

Article

Estimating the Value of Information Technology in the Productivity of the Transport Sector

Athanasios G. Giannopoulos¹ and Tatiana P. Moschovou^{2,*}

¹ Transportation and IT Consultant, TREDIT SA, and Hellenic Institute of Transport, 54006 Thessaloniki, Greece; tgiannopoulos@tredit.gr

² Department of Transportation Planning and Engineering, National Technical University of Athens, 10160 Athens, Greece

* Correspondence: tmosch@central.ntua.gr

Abstract: This paper expands a methodology, originally formulated for calculating the firm-level business value of Information Technology (IT), to that for a whole sector and applies it experimentally for the transport sector using statistical databases for several countries in Europe. The term “business value” means the quantified impact of a given technology, in this case, Information Technology, on the productivity of a sector or firm as measured by a given “yardstick” (e.g., sales, revenue, and many others). This is important to know in order to justify investments in a given technology or technological sector and for policy formulation or regulation. This paper proposes a novel methodology for calculating the business value of IT in a given sector. This is the first time that such a task is attempted because in the past most research was focused on calculating the business value at firm-level. The suggested methodology is then applied by use of panel data from the statistical records of national statistics for the transport sector. The results show that infrastructural investment in Information Technology has an impact on the transport sector’s output, in terms of its annual production value, of the order of 5–6%. Through sensitivity tests and a discussion of the results, it is estimated that the actual impact may probably be a bit higher but not much higher (in any case, something below the 10% figure). The application also shows that the suggested methodology can be applied for the estimation of the impact of any other technology or service on any given economic sector. Finally, a possible future conceptual model is presented for the expansion of the methodology to a more global and integrated level considering the interaction from other sectors as well as other technological and environmental factors.

Keywords: business value; information technology; transport sector; productive efficiency; Cobb–Douglas model; IT/BV; IT business value; IT applications



Citation: Giannopoulos, A.G.; Moschovou, T.P. Estimating the Value of Information Technology in the Productivity of the Transport Sector.

Future Transp. **2023**, *3*, 601–614.

<https://doi.org/10.3390/futuretransp3020035>

Received: 22 February 2023

Revised: 18 April 2023

Accepted: 24 April 2023

Published: 6 May 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Information Technology, IT, is a term used to express the technologies that allow computers to store, retrieve, manipulate, and communicate data and information by use of appropriate hardware and software infrastructures. Using the 2010 European System of Account’s (ESA 2010) terminology the following categories are the main elements of what is meant by “IT infrastructures” within a given sector: Computer hardware (ESA 2010 code N11321); telecommunications equipment (ESA 2010 code N11322); computer software and databases (ESA 2010 code N1173). In addition to the hardware and software resources, the application of Information Technology within a sector necessitates the application of various organizational, financial, and human resource elements to make them most productive and useful, but there are no separate statistical records on those items.

The impacts of IT infrastructures on the productivity of a firm in terms of increased output (e.g., sales, revenue, reliability, client base, etc.) represent what is usually called the IT “business value” of the firm, or firm-level business value, and is denoted as IT/BV.

This is a notion that has been discussed and analyzed extensively in the literature [1–5]. The impact on a sector's output of investments in IT infrastructures in the totality of firms within a sector (e.g., the transport sector) is the "sector-level business value" and is denoted by IT/SV. The way in which the "sector's output" is calculated will also determine the methodology with which the IT/SV could be calculated. In the next section (literature review), several methodologies that have been used to define and calculate the firm-level IT/BV are presented and some of these can be adopted for the sector-level IT/SV as well. In this paper, the IT/SV is expressed by the percentage contribution of IT infrastructure investment on the overall productivity of a sector as this is denoted by its productive efficiency (PE). This is further explained and expanded in Section 3.

In any given sector, IT is used for a multitude of tasks. These tasks can be distinguished as those that are "internal" to a firm, i.e., they are performed in order to produce value added for the firm itself (e.g., for order management, promotion, invoicing, personnel management, customer service, back-office operations, and so on) and those that are "external", i.e., they are performed for the operation of the sector as a whole and these are utilized by all users. As an example, in the transport sector, the IT investments of a train operating company that are utilized for the operation of that company and contribute to its own value added and output are "internal". The IT investments that are necessary for the operation and management of the rail network, its various traffic management and control devices, the operation of the stations, and so on, are considered "external". It follows that "external" IT investments (systems and applications) are also materialized through specific firms running these types of horizontal services and for them some of these tasks may be "internal".

There is currently a research gap in the existing work on "business value." The great majority of published papers so far refer to the calculation of firm-level business value (IT/BV) but not the sector-level one. Among the IT/BV published work is a previous publication by one of the current authors [5], in which the firm-level IT/BV was calculated with reference to the "internal" IT tasks of a firm, using a methodology based on production theory concepts and productivity. Calculating the sector-level IT/SV would theoretically necessitate calculating the combined effect of all "internal" and "external" IT/BV within a given sector. This, however, would necessitate a lot of data and surveys which, in most cases, are not feasible. A new methodology is necessary that would require less data and—most importantly—data that can be readily available in the normal statistical records kept at the national or sector level. This research gap is addressed by this paper whose main research questions can be formulated as: (a) Can a production-theory-based methodology be applied to the calculation of IT/SV? (b) Is it valid irrespective of the sector considered? (c) Can such a methodology utilize readily available data in statistical authorities' databases? (d) How reliable and how sensitive to those data is the IT/SV that is calculated? (Sensitivity analysis).

This paper adapts and modifies the methodology used for the production-theory-based calculation of IT/BV (in [5]) to calculate the IT/SV of a given sector by using readily available data in the statistical records. After it formulates the relevant methodology, it applies it to the sector of transport using panel data from 17 EU countries. The rest of the paper is structured as follows. First, an introduction and a literature review about the notion of (firm-level) "business value" is given. Then, the suggested methodology for calculating the sector-wide value for the impact of IT on the productivity of a given sector is presented based on the production theory and its notion of productive efficiency (PE). It consists of a series of steps that end with the calculation of the PE of a sector with and without IT investments. This methodology is then applied to the transport sector using panel data for 17 EU countries from publicly available databases in Eurostat (the statistics authority of the European Union).

