European Journal of Operational Research 228 (2013) 249–261

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Investigating and comparing the dynamic patterns of the business value of information technology over time

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ARTICLE INFO

Article history:
Received 16 February 2011
Accepted 7 January 2013
Available online 24 January 2013

Keywords:
Decision support systems
Time-varying stochastic CES production frontier
Dynamic patterns
The IT productivity paradox
Substitution and complement of inputs

ABSTRACT

The long-debated issue of the business value of information technology (IT) to the firm (country) has received a great deal of attention in the literature. But the studies have rarely examined the dynamic patterns of the IT value as measured by the firm's productive efficiency over time. The objective of this paper is to apply the three-factor constant elasticity of substitution (CES) time-varying stochastic production frontier models and use the same data set as used in several previous studies to investigate the dynamic patterns of IT value over time in connection with the issues of inputs substitution and complement and the productivity paradox. This paper adopts two analytical skills, collective and individual, to analyze the empirical results. Collectively, we find that the dynamic patterns of IT value are closely related to the substitution and complement of three inputs and the IT productivity paradox. Individually, we identify five common dynamic patterns of the IT value measured by productive efficiency and interpret their implications for the productivity paradox as summarized in a two by two matrix of practical applications and strategies. This matrix accounts for four different scenarios of the relationship between the average productive efficiency and the IT productivity paradox, illustrates some practical applications by the analytical results, and provides some business insights and managerial strategies for IT decision makers and PO/IS managers. This represents a new contribution to the understanding of the dynamic influence of IT investments upon the value of IT over time.

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1. Introduction

A long debated issue of the business value of information technology (IT) to the firm (country) as measured by productive efficiency and other metrics has received a great deal of attention in the literature. While the results of previous research are inconclusive, the IT investment of the firm has been fast increasing to achieve its business goals over the past decades. For example, IBM, the world largest IT service provider, has even reached historical high quarterly profits and raised the future outlook of its IT services in 2008 and 2009 during the most serious financial crisis since 1933. The total global investment on IT has increased from $2.1 trillion in 2001 to $3.4 trillion in 2007; the growth of the IT industry is expected to reach $4.4 trillion by 2011 at a compound annual growth rate of 7.7% (*Digital Planet* 2008). From the managerial and organizational perspectives, IT becomes an enabler to improve productivity, but it does not guarantee such thing.

As summarized in Lin and Shao (2006b), the measures of organizational performance frequently used for IT benefits include profitability (e.g., Hitt and Brynjolfsson, 1996; Weill, 1992), productivity (e.g., Dewan and Min, 1997; Giraleas et al., 2012; Hitt and Brynjolfsson, 1996; Mukhopadhyay et al., 1997; Shao and Shu, 2004; Weill, 1992), productive (or technical) efficiency (Chen, 2002; Collier et al., 2011; Lee, 2006, 2010; Lee et al., 2011; Lin and Shao, 2000, 2006a,b; Chen and Lin, 2009; Lin, 2009; Ondrich and Ruggiero, 2001; Shao and Lin, 2001, 2002; Shu and Lee, 2003), costs (Alpar and Kim, 1990), quality (Mukhopadhyay et al., 1997), consumer surplus (Bresnahan, 1986; Hitt and Brynjolfsson, 1996), operational efficiency (Kao, 2012; Krüger, 2012), Malmquist Productivity index (Lin, 2013; Malmquist, 1953; Tohidi et al., 2012), etc.

While we have sufficient research to enable us to understand the business value of IT, research results on the value of IT investment are inconclusive, with coexisting studies indicative of improved productivity (e.g., Brynjolfsson and Hitt, 1996) and failed positive benefits (Lin and Shao, 2006b) at the firm level, thereby the so-called IT productivity paradox. In country-level research, Dewan and Kraemer (2000) conclude that the productivity paradox is absent from the developed countries, but still exists in the developing countries; in contrast, Lin (2009), Chen and Lin (2009), and Lin and Chiang

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0377-2217/$ - see front matter Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.ejor.2013.01.023

(2011) argue that the productivity paradox exists in both developing and developed countries. Pitt and Lee (1981) and Chen and Tang (1987) find the phenomenon of the paradox at the firm and industry levels. Ulu and Smith (2009) argue that the technology's actual benefit may be constant or changing over time, using a dynamic programming model.

Although abundant research has been devoted to the business value of IT and its related issue known as the IT productivity paradox, virtually rare studies examine the dynamic patterns of IT value over time, as measured by productive efficiency. The gap must be filled since we believe that understanding the dynamic patterns of the IT value is critically important for making IT investment decisions and providing essential POM and ISM plans.

The remainder of the paper is organized as follows: Section 2 introduces the theory, research approach and performance measure used in this research paper. Based on Section 2, Section 3 presents four models used to conduct the research and describes the estimation algorithms. Section 4 explains the data. Section 5 applies the Wilcoxon signed-ranks non-parametric method to test the significance among different models. Section 6 provides estimated results, a collective analysis, and the impact of firm size. Section 7 undertakes an individual analysis of the dynamic patterns of IT value and presents the managerial implications of the dynamic patterns as well as a two by two matrix of managerial applications and strategies by the individual analytical results. Finally, Section 8 concludes the paper with some remarks.

