and an alternative to this approach -- *IT externality effects* (IT affects productivity through knowledge spillover). In the latter case, the technology level term A is no longer constant. The regression model given by (5) is expanded to include the term, $\dot{A}(t)/A(t)$, where $\dot{A}(t) = dA(t)/dt$. The expanded equation implies that the rate of technological progress is determined endogenously. In our view, this may pose a problem as the age-old assumption of the exogenous technical progress is now replaced by a more limiting assumption that the technical progress is determined by a single factor – the rate of IT investment.

## THE TOTAL OR MULTI FACTOR PRODUCTIVITY

Park, Shin and Sanders {Note that Park, Shin and Sanders (2007) study has two authors in common with Park, Shin and Shin (2007).} also employ the neoclassical Cobb-Douglas production function (with constant returns to scale assumption), however, they depart from the Park, Shin and Shin (2007) study in an important way – they use a different productivity measure. Their production function is expressed as:

$$Y = A\,\lambda^{N}\,K^{\alpha}\,L^{\beta} \qquad (6)$$

Equation (6) is same as (1), except that the $\lambda$ term captures the effect of each innovation on the technological level. N captures the extent of technologies in different countries. In this study, Park, Shin and Sanders (2007) use total factor productivity (TFP) as the productivity measure:

$$TFP = \frac{Y}{K^{\alpha}L^{\beta}} \qquad (7)$$

where $(\alpha + \beta) = 1$.

Substituting equation (6) in TFP expression (7) above and taking logs of both sides, we have:

$$\log TFP = \log A + N \log(\lambda) \qquad (8)$$

This expression was developed by Park, Shin and Sanders (2007) into a regression model. We however do not pursue this course since we are confining to single country studies. However, the Park, Shin and Sanders (2007) study illustrates the use of TFP as a productivity measure.

**Multiple Capital Components.**

As postulated by Solow, the total factor productivity is captured by finding the *residual* term after allowing for growth in all other factors. However, there are differences in the way this residual is arrived at. Oliner and Sichel (2000; JEP) use this theoretical underpinning and postulated decomposition of output growth attributable to five inputs, labor quality and the residual (termed as multi-factor productivity [MFP] residual, attributable to technological or organizational improvements):

$$\dot{Y} = \alpha_C \dot{K}_c + \alpha_{SW} \dot{K}_{SW} + \alpha_M \dot{K}_M + \alpha_0 \dot{K}_0 + \alpha_L(\dot{L} + \dot{q}) + \dot{MFP} \quad (9)$$

where $K_C$ = Contributions from computer hardware
$K_{SW}$ = Contributions from computer software
$K_M$ = Contributions from communications equipment
$K_0$ = Contributions from other capital
$L$ = Contributions from labor hours
$q$ = Contributions from labor quality
$MFP$ = Contributions from multi-factor productivity

The dot over a variable indicates the rate of change expressed as a log difference, and α terms represent income shares of the attributes listed.

It is important to point out that the neoclassical model on which (9) is based assumes that businesses always maintain their capital stock at or near their optimal long-run levels. This implies that all types of capital earn the same competitive rate of return at the margin, net of depreciation, taxes and other costs associated with owning each asset. This concept is important in determining the income shares of various inputs. Utilizing the BLS framework, the income share of personal computers, for example, is given by:

$$\alpha_C = \{[r + \delta_C - \pi_C]\, p_C K_C\, T_C\}/pY \quad (10)$$

where $r$ = a measure of the real net rate of return common to all capital
$pY$ = total nominal output/income
$\delta_C$ = the depreciation rate for computer
$\pi_C$ = the rate of capital gain for computer (which is actually a loss for computer)
$p_C K_C$ = the nominal capital stock of computer, and
$T_C$ = represents a variety of tax terms for computer.

Equation (9) above provides a decomposition of *output growth.* An alternative is to decompose the growth in labor productivity (output per unit of labor). This could be accomplished by subtracting the growth rate of total hours worked ($\dot{L}$)from both sides of this equation as follows:

$$\dot{Y} - \dot{L} = \alpha_C(\dot{K}_c - \dot{L}) + \alpha_{SW}(\dot{K}_{SW} - \dot{L}) + \alpha_M(\dot{K}_M - \dot{L}) + \alpha_0(\dot{K}_0 - \dot{L}) + \alpha_L \dot{q}) + M\dot{F}P \qquad (11)$$

Oliner and Sichel (2000; JEP) estimated this equation as well. This enables one to estimate the contributions of *capital deepening* (due to computer hardware, software, communications equipment, and other capital), growth in labor quality and multifactor productivity (also called total factor productivity?).

**Treatment of Capital**

Not surprisingly, the treatment of capital itself varies. In the model given by equation (11), Oliner and Sichel (2000; JEP) use what they call "productive" capital stocks – they measure the income producing capacity of the existing stock during a given period. The concept of productive capital stock differs from a "wealth" stock, which measures the current market value of assets in use.

**Multiple Output Categories**

Jorgensen and Stiroh (1999; AER) also use the methodology developed by Solow (1957) to examine if the IT investment has been accompanied by technical change – using the residual in economic growth (after the growth of all other inputs, including IT investment are taken into account) to quantify spillovers.