2. Literature Review

The *theory of production* that examines the relationship between the factors of production (i.e., land, labor, and capital) and the output in terms of goods and services produced is a theory used in the literature for the calculation of firm-level IT/BV and is also used in this paper for the calculation of sector-level business value. *Competitiveness* and *productivity* are the two major concepts of production theory that have been thoroughly researched in the past in terms of IT/BV and IT/SV and have been defined and analyzed by several authors [6–12]. The firm-level business value of IT (IT/BV) is a notion that has been extensively researched and several definitions are available in the literature [1–4,6,7,13,14]. The most common theories used to define it in the literature are as follows: the *Microeconomics* theory definitions (production theory, consumer demand theory, opportunity cost theory, and others) [3,4]; the *Industrial Organization* theories, e.g., the game theory [15], agency or transaction cost theory [14] and others; the definitions based on *Organizational Behavior* theory (that relate IT/BV to profitability and quality as well as to overall organizational performance [6] or to the business process re-engineering (BPR) concepts [2]); the *Resource-based* theory [16]; and the definitions based on *Process Theory* [17,18].

Considering the measures of quantification of IT/BV, the literature provides a multitude of suggestions, applications, and results that can be found in several publications, e.g., [8,18–25]. Examples of such measures are the various economic indicators of the outcome, such as *profitability* measured by, e.g., the return on sales [16], *productivity* measured by the output per unit input [26], *productive efficiency* [6,7] (this will be examined in more detail in the following sections), increase in *organizational capabilities*, *new strategic position* in the market and several others [1]. Most of this research work attempts to estimate the firm-level IT/BV by measuring its impact on “firm performance” [27] using operational-level variables of “firm performance” as measures, such as “productivity” and “capacity utilization” of specific strategic business units [28], or higher-level variables, such as “market share” and “profitability” [29].

Perhaps the most well-publicized study on firm-level IT/BV was the one that unveiled the so-called “*productivity paradox*”, i.e., the observation that IT spending within a firm did not necessarily have a notable effect on its productivity and output. This paradox was first published in a paper by Brynjolfsson [26] and gave rise to many publications and subsequent research with mixed results. On the one hand, some confirmed the “paradox”, i.e., they failed to find strong evidence to support a positive correlation between investments in IT and increased “business value” [23,30]. On the other hand, several other studies reported significant evidence of positive impacts. In the end, the author of the original “productivity paradox” paper in a later publication, based on an input/output and price deflators study of some 400 firms, concluded that IT spending had made a “statistically significant contribution to firm output”, and thus there was no “paradox” [31]. The appearance of the “paradox” was finally explained by the fact that productivity benefits from IT investments usually show up after several years and by the fact that IT investments should normally be combined with a thorough re-organization of the firm to be most effective [21,22].

Sector-level IT business value (IT/SV) estimation is rare in the literature. The reason is probably the difficulties associated with the existence of a multitude of factors and variables that can be considered, as well as the potential influence of too many external factors (i.e., factors outside the sector considered). A notable effort at calculating the sector-level IT/BV has been performed by a study using data from 14 OECD countries [7]. Additionally, some work has been devoted to calculating the IT/SV for all sectors at the country level. A comprehensive summary of country-level IT/SV studies is given in [32], Table 1. This reference presents the results of eight such studies with mixed findings. Some have concluded the contribution of IT to “business value” at the country level is expressed by measures of economic growth, but this is mainly for developed countries [33]. Others did not find notable effects in both developed and developing economies [34]. This is probably because the impacts of IT investment on IT/SV at the country level may include

potentially substantial redistribution effects which may cause negative impacts on other parts of the sector or country, and thus diminish or blur the overall result of IT investment on the output (business value) for the whole country.

3. Materials and Methods (Methodological Formulation)

3.1. Basic Definitions

Competitiveness is defined as the ability of a firm or sector to optimize its performance (attractiveness to the user or customer) to deliver quality services and be innovative and effective in providing good value for money [7,9]. Competitive transport services are those that attract customers and gain market shares (at domestic or global marketplaces) while ensuring that the available resources supporting them are used efficiently and in a sustainable way. *Productivity* is defined as the output for a given input (with reference to a specific firm or sector), while the collective productivity performance of the firms constituting a certain sector can be defined as the productivity of the whole sector. Productivity is often expressed as the so-called *productive efficiency* (PE), i.e., the efficiency of the production process which transforms inputs into outputs. A *production frontier* (PF) or *production possibility curve* is a curve on a graph that illustrates the possible quantities that can be produced with two products or services if both depend upon the same finite resources for their production.

Within a sector (such as within a firm), the PE can be thought of as the level at which we cannot increase the production of one good or service without sacrificing the production of another good or service within the constraints of current technology levels. Correspondingly, the production frontier (PF) function represents the maximum, i.e., the ideal or desired, output level realizable from a given combination of inputs (resources) and technological capabilities. The difference between the “ideal” and the “actual” output levels of a sector is its *productive inefficiency* (PI). Productive inefficiency occurs when most firms within a given sector are not producing at their lowest unit cost usually due to the lack of technological innovation. The smaller the technological innovation change over a given period (t), the larger the PI change becomes, as shown below:

$$\text{PI change at a time (t)} = [\text{Productivity change} / \text{Technological change}] \text{ at a time (t)} \quad (1)$$

These are key concepts of the theory of production that can be used for calculating the IT/SV for any given sector.

3.2. Model Formulation

Based on the above concepts, if we can formulate a mathematical model for calculating the sector-level *productive efficiency* (PE) of a specific sector and correlate this with a number of factors, one of which represents the level of IT infrastructures that is available, then the % difference in the value of this PE, with and without the influence of the IT related infrastructures, can be the measure of sector-level IT/SV for that specific sector. The function that will be formulated for the calculation of the PE is in effect the so-called *Stochastic production frontier* (SPF) curve for the specific sector and its technological level of development. The mathematical model formulations that can be used for the definition of the SPF function are well-known in the literature and more specifically are the *generalized Cobb–Douglas* (CD), the *Box–Cox* (BC), the *Box–Tidwell* (BT), and the *Translog* (TL) models [3,4,6,16,23,32]. All four of these model specifications have been utilized for calculating the IT/SV for all sectors at the country level in [32], and most of them have a similar context at the firm level in [7,8].

