



# Assessing the values of EC and IT separately and simultaneously and inputs substitution and complement: The CES-based stochastic frontier approaches



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## ARTICLE INFO

### Article history:

Received 23 May 2012

Received in revised form 11 March 2015

Accepted 8 September 2015

Available online 12 September 2015

### Keywords:

Theory of production

Time-varying stochastic production frontier approaches

Productive (technical) efficiency

Constant elasticity of substitution (CES)

frontier productions

Input substitution and complement

Complementarity and substitutability

phenomena

## ABSTRACT

The objective of this research is to critically explore four interrelated issues at the country level by evaluating the values of e-commerce (EC) and information technology (IT) both separately and simultaneously; examining the possibilities of complementarity and substitutability phenomena; analyzing the impacts of substitution and complement relations among ordinary capital, ordinary labor, and IT capital on the business values of EC and IT; and revisiting the productivity paradox by using the stochastic frontier approaches, which incorporate the CES production functions. The empirical results imply that it is important to assess the values of EC and IT simultaneously rather than separately.

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## 1. Introduction

A careful review of the literature on production and operations research/economics (POR/E) and information systems (IS) clearly indicates that the business values of information technology (IT) and e-commerce (EC) have been assessed separately rather than jointly. This mode of research inquiry undermines the positive and/or negative interactions between IT and EC and thus leads to an under- or over-estimation of the real values of IT and EC. Zhu and Kraemer [48] and Zhu [49] sought to confirm the positive interaction (called complementarity) of IT infrastructure and EC capability at the firm level by using a classical regression approach.

It is conceivable that the presence of EC may strengthen the value of IT (thus giving rise to the phenomenon of complementarity) or weaken it (thus resulting in the phenomenon of substitutability), and vice versa, which provides a good explanation for the

disappearance or existence of the so-called productivity paradox. In other words, it can be argued that when EC and IT are present simultaneously, they do not necessarily become more powerful in creating greater value than by themselves alone; hence, the notions of both complementarity and substitutability may prevail. Note that being powerful is measured by productive (technical) efficiency. For instance, if EC creates larger (smaller) productive efficiency than IT, then EC is more (less) powerful than IT, and vice versa.

Moreover, according to Chen and Lin [10], the functional form of frontier productions (e.g., the constant elasticity of substitution known as CES, CD, BC, and BT) and the substitution and complement of inputs are important sources of productive (in)efficiency on the technological side. Dewan and Min [15], Lin and Shao [28], and Chen and Lin [10] agreed that the substitution and complement relations of production factors (e.g., ordinary capital, ordinary labor, and IT capital) are a very complex matter; therefore, their impacts on IT and EC values must not be ignored. Thus, four interrelated research problems must be resolved to more accurately and properly assess the values of EC and IT: (i) evaluating the business values of IT and EC simultaneously rather than separately; (ii) examining the possibilities of complementarity and substitutability phenomena; (iii) deploying an appropriate production frontier function that enables us to analyze the impacts

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of inputs substitution and complement relations among ordinary capital (i.e., non-IT capital), ordinary labor, and IT capital upon the values of IT and EC; and (iv) revisiting the existence of the productivity paradox with the notion that the values of IT and EC must be evaluated jointly rather than independently.

Thus, the objective of this paper is to investigate four problems of critical importance both simultaneously and jointly: the assessment of IT and EC values, the presence of the complementarity and substitutability phenomena, the impacts of the complement and substitution of inputs, and a revisit of the productivity paradox. To accomplish this goal, we propose to apply the time-varying stochastic production frontier (SPF) approaches that are derived from the theory of production and their built-in performance metric, known as productive (technical) efficiency, by incorporating the two-factor [2,24,28,45] and three-factor (Chen and Lin [10]) constant elasticity of substitution (known as CES) production frontiers (see Appendix 1 for details). The stochastic production frontiers specified by the Cobb–Douglas (CD) production function, the Box–Cox (BC) transformation function, and the Box–Tidwell (BT) transformation function, as applied by Lin and Shao [28] and Lin [29], are not capable of resolving the four issues jointly. Although CD, BC, and BT can be deployed to investigate research issues (i), (ii), and (iv), they, unlike CES, are not equipped with the so-called substitution parameter (Appendix 1) that enables us to resolve research issue (iii) with the other three issues.

EC and IT are also essential parts of production and operations (PO) and information systems (IS); accordingly, the values of EC and IT are critically relative to both firm and country performance. The present study is expected to provide new insights into EC and IT values and will consequently lead to better decisions on IT and EC investments in production processes.