To determine sources of economic growth, Jorgensen and Stiroh (1999; AER) employ Christensen and Jorgenson's (1973) framework to distinguish between output of investment and consumption goods, and inputs of capital and labor services. IT equipment can be considered as both an input into production by firms, and as a form of consumption by households. The aggregate production function can then be stipulated as:

$$g(I, C, S) = f(K, D, L, T) \qquad (12)$$

where K, D, L, and T stand for the following inputs:

K = Capital services
D = Consumer durable services
L = Labor input
T = Technology

The letters I, C, and S stand for the following outputs:

I = Investment goods
C = Consumption goods and services
S = Flow of services from consumer durables

To isolate the impact of computers, Jorgensen and Stiroh (1999; AER), the aggregate production function given by (1) is decomposed as follows:

$$g(I_c, I_n, C_c, C_n, S_c, S_n) = f(K_c, K_n, D_c, D_n, L, T) \qquad (13)$$

where the subscript "c" refers to the computer portion and the subscript "n" refers to the non-computer portion.

## DATA UTILIZED

### Variations in Scope of Data

Most studies for the U.S. utilize the BLS and BEA data. However, results are not always truly comparable. For example, while both Oliner and Sichel (2000; JEP) and Jorgensen and Stiroh (1999; AER) examined the role of IT for the U.S., they differ with respect to the scope of their data – that is, the extent of the U.S. economy covered by data utilized by them. Jorgensen and Stiroh (1999; AER) focused on the private sector economy (leaving out government and rest of the world), while Oliner and Sichel (2000; JEP) focused on the non-farm manufacturing component of the U.S. economy.

### Defining Variables in Utilizing Data

As pointed out in section 3, the concept of capital itself has been defined differently in different studies. There is a significant difference, for example, between the concepts of "productive" capital and "wealth" capital.

Even decomposition IT into different components as well as differing combinations of IT components can lead to differences as well. Earlier work by Oliner and Sichel (Oliner and Sichel, 1994; Oliner and Wascher, 1995; and Sichel, 1997, 1999) focused on computer hardware and software. However, Oliner and Sichel (2000) groups communication equipment with hardware and software.

Of course differences in results can be due to a combination of both data and model differences. As equations (1) and (2) show the models employed by Jorgensen and Stiroh (1999; AER) and Oliner and Sichel (2000; JEP) are both based in neoclassical growth theory. Nevertheless, there are major differences in the decomposition of output.

**A POSSIBLE METHOD TO RESOLVE VASTLY DIFFERING RESULTS.**

Two clear components of a possible resolution strategy emerge – model specification, and data scope and definition. In order to produce results that are comparable:

1. We must first confine to a given country (U.S. in our case, for convenience) and to a given period (the longest possible period for which data is available). Also, we will limit our study to the private sector economy.

2. We then start with the simplest Cob-Douglas model make it increasing detailed by introducing components of first capital and then output.

3. Each variation of the model in (2) is estimated using the same set of data (as specified in (1).

4. Once we are done with (1) through (3), we repeat it for the manufacturing sector.

We expect that the results will change as we vary the models and the scope of data. It is extremely likely that we will be able to explain away the *productivity paradox*. likely outcome will be

## ENDNOTES

*Dr. Anandi P. Sahu is a Professor of Economics and Dr. Ronal L. Tracy is an Associate Professor of Economics at the School of Business Administration, Oakland University, Rochester, MICHIGAN.

## REFERENCES

**Baily, M.N. and R.Z. Lawrence** (2001), "Do We Have a New e-Economy? *The American Economic Review*, 91, pp. 308-312.

**Basu, S., J.G. Fernald, N. Oulton and S. Srinivasan** (2003), "The Case of the Missing Productivity Growth," in M. Gertler and K. Rogoff (eds.), *NBER Macroeconomics Annual*, MIT Press Cambridge, MA, pp. 9-63

**Jorgenson, Dale W., Mun S. Ho and Kevin J. Stiroh** (2006), "Potential Growth of the U.S. Economy: Will the U.S. Productivity Resurgence Continue." *Business Economics,* Vol. 41, No. 1, pp. 7-16.

**Jorgenson, Dale W. and Kevin J. Stiroh** (2000), "Raising the Speed Limit: U.S. Economic Growth in the Information Age," *Brookings Papers on Economic Activity,*1:2000, pp.125-235.

**Jorgenson, Dale W. and Khuong Vu** (2005), "Information Technology and the World Economy," *Scandinavian Journal of Economics,* Vol. 107, Issue 4, pp. 631-650.

**Oliner, S. D. and D. E. Sichel** (2000), "The resurgence of growth in the late 1990s: Is information technology the story?" *The Journal of Economic Perspectives*, 14(4): 3.

**Oliner, S. D. and D. E. Sichel** (2002), "Information Technology and Productivity: Where are we now and where are we going?" *Economic Review*, 3, 3, pp. 15-41.

***Shih,*** **Eric, Kenneth L.** ***Kraemer and*** **Jason** ***Dedrick*** *(2007), "*Determinants of Country-Level Investment in Information Technology," *Management Science,* Vol. 53, No. 3, pp. 521–528

**Stiroh, K. J.** (2002). "Information technology and the U.S. Productivity revival: What do the industry data say?" *The American Economic Review,* 92(5): 1559.