In this paper, the application of the *Cobb–Douglas* (CD) formulation is used as it is the simplest and most easily applied with the kind of data that are to be used. Thus, the SPF for a given sector (i) at a time period (t) is of the following form:

$$Y_{it} = f(X_{it}; \beta) + (v_{it} - u_{it}) \quad (2)$$

where,

Y_{it} : The observed output of the sector in terms of a suitable measure (e.g., the gross value of production, gross revenue, added value, etc.).

$f(X_{it}; \beta)$: The stochastic production frontier (SPF) function. X_{it} refers to the set of inputs (independent variables) that are considered to best explain the output produced. In our application case, the inputs used can be the total capital investment in the sector distinguished in IT capital and non-IT capital (see Section 3.3), and the amount of labor in terms of the total number of people employed.

β : A set of coefficients to be specified.

$(v_{it} - u_{it})$: The standard error of the function. It shows the deviation of the prediction from the observation, and it consists of:

- v_{it} , which represents the deviation due to random error distributed according to a normal distribution, $N(0, \sigma_v^2)$;
- u_{it} , which is the error term representing “inefficiency”. This “inefficiency” term is a very useful item for our analysis since its value can be used to calculate the *productive efficiency* of the sector (i) at a time (t) by use of the production theory relation:

$$PE_{it} = e^{-u_{it}} \tag{3}$$

The standard error term $(v_{it} - u_{it})$ is a single numerical figure that is produced by the regression–correlation analysis and normally follows a one-sided (half normal) distribution $|N(0, \sigma_u^2)|$. Jondrow et al. have suggested a methodology to estimate the expected value of u_{it} conditional on the term $(v_{it} - u_{it})$ [35,36]. Once the value of u_{it} is estimated, the productive efficiency (PE) of the sector can be calculated by use of Equation (3). The values of PE will range between 1 and 0, so when u_{it} is 0 (no inefficiency), the sector-wide PE term $e^{-u_{it}}$ is 1 (i.e., the sector shows the highest efficiency). As the u_{it} term increases and tends to ∞ (i.e., we have the highest inefficiency), the productive efficiency term $e^{-u_{it}}$ is reduced and tends to zero (no efficiency).

The CD model formulation of relation (2) that can materialize the SPF function for the quantification of IT/SV is the following:

$$Y_{it} = \alpha K_{it}^{\beta_1} L_{it}^{\beta_2} I_{it}^{\beta_3} e^{[v_{it} - u_{it}]} \tag{4}$$

where,

Y_{it} : The “observed” output of the sector.

K_{it} : It represents the non-IT capital used in the sector in terms of investments made in infrastructures and equipment other than IT in the period considered (usually annually). Typical items in the non-IT capital are investments in buildings and other structures in the sector, equipment, and so on (see Section 3.3).

I_{it} : This represents the capital related to IT infrastructures (Capital IT). In the case of the available Eurostat data, this represents the capital invested for computer hardware and software, databases, and telecommunications. Additionally, if the data are available, it could also include the amount of IT spending related to labor costs. In such cases, a composite measure such as the so-called “IT stock” can be used. This is expressed as (*IT infrastructure capital + 3 x Information Systems labor spending*). Factor 3 represents the assumed service life of the assets created by IT-related labor [34].

L_{it} : This is a measure of the labor force serving the sector. It can be distinguished from IT and non-IT labor if the data exist and can be measured by the number of people, the total salary expenses, or other appropriate measures. In the case of our application, the data available in the Eurostat databases did not allow us to distinguish the labor between IT and non-IT; therefore, we used the total labor figures for the transport sector.

$\beta_1, \beta_2, \beta_3$: The coefficients that need to be defined by the regression.

v_{it} and u_{it} : As defined previously for Equation (2).

The above form of the SPF is preferred because in this form the values of the β parameters are equal to the elasticities of Y with respect to the corresponding independent

variable (K, L, I). Equation (4) is transformed into a linear form through logarithmic conversion as shown in Equation (5) below.

$$\ln Y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln I_{it} + (v_{it} - u_{it}) \quad (5)$$

where, $\beta_0 = \ln \alpha$, and all other symbols represent the same as defined for Equation (4).

The values of the parameters β and the value of the term $(v_{it} - u_{it})$ are calculated via regression analysis on cross-sectional or time-series data at the sector level for the period considered.

The percentage difference of the PE that results (calculated in Equation (3)) from the runs **with** and **without** the inclusion of the IT inputs in the regression (i.e., with and without the terms “I” in the formulation of Equation (4)) gives us a measure of the sector-level IT/SV in the specific sector.

3.3. Sources of Data

All data required for the run of the above models are available in existing and publicly available databases of EUROSTAT, the EU’s statistical Authority (<https://ec.europa.eu/eurostat> (accessed on 12 February 2023)). For the application in the case of the transport sector, the following Eurostat databases were used:

- *Structural Business Statistics (SBS)* database with metadata (Euro SDMX metadata Structure–ESMS).
- *Annual detailed enterprise statistics for services* (NACE Rev.2 H-N and S95).
- *Cross-classification of fixed assets by industry and by asset*.

