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The business value of information technology and inputs substitution: The productivity paradox revisited

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Abstract

The business value of information technology (IT) is an extremely important but highly controversial issue that has sparked a great deal of research during the past two decades. Closely related to the issue are the productivity paradox of information systems and the substitutability of IT stock for both traditional capital and labor. Numerous studies have been undertaken to either explain or dispel the paradox. This paper represents one significant extension to previous work and is a further effort to jointly investigate the business value issue, the paradox, and the potential of the substitution between IT capital and ordinary capital and labor, by estimating the IT business value in terms of the impact of IT on technical efficiency, based on the constant elasticity of substitution (known as CES) stochastic production frontier model, at three levels: firm, industry, and sector. The major findings include: the relationship between technical efficiency and IT investment is not robust with respect to the specifications of production frontiers; the productivity paradox is still existent, inconsistent with conventional wisdom, IT has substantial impacts on the five parameters associated with the CES production process; IT stock, traditional capital, and traditional labor are not pairwise substitutable; IT stock appears to be as important as capital, but it is not possible to use IT stock to replace the role of labor entirely; decreasing returns to scale are found irrespective of the levels of IT investments, and technical efficiency tends to decrease as IT investments increase; the industry-level analysis suggests that IT capital is more important for the services industries than for the manufacturing industries; and the sector analysis seems to indicate that the services sector is just slightly less technically efficient than the manufacturing sector.

Keywords: Information technology; IT investments; Productivity paradox; Technical efficiency; CES production function; Substitutability; Complementarity

1. Introduction

During the past two decades, information technology (IT) has become a major driver of economic change and restructured the landscape of a business organization. IT spendings have increased faster than expected in recent years. For example, the IT spendings in 2001 for the United States and Japan were $546,681 and $188,012 (in millions of US dollars, source: *Digital Planet 2002: The Global Information Economy*, p. 29), respectively. Therefore, IT has played an increasingly important role in a business organization and the business value of IT investments has become a crucial but controversial issue. Abundant research has been

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devoted to resolving this issue using different performance measures. Notable examples include the studies of Cron and Sobol [15], Bender [7], Dos Santos et al. [18], Strassman [37], and Hitt and Brynjolfsson [21], using the measures of productivity, consumer surplus, and profitability; the work by Weill [39], Dewan and Min [17], Dewan and Kraemer [16], and others, by means of productivity; the research by Bresnahan [10] and Hitt and Brynjolfsson [21] relying on consumer surplus, by Mukhopadhyay et al. [28] using quality, and by Banker et al. [6] utilizing operational efficiency; and the paper by Bharadwaj et al. [9] based on Tobin's q.

In essence, the empirical results of the studies addressing the business value of IT are inconclusive and conflicting (Mukhopadhyay et al. [28]). In particular, closely related to the issue of IT business value is the phenomenon known as the productivity paradox of information systems (IS) (Bailey and Gordon [4] and Roach [32]) that was found to exist in the 1980s but was shown to have disappeared in the early 1990s (Brynjolfsson [11], Brynjolfsson and Hitt [12], and Hitt and Brynjolfsson [21]). Based on a set of country-level data, Dewan and Kraemer [16] have concluded that the productivity paradox is absent from the developed countries but does exist in the developing countries in their sample.

Recently, Lin and Shao [25] have adopted a different approach to re-examine the issue of IT business value, using a performance measure called technical (or productive) efficiency (also see Shao and Lin [34–36]). Technical efficiency is a useful economic performance measure (Lin and Shao [25]) different from profitability, productivity, consumer surplus, quality, operational efficiency, and Tobin's q. Under a variety of specifications of the stochastic production frontier, including the generalized Cobb–Douglas function (Lin and Shao [25] and Shao and Lin [34,35]), the Box–Cox and Box–Tidwell transformations (Lin and Shao [25]), the translog frontier (Shao and Lin [34,35]), and data envelopment analysis and the Tobit regression (Shao and Lin [36]), and employing the same data set as used in a number of studies such as Hitt and Brynjolfsson [21] and Dewan and Min [17], Lin and Shao [25] have concluded that the disappearance of the productivity paradox is supported by the efficiency enhancement of IT investments.

The positive effect of IT investments on technical efficiency is a good news in favor of the argument of the productivity paradox disappearance. However, we question if such a pleasing conclusion is robust with respect to the specification of stochastic production frontiers. A major finding of Lin and Shao [25] is that there is a robust and consistent relationship between IT investment and efficiency, irrespective of the production frontier model employed. Thus, the debates go on. We argue that the question of whether the productivity paradox disappears or exists depends on the specifications of the stochastic production frontier.

Another important issue that is also closely related to the business value of IT is the substitutability of IT for both traditional capital and labor. Although the IS literature seems to abound in research dedicated to either explain or dispel the productivity paradox of IS, it is the scarcity of research that makes the substitutability of IT for ordinary capital and labor a subject for serious inquiry along with the business value of IT. The only exception is the study of Dewan and Min [17] which estimates IT substitutability by relating it to the marginal products of inputs, using the partial elasticity of substitution of Allen and Hicks [2]. Since the ability to secure the benefits of IT is partially determined by the potential of substituting IT for capital and labor, the inputs substitution issue is equally important and deserves our efforts.

This paper offers a joint study on the relationship between IT and technical efficiency, the existence of the productivity paradox, and the possibility of the substitution of IT capital for both traditional capital and labor, within the framework of the constant elasticity of substitution (known in the econometrics literature as CES) stochastic production frontier model. More specifically, the primary objective of this research is three-fold: one, to assess how IT investments affect technical efficiency; two, to revisit the productivity paradox; and three, to explore the importance of IT in comparison with, and the substitutability (or complementarity) between IT and, the traditional production factors (capital and labor). A secondary objective is to analyze how IT impacts the five important parameters associated with the CES production process, namely, the efficiency parameter, the distribution parameters, the returns-to-scale parameter, and the substitution parameter. Especially, the question of the substitution between IT and capital and between IT and labor is dealt with based on the substitution parameter. Since the CES stochastic production frontier models have never been applied in the IS literature as a methodological basis, the empirical results are both interesting and challenging.

It should be noted that, methodologically, there is a choice between a parametric approach (e.g., the translog cost function used in Menton and Lee [27] and the stochastic production frontier approach as discussed in Jondrow et al. [22] and used in Lin and Shao [25] for the first time in the IS literature, Shao and Lin [34,35],