Though this research is devoted to the impacts of IT and EC on country performance at the country level of analysis, it actually informs managers of PO and IS and benefits firms. Numerous authors (e.g., [10,16,29,32,37,38,41,44]) have argued in favor of research at the country level. The reasons cited include, but are not limited to, the following (Lin [29]): (i) because too much attention has been paid to large U.S. firms, further research in comparative studies at the country level is called for; (ii) IT and EC value research at the firm level is abundant, but the knowledge accumulation of IT and EC values at the country level is poor; (iii) firm-level results require validation to determine whether they are applicable across national boundaries, i.e., external validity of firm-level conclusions on IT and EC values is required; (iv) a key dimension of external validity is international generalization, and a country-level study on IT and EC values is an international generalization; (v) the scarcity of IT and EC data at the firm level makes it impossible to undertake a research inquiry such as this study intends to do; and (vi) cross-country studies look for both similarities and differences in PO/IS practices [37] and can be used to discover emergent universality and shape competitive advantages when managers of IS/PO face increasing globalization. This study responds to the call for country-level research.

The remainder of this research is organized as follows. Section 2 undertakes a literature review. Section 3 describes the theory of production, research methodology, and performance measures; and Section 4 details the stochastic CES production frontier models. Section 5 defines the variables involved and describes the country-level panel data used. Section 6 reports and discusses the empirical results obtained and derives major findings. Finally, Section 7 concludes the paper with some remarks.

**2. Literature review**

Because of the rapidly increasing IT investment, the business value of IT has been the focus of many studies at the firm level and

several studies at the country level over the past two decades (see Table 1 in Lin [29]; the list includes, e.g., [3,6,7,9,16,26–29,31,32,35,36,39–41,44]). Some of these studies have reported a positive impact of IT on the firm’s or country’s performance, which suggests that the productivity paradox has disappeared. Contradictory conclusions, however, have also been reached in a number of studies (e.g., [10,26,28,29]), which claim that the productivity paradox remains existent.

In contrast, recent years have witnessed the increasing popularity of EC activities; therefore, the business value of EC investments has become a great concern. EC is an unfolding phenomenon [49] defined as business activities (e.g., e-links with supplies, online connections with customers, dissemination of product information) that are constructed over the Internet. A list of studies examining the benefits of EC as the primary subject includes [4,8,11,14,17,18,20,25,34,42,43,46,48,49]. In particular, Zhu [49] has reviewed fourteen papers relevant to EC value, which were published over the past ten or so years.

Virtually, these studies are characterized by a common feature, that is, they have assessed IT and EC value separately and independently, rather than jointly and simultaneously. [49] is an exception but differs from this study in its theory, research approach, analytical method, performance measure, data used, and, accordingly, conclusion. Zhu’s study is based on the resource-based theory; applies the classical OLS regression approach; uses four performance measures (i.e., the ratio of sales to employees, the ratio of the cost of goods sold to employees, return on assets, and inventory turnover) to serve as dependent variables; relies on the *collective* analytical method (i.e., based simply on the statistical significance and signs of coefficient estimates) to analyze the OLS estimates that were obtained from a set of cross-sectional data from 114 firms in the U.S. retail industry; and concludes that a positive interaction effect (i.e., the phenomenon of complementarity, not substitutability) exists between IT and EC. No comparisons of individual firms are permitted by the OLS regression approach of Zhu [49]. The estimates of  $APE_{i,t}$ s, as presented in this study, make comparisons of individual countries possible. In the absence of similar estimates for individual firms, Zhu [49] is unable to conduct a comparison of the performance of individual firms.

In contrast, the present work is based on the theory of production; applies the time-varying stochastic production frontier (SPF) approaches underlying this theory; uses productive (technical) efficiency derived from the SPF approaches as the performance measure (i.e., rather than from outside the research approaches); analyzes empirical estimates using both collective and individual analytical methods; and uses a panel dataset at the

**Table 1**  
Some general and limiting cases of correspondences between  $\rho$  or  $\rho_i$  and  $\sigma$  in the CES production models.

Parameter of substitution: $\rho$ and $\rho_i$ ( $i = 1, 2, 3$ ) Range	Elasticity of substitution: $\sigma$ Range	Economic meaning
$[-1, \infty]$ 0	$[-\infty, \infty]$ 1	The CES reduces to the Cobb–Douglas function with constant returns to scale
$\infty$	$\infty$	The CES reduces to fixed proportions (a straight line)
$>0$	$>0$	Inputs substitution
$-1 \leq \rho, \rho_i < 0$ ( $i = 1, 2, 3$ )	$<0$	Inputs complement

Note:  $\rho$  and  $\rho_i$  ( $i = 1, 2, 3$ ) are the substitution parameters in the two-factor model and the three-factor model considered in Lin and Shao [28] and Chen and Lin [10], respectively.

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