The above databases contain data sets for several sectors of economic activity. The specific data sets used for the application of the methodology in the transport sector were the following:

- For Y_{it} (“observed” output of the sector), the *annual production value* (in millions of Euros) of the transport and storage sector is available in Eurostat’s *SBS database* [37]. The “production value” is defined by Eurostat as the turnover, plus or minus the changes in stocks of finished products, work in progress, and goods and services purchased for resale, minus the purchases of goods and services for resale, plus capitalized production and other operating income (excluding subsidies) [37]. This value was considered a good measure of sector “output” as it is a result of the inner interactions and workings of the various businesses and economic sub-elements within the sector (which are expressed as the independent variables). The *annual production value* came under different configurations in the Eurostat database, and therefore, several of these configurations were tested (see Table 1).
- For K_{it} (non-IT capital), the non-IT capital for the transport sector is found in the *cross-classification of fixed non-IT assets* database of Eurostat, specified according to the statistical classification of economic activities in the European Community (NACE revision 2) [38]. These non-IT assets are given under the following cross-classification codes:
 - N111—Dwellings;
 - N112—Other buildings and structures;
 - N1131—Transport equipment;
 - N110—Other machinery and equipment;
 - N110—intellectual property products;
 - N1171—Research and Development.
- For I_{it} (IT-capital), the same as with the K_s database was used, but the IT-capital data are classified under the European System of Accounts—ESA 2010 (9/28) classification “ICT equipment” [38]. The figures include investments for the following classification codes:
 - N11321—Computer hardware;
 - N11322—Telecommunications equipment;
 - N1173—Computer software and databases.

All the above data provided are chain linked to 2015, in millions of Euros.

- For L_{it} (labor), it represents the total number of persons employed in the transport sector under different configurations (see Table 1) [39]. It is defined by Eurostat as the total number of persons who work in the sector’s firms both “internally”, i.e., working personnel inclusive of working proprietors, partners working regularly in the firms, and unpaid family workers, as well as “externally”, i.e., persons who work outside the firm but belong to it and are paid by it (e.g., sales representatives, delivery personnel, repair, and maintenance teams).

The utilization of readily available data is a great simplification of the whole procedure as it does not necessitate holding expensive and time-consuming surveys for data collection. It also allows for testing any number or combinations of data between countries, time periods, or variables, to find the best fit for the functions.

A summary of the variables used is shown in Table 1.

Table 1. The variables used in various combinations for the formulation of the Cobb–Douglas Production Frontier model for the transport sector based on Eurostat data.

Name of Variable [Sign Used]	Description	Source	Unit
Productivity 1 [PR1]	Annual turnover value of transport and storage sector	Eurostat, table SBS_NA_1A_SE_R2 [39]	Million Euros
Productivity 2 [PR 2]	Annual value added at factor cost of transport and storage sector	Eurostat, table SBS_NA_1A_SE_R2 [39]	Million Euros
Productivity 3 [PR 3]	Annual index of turnover in services of transport and storage sector	Eurostat, table STS_SETU [40]	Index of turnover, 2015 = 100
Productivity 4 [PR 4]	Annual turnover per person employed in the transport and storage sector	Eurostat, table SBS_NA_1A_SE_R [39]	Thousand Euros
Capital non-IT [K1]	Non-IT capital, i.e., expenditure on non-IT infrastructure investments as those listed for the Kit variable above.	Eurostat, table NAMA_10_NFA_ST [38] Cross-classification tables of fixed assets for the transport and storage sector by non-IT assets	Chain linked volumes (2015), in million Euros
Capital IT [K2]	IT capital, i.e., expenditure on IT infrastructure investments as those listed for the I_{it} variable above.	Eurostat, table NAMA_10_NFA_ST [38] Cross-classification of fixed assets for the transport and storage sector by IT asset	Chain linked volumes (2015), in million Euros
Labor 1 [L1]	Annual number of persons employed in the transport and storage sector	Eurostat, table STS_SELB [41]	Index, 2015 = 100
Labor 2 [L2]	Annual number of persons employed by sex, age, and economic activity (transport and storage sector)	Eurostat, table LFSA_EGAN2 [42]	Thousands of employed persons
Labor 3 [L3]	Annual total employment for the transport and storage sector (National accounts employment data by industry)	Eurostat, table NAMA_10_A64_E [43]	Thousands of persons
Labor 4 [L4]	Annual persons employed in the transport and storage sector	Eurostat, table SBS_NA_1A_SE_R2 [39]	Number of persons employed

The data sets used were articulated as panel data, the time-series of which resulted from considering a 11-year period from 2010 to 2020, while the cross-sectional series were gathered from the relevant data sets for 17 countries (Austria, Belgium, Czech Republic, Estonia, Finland, France, Greece, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Norway, Slovakia, Slovenia, and Sweden). This set of countries was selected after a first review and assessment of the completeness and availability of their Eurostat data

for all time periods. Therefore, for the whole set of 17 countries, the sample size for the regressions was $17 \times 11 = 187$ data sets.

It follows that according to the specific interests of each application case, a different subset of countries or time periods can be considered. The results presented in the following are meant as an example of the use and utilization of the proposed methodology for estimating the “value” (contribution) of a given technology or service (such as IT) to the overall output of a given sector by using data available in the statistical databases found in national or regional statistics.

4. Results

The above formulations and data have been applied for the estimation of the IT/SV in the transport sector with data that are readily available in the statistical authorities’ databases.

The application of the methodology to the transport sector started with running several regression analyses on the 187 series of panel data with different combinations of variables. Several such combinations were tested and evaluated based on the CD model’s resulting regression statistics at any given run (e.g., R^2 , standard errors, significance levels, F factors, and so on). Then, from the value of the overall standard error of each resulting equation (i.e., the value of the $v-u$ factor), the value of u was estimated (conditional to the $v-u$ factor according to [35,36]). Finally, from Equation (3), the sector PE (productive efficiency) was calculated. By going through these steps, once with and once without the terms I_{it} (IT capital), a measure of the IT “impact” in each case was obtained. This is taken to represent the IT/SV. All regressions were made using the PLS-SEM (partial least squares structural equation modeling) module of the SmartPLS4 (partial least squares structural equation) software package. It should be noted that the coefficients β also represent the elasticities of the observed output of the sector to the respective independent variable.