2. Theory, research approach, and performance measure

2.1. Theory of production

This research is based on the theory of production which, in symbol, is described by $Y_{it} = f(\boldsymbol{X}_{it}; \boldsymbol{\beta})$, where Y_{it} is the observed (actual) output for firm i at time t, $f(\boldsymbol{X}_{it}; \boldsymbol{\beta})$ is the ideal (maximum, expected, or desired) output produced by a set of production inputs $\boldsymbol{X}_{it}$, and $\boldsymbol{\beta}$ is a vector of unknown coefficients. However, since technological or other production and managerial constraints always exist, the actual output is less than or equal to the desired output, that is, $Y_{it} \leqslant f(\mathbf{X}_{it}; \boldsymbol{\beta})$ or

$$Y_{it} = f(\mathbf{X}_{it}; \boldsymbol{\beta}) - u_{it}, \quad i = 1, \ldots, n \quad \text{and } t = 1, \ldots, m, \tag{1}$$

where u_{it} is an inefficient, non-negative random error that is usually assumed to follow a one-sided normal distribution, $|N(0, \sigma_u^2)|$, for all i and t. Thus, $u_{it} = f(\boldsymbol{X}_{it}; \boldsymbol{\beta}) - Y_{it}$ represents technical (productive) inefficiency which may be caused by controllable influencing factors of the firm (Chen and Lin, 2009; Lin, 2009, 2013; Lin and Shao, 2000).

2.2. The time-varying stochastic production frontier approach

Adding a conventional random error v_{it} to the right-hand side of Eq. (1) results in Eq. (2) given by

$$Y_{it} = f(\mathbf{X}_{it}; \boldsymbol{\beta}) - u_{it} + v_{it}, \quad i = 1, \ldots, n \quad \text{and } t = 1, \ldots, m, \tag{2}$$

where v_{it} is assumed to be distributed according to $N(0, \sigma_v^2)$. Eq. (2) specifies the time-varying stochastic production frontier (SPF) approach (see, e.g., Chen and Lin, 2009; Lin, 2009, 2013; Lee, 2006, 2010; Lin and Shao, 2000, 2006a,b). Based on the theory of production, this research is built on the time-varying SPF approach in which the set of production factors $\boldsymbol{X}_{it}$ is composed of ordinary or non-IT capital (K_{it}) and ordinary labor (L_{it}) considered as production factors conventionally; and IT-capital (I_{it}) is introduced to serve as an additional production factor.

2.3. The performance measure

Given that u_{it} in Eq. (2) is one-sided normal distribution and must lie in [0, ∞], PE_{it}, the productive efficiency of firm i at time t, can be defined as (Lin and Shao, 2000, 2006a,b; Lee, 2006, 2009; Chen and Lin, 2009; Lin and Chiang, 2011, among others)

$$PE_{it} = \exp(-u_{it}), \quad i = 1, \ldots, n \quad \text{and } t = 1, \ldots m, \tag{3}$$

which lies between 0 and 1. Then, the individual analytical method is based on the dynamic pattern average productive efficiency (APE_{pt}) given by

$$APE_{pt} = \sum_{i=1}^{n_p} PE_{it}/n_p, \quad t = 1, \ldots, m, \tag{4}$$

where n_p is the number of firms revealing pattern p and p = the linear, quadratic, cubic, quartic, and irregular dynamic patterns (see Section 7.1 below); and $\sum_p n_p = n$.

The dynamic average productive efficiency (APE_t) of a research model used to analyze the whole sample of observations in each year during the time period is denoted by

$$APE_t = \sum_i PE_{it}/n, \quad t = 1, \ldots, m. \tag{5}$$

Then, the overall average productive efficiency (APE) is given by

$$APE = \sum_{i,t} PE_{it}/nm. \tag{6}$$

Consequently, the time-varying SPF approach is the companion of the theory of production and the technical (productive) efficiency metric is the companion of the SPF approach. Therefore, Eqs. (1)–(6) are interrelated rather than mutually exclusive.

3. Research models and estimation method

Since this research is an extended study of Lin and Shao (2006b) and Chen and Lin (2009), the functional forms of the production function $f(\boldsymbol{X}_{it}; \boldsymbol{\beta})$ will be specified as the two-factor CES (Arrow et al., 1961; Lin and Shao, 2006b) and three-factor CES (Chen and Lin, 2009) production frontiers (see Appendix 1 for details). These specifications result in four research models of particular interest, of which the most interesting is the three-factor CES frontier model which introduces IT capital as an additional production factor along with the conventional inputs (ordinary capital or non-IT capital and ordinary labor).

3.1. Model 1: The two-factor model without IT and without firm size

To compare with other models and analyze the dynamic patterns of the IT value, this research begins with the simplest two-factor CES production frontier as given by Model 1 in Lin and Shao (2006b, p. 496). This is also designated as Model 1 (see Eq. (A3) in Appendix 1):

$$\ln Y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 (\ln K_{it} - \ln L_{it})^2 - u_{it} + v_{it}. \tag{7}$$

Lin and Shao (2006b) investigate the relationships of substitution/complement between non-IT capital (K) and non-IS labor (L), between non-IT capital (K) and IT capital (I), and between non-IS labor (L) and IT capital (I). To do a meaningful comparison of the results of the two-factor (KL) production frontier with those of the three-factor (KLI) production frontier and to avoid potential bias and inconsistency arising from the two-factor models when there are three input variables available, this research considers the two-factor (KL) model of Eq. (7) in comparison with the three-factor (KLI) model of Eq. (8) (Chen and Lin, 2009) below.