A summary of the most “successful” runs (in terms of their statistics), made according to the above as well as their main results, is given in Table 2. The figures in this table show the values of the main parameters and statistical results of the five runs with the most “successful”, i.e., statistically trustworthy, results. They show that the contribution of the IT sector infrastructure investments to the total annual output of the transport sector for the 17 EU countries is of the order of 5–6%. These results are indicative of the validity of the methodology described, but one must be careful to consider several related issues, one of which is the sensitivity of the results to changes in the independent input variables. Therefore, a sensitivity analysis was carried out for the values of Y and the resulting sector PEs under the hypothesis of having different values of the *Capital IT* variable (I). This was mainly of interest to see because the value of “IT investments” in the statistical records normally does not include the IT organizational and labor expenses. Thus, by calculating the sensitivity of Y to different values of (I), i.e., the *Capital IT* variable, one can have an idea of the resulting changes to the IT/SV. A sensitivity analysis performed on these hypotheses showed that the values of Y (and thus IT/SV) have a relatively small sensitivity to the values of (I). This is also shown from the low values of the β_3 parameters (in Table 2 in relation to observation “e” below the table). For example, for a 50% increase in the value of the *capital IT* variable, the % increase of the Y values are of the order of 8–10% max (see Table 2 where the values of the β_3 parameters are 0.16, 0.159, 0.108, 0.117, etc.).

Table 2. Summary of the results for the five most promising runs.

Test Run 1 (PR1 vs. K1, L2, K2)	β_1 *	β_2 *	β_3 *	Sum of β **	Std Error ($v-u$)	R^2	u	PE ($e^{-U_{it}}$)
With IT	0.556	0.233	0.160	0.948	0.4490	0.893	0.1796	0.8356
Without IT	0.663	0.272	-	0.935	0.4603	0.887	0.2394	0.7871
Test Run 1: % Contribution of IT ***								6.2%

Table 2. Cont.

Test Run 2 (PR1 vs. K1, L3, K2)	β_1^*	β_2^*	β_3^*	Sum of β^{**}	Std Error (v-u)	R ²	u	PE (e ^{-Uit})
With IT	0.418	0.428	0.159	1.005	0.4180	0.909	0.1672	0.8460
Without IT	0.511	0.470	-	0.994	0.4305	0.903	0.2152	0.8063
Test Run 2: % Contribution of IT ***								4.9%
Test Run 3 (PR1 vs. K1, L4, K2)	β_1^*	β_2^*	β_3^*	Sum of β^{**}	Std Error (v-u)	R ²	u	PE (e ^{-Uit})
With IT	0.426	0.469	0.108	1.004	0.4129	0.910	0.1652	0.8477
Without IT	0.488	0.511	-	0.999	0.4179	0.907	0.2090	0.8114
Test Run 3: % Contribution of IT ***								4.5%
Test Run 4 (PR2 vs. K1, L3, K2)	β_1^*	β_2^*	β_3^*	Sum of β^{**}	Std Error (v-u)	R ²	u	PE (e ^{-Uit})
With IT	0.502	0.351	0.177	1.031	0.3850	0.927	0.1540	0.8573
Without IT	0.620	0.398	-	1.018	0.4021	0.920	0.2011	0.8179
Test Run 4: % Contribution of IT ***								4.8%
Test Run 5 (PR2 vs. K1, L4, K2)	β_1^*	β_2^*	β_3^*	Sum of β^{**}	Std Error (v-u)	R ²	u	PE (e ^{-Uit})
With IT	0.529	0.355	0.146	1.031	0.3798	0.929	0.1519	0.8590
Without IT	0.613	0.412	-	1.025	0.3908	0.925	0.1954	0.8225
Test Run 5: % Contribution of IT ***								4.4%

(*) All values of the β parameters tested were significant at the 5% level by the p -value for the null hypothesis, i.e., $p < 0.05$. (**) A value greater than 1 means increasing “returns to scale” (i.e., a higher rate of increase of “production” in the future relative to associated increases in the “inputs”). (***) Difference between PE with and without IT variables expressed as %.

As regards the quality of the results of the regressions performed, the following observations can be made:

- a. The R² values are comfortably high indicating high levels of correlation between the variables selected (for reasons of economy of space, Table 2 shows only the results from the most “successful” runs and not of all the runs made which were more than 25).
- b. The sums of the β values are very close to 1, indicating that all equations are close to homogeneity, i.e., of degree 1 (constant returns to scale). This is a very welcome result indicating stability and robustness in the estimated production frontier models.
- c. All β parameters are significant at the 5% level. A reduction in the level of significance might result in the invalidation of a few runs, but this does not invalidate the methodology presented or its basic results.
- d. The sensitivity of the results to the “u” values was also examined. This seems to be quite high because the PE values are directly proportional (inverse proportional, but still “proportional”) to the “u” values. This gives high importance to the method of estimating the “u” values from the (v-u) standard error estimate of each regression.
- e. As already pointed out, the values of the coefficients β represent the corresponding elasticities of the respective variable relevant to the sector’s output. This is quite a useful result from the specific formulation selected for the production frontier model in the form of Equation (4). For example, (with reference to the results of Test Run 1, the first line of Table 2), the values of the β coefficients indicate that the elasticity of, e.g., non-IT capital (K1), with respect to the output of the transport sector (i.e., its annual turnover value) is 0.556. This means that for a 10% increase in the non-IT capital used, there will be a 5.56% increase in the sector’s output. Additionally, in the

same line, one can see that the β value for IT capital is 0.160, indicating that for a 10% increase in IT capital, there will be a 1.6% increase in the sector's output.

5. Discussion and Conclusions

The methodology and the results presented in this paper show that a definition of IT/SV (the sector-level business value of IT) is possible with a “top-down” approach using readily available data on statistical records rather than using the “bottom-up” approach of trying to estimate the combined effect of all “internal” and “external” IT/BV (i.e., at firm-level) within a given sector. The latter would necessitate a lot of data and surveys, which are expensive, time-consuming, and not always feasible. The successful approach used here calculates the IT/SV as the percentage contribution of IT infrastructure investment on the overall productivity of a sector as this is denoted by its productive efficiency (PE), i.e., the efficiency of the production process of this sector. The successful application of the production theory methodology in Sections 3 and 4 shows that this theory can form a valid basis for the calculation of any IT/SV, i.e., for any sector. This is derived from the fact that the production theory-based methodology is independent of a specific sector's types of outputs but rather depends on standard data sets that exist on the relevant national statistical records data related to a sector's performance. These are, for example, its annual turnover, annual value added, etc. (see Table 1).

Another valuable and practical quality result of the methodology used is the form of the production frontier model used, i.e., the Cobb–Douglas (CD) type using the exponential form (see Equation (4)). By using this form the resulting values of the β parameters are the elasticities of the dependent variable (in this case, the observed “output” of the sector) to the values of the corresponding independent variable. In this way, we can have a quick and reliable sensitivity analysis because the β values show in effect how sensitive the existing data are to the results of the IT/SV calculation, and this provides the answer to our fourth research question that was presented at the end of the introduction section.

For the application in the transport sector in Europe, the results indicate that the investment in IT infrastructures has an average overall contribution to the output of that sector of the order of 5–6%. This figure may be an underestimation if one considers that the IT capital resources that are found in the statistics refer to the investments in IT infrastructures and do not include labor or other expenses. It was not possible to locate such additional information, so it is estimated that the actual contribution of the IT-related investments in the transport sector's output is maybe somewhat higher. As an order of magnitude, the 5–6% figure should be considered as the lower limit with the true magnitude of IT's contribution probably a bit higher but, in any case, within the 8–10% value as an upper limit. This estimate is based on the sensitivity analysis that was performed in Section 4 on the values of Y and the resulting sector PEs with different values of the Capital-IT variable (I). This was performed to account for the increased “IT investments” value in case we could include in it the IT organizational and labor expenses (which are not included in “IT investments”).

A considerable practical advantage of the suggested methodology is that it can produce quick and reliable results as it is independent of the need for collecting new (dedicated) data which will normally necessitate expensive and cumbersome surveys. As it utilizes data that are normally found in the statistical databases at the national or regional level it can also be performed inexpensively (at low or no cost). Its main practical use can be seen in several areas from satisfying academic research interests and research funds allocation to supporting high-level decision making in investment allocation. By knowing the contribution (“business value”) of a specific technology to one or more economic sectors, policy makers can make better decisions on how to allocate limited resources and their corresponding priorities.

Regarding future improvements, one could imagine a more comprehensive and expanded approach for calculating sector-level IT/SV based on a more complex conceptual model as shown in Figure 1. This conceptual model involves (for the calculation of IT/SV)

the analysis and inclusion in the calculation process or model of three interacting elements. The first is *IT resources*. These are distinguished in *IT assets* and *IT capabilities*. The *IT assets* include all firm-level IT resources, such as *networking infrastructures*, *technological innovation*, *development capabilities* as well as skilled labor for *efficient and cost-effective operations*. The *IT capabilities* part accounts for the *integration and cooperation of IT systems and services* within the sector for the facilitation of the sector businesses. The second is the *other (non-IT) inputs and resources*. These elements also influence the sector's performance by mutually reinforcing the competencies and practices of the sector by interacting with the competencies and practices of other sectors. These interactions usually enable greater value generation per unit of IT investment. An interesting account of these interrelations can be found in [44].

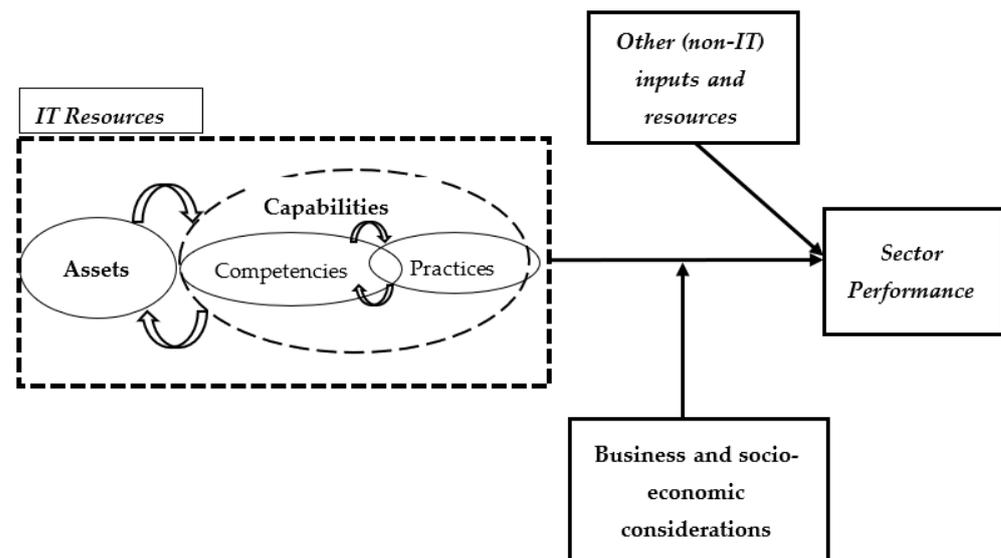


Figure 1. Conceptual model of a new and expanded estimation methodology for sector-level IT/SV.

Thirdly, there are *business and socio-economic considerations*. These influence a sector's performance in various ways, and thus the IT contribution to it (IT business value). A sector's productivity cannot be pursued in an absolute way at the expense of the community. Productivity expansion may have social costs and other externalities which will have to be considered. Cavallaro and Nocera [45] consider the economic valuation assigned to transport externalities in relation to the installation of photovoltaic noise barriers and present a novel method for calculating the variation in economic benefits from the installation of such barriers with the variation in the policy framework while keeping other social and economic elements constant. A similar approach to this could be considered for the calculation of the social impacts of increased sector productivity and performance. Increasing the productivity of a sector may have negative socio-economic impacts, i.e., on the welfare of the community. In such cases, the IT/SV will be reduced, and the planners or decision makers will need to address these impacts in the finalization of their IT investment plans.

The conceptual model of Figure 1, therefore, goes beyond the simplistic model for calculating IT/SV that was presented in this paper and should be further investigated. This would necessitate an extensive research and development phase to analyze and define the inner workings as well as the expression parameters and variables of each of the three main input elements. It would also necessitate the collection of specific data through dedicated surveys because the dedicated data that would be necessary are not usually found in national or regional databases. It is hoped that the formulation and application of the above more detailed and comprehensive methodology will be a further expansion and development of the process for estimating the IT/SV, to which we can return in the future. Nevertheless, these future considerations do not reduce the value of the

methodology shown in this paper. On the contrary, they reinforce it as a plausible and, above all, simple and practical methodology for assessing the IT/SV of a given sector with minimum analytical skills and data requirements.

Author Contributions: Conceptualization, A.G.G.; methodology, A.G.G.; software, T.P.M.; validation, T.P.M. and A.G.G.; formal analysis, T.P.M. and A.G.G.; investigation, T.P.M. and A.G.G.; resources, T.P.M.; data curation, T.P.M.; writing—original draft preparation, A.G.G.; writing—review and editing, A.G.G. and T.P.M.; visualization, A.G.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data is available upon reasonable requests from the corresponding author.

Acknowledgments: The research work on the notion of IT business value started when the first of the authors was a student at the Athens University of Economics and Business under G. Doukidis and Ek. Pramadari. All subsequent development of the methodology for sector-level business value and its application in the transport sector was performed at later stages by the authors under the supervision of G. A. Giannopoulos.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

LIST OF ABBREVIATIONS

BV	Business Value
SV	Sector Value
CD	The Cobb–Douglas mathematical formulation for the calculation of productive efficiency
EUROSTAT	The EU’s Statistical Authority
IS	Information Systems
IT	Information Technology
IT/BV	The business value of IT at firm-level
IT/SV	The business value of IT at sector-level
PE	Productive Efficiency
PF	Production Frontier
SPF	Stochastic Production Frontier

References

1. Giannopoulos, A. Defining IT Business Value Under Conditions of Economic Uncertainty. *J. Adv. Manag. Sci. Inf. Syst.* **2017**, *3*, 36–48. [CrossRef]
2. Devaraj, S.; Kohli, R. Information technology payoff in the health-care industry: A longitudinal study. *J. Manag. Inf. Syst.* **2000**, *16*, 41–68. [CrossRef]
3. Alpar, P.; Kim, M. A Microeconomic Approach to the Measurement of Information Technology Value. *J. Manag. Inf. Syst.* **1990**, *7*, 55–69. Available online: <https://www.jstor.org/stable/40397946> (accessed on 21 February 2023). [CrossRef]
4. Dewan, S.; Michael, S.; Min, C. Firm characteristics and investments in information technology: Scale and scope effects. *Inf. Syst. Res.* **1998**, *9*, 219–232. [CrossRef]
5. Giannopoulos, A.G. Quantifying the role of IT in the ITS sector. In Proceedings of the IEEE 23rd Intelligent Transportation Systems Conference ITSC 2020, Rhodes, Greece, 20–23 September 2020.
6. Melville, N.; Kraemer, K.; Gurbaxani, V. Information technology and organizational performance: An integrative model of IT business value. *MIS Q.* **2004**, *28*, 283–322. [CrossRef]
7. Shu, W.S.; Lee, S. Beyond productivity—Productivity and the three types of efficiencies of information technology industries. *Inf. Softw. Technol.* **2003**, *45*, 513–524. [CrossRef]
8. Soh, C.; Markus, M. How IT creates business value: A process theory synthesis. In Proceedings of the 16th International Conference on Information Systems, Amsterdam, The Netherlands, 10–13 December 1995; pp. 29–41.
9. Dupeyras, A.; MacCallum, N. *Indicators for Measuring Competitiveness in Tourism: A Guidance Document*; OECD Tourism Papers, No. 2013/02; OECD Publishing: Paris, France, 2013. [CrossRef]

10. Borgström, B.; Gammelgaard, B.; Bruun, P. Competitiveness in Road Transport: The Market Liberalized Haulier. In Proceedings of the 11th European Research Seminar on Logistics and SCM. ERS 2016, Vienna, Austria, 12–13 May 2013.
11. Lee, S.; Xiang, J.Y.; Kim, J.K. Information technology and productivity: Empirical evidence from the Chinese electronics industry. *Inf. Manag.* **2011**, *48*, 79–87. [[CrossRef](#)]
12. Wade, M.; Hulland, J. The Resource-Based View and Information Systems Research: Review, Extension, and Suggestions for Future Research. *MIS Q.* **2004**, *28*, 107. [[CrossRef](#)]
13. Giannopoulos, A.G. Exploitation of IT Research Results and the Creation of Innovation in the Context of Collaborative Transport R&D Projects. Ph.D. Thesis, Athens University of Economics and Business, Athens, Greece, 2019.
14. Gurbaxani, V.; Whang, S. The impact of information systems on organizations and markets. *Commun. ACM* **1991**, *34*, 59–73. [[CrossRef](#)]
15. Belleflamme, P. Oligopolistic competition, IT use for product differentiation and the productivity paradox. *Int. J. Ind. Organ.* **2001**, *19*, 227–248. [[CrossRef](#)]
16. Bharadwaj, A.S. A Resource-Based Perspective on Information Technology Capability and Firm Performance: An Empirical Investigation. *MIS Q.* **2000**, *24*, 169–196. [[CrossRef](#)]
17. Mukhopadhyay, T.; Kekre, S.; Kalathur, S. Business Value of Information Technology: A Study of Electronic Data Interchange. *MIS Q.* **1995**, *19*, 137–156. Available online: <https://www.jstor.org/stable/249685> (accessed on 1 November 2021). [[CrossRef](#)]
18. Tam, K. The impact of information technology investments on firm performance and evaluation: Evidence from newly industrialized economies. *Inf. Syst. Res.* **1998**, *9*, 85–98. [[CrossRef](#)]
19. Ahn, S.C.; Lee, Y.H.; Schmidt, P. Stochastic frontier models with multiple time-varying individual effects. *J. Product. Anal.* **2007**, *27*, 1–12. [[CrossRef](#)]
20. Brynjolfsson, E.; Hitt, L.M. Computing productivity: Firm-level evidence. *Rev. Econ. Stat.* **2003**, *84*, 793–808. [[CrossRef](#)]
21. Mitra, S.; Chaya, A.K. Analyzing Cost-Effectiveness of Organizations: The Impact of Information Technology Spending. *J. Manag. Inf. Syst.* **1996**, *13*, 29–57. [[CrossRef](#)]
22. Mooney, J.; Gurbaxani, V.; Kraemer, K. A process oriented framework for assessing the business value of information technology. In Proceedings of the 16th International Conference on Information Systems, Amsterdam, The Netherlands, 10–13 December 1995; pp. 17–27. [[CrossRef](#)]
23. Tyrrell, T.; Paris, C.M.; Biaett, V. A Quantified Triple Bottom Line for Tourism. *J. Travel Res.* **2013**, *52*, 279–293. [[CrossRef](#)]
24. Brynjolfsson, E. The Contribution of Information Technology to Consumer Welfare. *Inf. Syst. Res.* **1996**, *7*, 281–300. [[CrossRef](#)]
25. Hitt, L.M.; Brynjolfsson, E. Productivity, business profitability, and consumer surplus: Three different measures of information technology value. *MIS Q.* **1996**, *20*, 121–142. [[CrossRef](#)]
26. Brynjolfsson, E.; Hitt, L.M. Paradox lost? Firm-level evidence on the returns to information systems spending. *Manag. Sci.* **1996**, *42*, 541–558. [[CrossRef](#)]
27. Shao, B.B.M.; Lin, W.T. Technical efficiency analysis of information technology investments: A two-stage empirical investigation. *Inf. Manag.* **2002**, *39*, 391–401. [[CrossRef](#)]
28. Brynjolfsson, E.; Hitt, L.M. Beyond computation: Information technology, organizational transformation and business performance. *J. Econ. Perspect.* **2000**, *14*, 23–48. [[CrossRef](#)]
29. Barua, A.; Kriebel, C.; Mukhopadhyay, T. An economic analysis of strategic information technology investments. *MIS Q.* **1991**, *15*, 313–331. [[CrossRef](#)]
30. Baker, J.; Song, J.; Jones, D. Refining the IT business value model: Evidence from a longitudinal investigation of healthcare firms. In Proceedings of the International Conference on Information Systems, ICIS 2008, Paris, France, 14–17 December 2008. Available online: <https://aisel.aisnet.org/icis2008/137/> (accessed on 1 October 2021).
31. Brynjolfsson, E. The productivity paradox of information technology. *Commun. ACM* **1993**, *36*, 67–77. [[CrossRef](#)]
32. Lin, W.T.; Shao, B.B.M. Assessing the input effect on productive efficiency in production systems: The value of information technology capital. *Int. J. Prod. Res.* **2006**, *44*, 1799–1819. [[CrossRef](#)]
33. Lin, W.T. The business value of information technology as measured by technical efficiency: Evidence from country-level data. *Decis. Support Syst.* **2009**, *46*, 865–874. [[CrossRef](#)]
34. Chen, Y.H.; Lin, W.T. Analyzing the relationships between information technology, inputs substitution and national characteristics based on CES stochastic frontier production models. *Int. J. Prod. Econ.* **2009**, *120*, 552–569. [[CrossRef](#)]
35. Jondrow, J.; Lovell, K.; Materov, I.; Schmidt, P. On the estimation of technical inefficiency in the stochastic frontier production function model. *J. Econom.* **1982**, *19*, 233–238. [[CrossRef](#)]
36. Belotti, F.; Ilardi, G. Consistent inference in fixed-effects stochastic frontier models. *J. Econom.* **2018**, *202*, 161–177. [[CrossRef](#)]
37. Eurostat. Structural Business Statistics (SBS), Reference Metadata in Euro SDMX Metadata Structure (ESMS). Available online: https://ec.europa.eu/eurostat/cache/metadata/en/sbs_esms.htm (accessed on 1 February 2023).
38. Eurostat. Cross-Classification of Fixed Assets by Industry and by Asset (Stocks) Nama_10_nfa_st Table. Available online: [https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_NFA_ST\\$DV_647/default/table?lang=en&category=isoc.isoc_se](https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_NFA_ST$DV_647/default/table?lang=en&category=isoc.isoc_se) (accessed on 1 February 2023).
39. Eurostat. Annual Detailed Enterprise Statistics for Services (NACE Rev.2 H-N and S95), sbs_na_1a_se_r2 Table. Available online: https://ec.europa.eu/eurostat/databrowser/view/SBS_NA_1A_SE_R2/default/table?lang=en (accessed on 1 February 2023).

40. Eurostat. Turnover in Services—Annual Data, Table TS_SETU_A. Available online: https://ec.europa.eu/eurostat/databrowser/view/STS_SETU_A__custom_4919922/default/table?lang=en (accessed on 1 February 2023).
41. Eurostat. Labour Input in Services—Annual Data, Table STS_SELB. Available online: https://ec.europa.eu/eurostat/databrowser/view/STS_SELB_A__custom_4919932/default/table?lang=en (accessed on 1 February 2023).
42. Eurostat. Employment by Sex, Age and Economic Activity (from 2008 onwards, NACE Rev. 2)—1000, Table LFSA_EGAN2. Available online: https://ec.europa.eu/eurostat/databrowser/view/LFSA_EGAN2/default/table?lang=en (accessed on 1 February 2023).
43. Eurostat. National Accounts Aggregates by Industry (up to NACE A*64), Table NAMA_10_A64_E. Available online: https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_A64/default/table?lang=en (accessed on 1 February 2023).
44. Aral, S.; Weill, P. IT Assets, Organizational Capabilities, and Firm Performance: How Resource Allocations and Organizational Differences Explain Performance Variation. *Organ. Sci.* **2007**, *18*, 763–780. [CrossRef]
45. Cavallaro, F.; Nocera, S. Are transport policies and economic appraisal tools aligned in evaluating road externalities? *Transp. Res. Part D Transp. Environ.* **2022**, *106*, 103266. [CrossRef]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.