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Contaduría y Administración

Accounting & Management

Contaduría y Administración 66 (1), 2021, 1-32

Port productivity in the APEC region: A study through stochastic frontier analysis

La productividad de los puertos en la región del APEC: un estudio a través del análisis de la frontera estocástica

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Received April 9, 2018; accepted November 7, 2019
Available online March 21, 2023

Abstract

This research aims to determine Total Factor Productivity (TFP) of 40 main ports of the APEC region during the period 2005-2015. TFP is measured from its components: technological change, efficiency technical change and scale efficiency change, instrumenting Stochastic Frontier Analysis (SFA). The number of teusisthe dependent variable and the length of dock and personnel employed asindependent variables. On average, the APEC ports had an increase in their TFP of 5.10%, where scale efficiency change is the one with the highest incidence with 4%.

JEL Code: C51, L91, O33
Keywords: APEC; stochastic frontier; total factor productivity; ports

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

http://dx.doi.org/10.22201/fca.24488410e.2021.1998

http://dx.doi.org/10.22201/fca.24488410e.2021.1998

Resumen

Esta investigación tiene como objetivo determinar la Productividad Total de los Factores (PTF) de los 40 principales puertos de la región del APEC durante el periodo 2005-2015. Se mide la PTF a partir de sus componentes: cambio tecnológico, cambio en la eficiencia técnica y cambio en la eficiencia de escala, instrumentando el Análisis de la Frontera Estocástica (SFA). Se tiene como variable dependiente el número de teus y como variables independientes la longitud del muelle y el personal ocupado. En promedio los puertos del APEC tuvieron un incremento en su PTF del 5.10% durante los años de estudio, donde el aumento en la eficiencia de escala es quien más incidencia tiene con un 4%.

Código JEL: C51, L91, O33
Palabras clave: APEC; frontera estocástica; productividad total de los factores; puertos

Introduction

The Asia-Pacific Economic Cooperation (APEC) is a regional forum comprising 21 economies: Australia, Brunei, Canada, Indonesia, Japan, South Korea, Malaysia, New Zealand, the Philippines, Singapore, Thailand, the United States, the Republic of China, Hong Kong, Taiwan, Mexico, Papua New Guinea, Chile, Peru, Russia, and Vietnam. In 2014, its participants represented 54% of the world's Gross Domestic Product (GDP), 50% of international trade, and 40% of the planet's population (APEC, 2015).

The Asia-Pacific Economic Cooperation (APEC) has its origins in the first meeting held in Canberra, Australia, on November 6, 1989, where the four items on the agenda were: a) global and regional economic development; b) liberalization of world trade, the role of the Asia-Pacific region; c) opportunities for regional cooperation in specific areas; and d) future steps for Asia-Pacific economic cooperation (APEC, 1989). In other words, APEC member economies are grouped to achieve common objectives that lead them to constitute themselves as a region.

The relevance of this study in Asia-Pacific economies stems from the fact that this region's share of maritime trade ranks first globally, and that APEC recognizes that maritime transport service is vital to increase trade competitiveness (APEC, 2016).

The strategic importance of maritime transport infrastructure and services for market access, globalized production, and trade competitiveness is key to a country's development, which is why APEC has the APEC Transport Working Group (TPT-WG), which works to improve connectivity and deepen regional economic integration by promoting quality infrastructure connectivity; improving transport accessibility, safety, resilience, efficiency, and sustainability; and general socio-economic improvement (APEC, 2019).

Nowadays, ports are looking for solutions to reduce cargo movement times by improving the efficiency of their operations. The more efficient use of port facilities, together with improvements in the scale of operations, allows improvements in total factor productivity and thus enhances the competitiveness of maritime transport. All these elements point to the need to conduct studies to increase the productivity of ports in APEC economies, thus impacting their economic dynamism.

The Asia Pacific maritime industry has a 39% share of the entire global market (IMO, 2015). Due to the high trade flow in the region, maritime operation is an essential part of its commercialization, and according to the World Shipping Council (2017), the ports with the highest container mobilization in 2015 are in the APEC region: China, Singapore, Korea, Hong Kong, and Japan. Nonetheless, Mexico has not been able to position itself among the most competitive ports worldwide. According to the global competitiveness index conducted by the World Economic Forum (WEF) (2017), Mexico ranked number 57 in 2016 in the category of port infrastructure. By 2017 it had dropped to 62nd place. This demonstrates the need for studies, proposals, and investment to increase productivity and thus strengthen the port system, directly impacting the country's economic development. Productivity can be further improved with greater use of existing technology such as gantry cranes, automation, and software to increase traffic flow and storage, as factors such as dock waiting times and the availability of cranes and equipment are key determinants of efficiency (Sánchez et al., 2015).

In the case of Mexico, it is currently in a stage of port growth due to the expansion of foreign trade worldwide (UNCTAD, 2018). One of the objectives of the General Directorate of Ports (2016) is to promote the development of ports in conditions of competitiveness, quality, and efficiency, as well as to improve the exploitation of the value of port spaces to increase the availability of resources for new investments to promote the development of business in Mexican ports. Therefore, it is necessary to carry out studies to identify port productivity in our country, comparing it with the main ports of the most dynamic region in the world, APEC, which will contribute to the implementation of public policies aimed at establishing Mexican seaports of international standard.

This study considers the period from 2005 to 2015 since, according to the United Nations Conference on Trade and Development (UNCTAD), in 2015, the growth of the port sector experienced notable reductions; specifically, maritime containerized cargo freight rates decreased continuously during 2015, reaching minimum levels. To arrest the fall in freight rates and reduce losses, different industry players, as well as researchers, have studied several measures to improve efficiency and optimize operations (UNCTAD, 2016).

Merchandise trade growth has also been weak relative to global GDP growth due to weak global demand, deceleration of economic activity, and structural factors such as fragmented supply chains (UNCTAD, 2017).

The needs of ports have changed over the last twenty years, whereas previously, the concern revolved only around the support of maritime services. Nevertheless, ports are currently being sought as logistics platforms that combine various means of transportation, warehousing, industries, and greater hinterland and foreland connectivity (Garcia, 2018).

The port industry depends on exogenous and endogenous factors. Exogenous factors include the slowdown in world trade. On the other hand, endogenous factors in the public sector include port and logistics governance and the management of bureaucratic procedures, such as customs, health, and migration. Endogenous factors in the private sector are those pertaining to each port company and its entire operationalization (port industry) (Sanchez & Lara, 2016).

The problems in the port industry are accentuated as a result of the following:

a. The intensity of the phenomena and the variations in both exogenous and endogenous factors

b. The confluence of all of them simultaneously

Within the private port sector, it is important to highlight that the port activity itself, where there are currently more mergers and acquisitions, brings, therefore, the pressure for lower rates and higher speed in the handling of containers. This has also resulted in a shortening of the life cycle of port investments and a certain decline in productivity, lower corporate returns, and lower proportions of terminal sales values (Sanchez & Lara, 2016).

The organization of the shipping industry has a profound impact on trade volume, transport costs and economic competitiveness (UNCTAD, 2016). In ports, in general, various stakeholders drive the demand for performance indicators. Policymakers need evidence-based research, investors need means to reflect performance, and port managers need a practical comparative basis for benchmarking and strategic planning.

UNCTAD (2015) mentions that the performance of ports and terminals is significant as it influences a country's trade competitiveness. The determinants of port and terminal performance are many: labor relations, quantity and type of cargo handling equipment, quality of the transshipment area, port access channels, access from land, customs efficiency, and possible concessions to international terminal operators.

http://dx.doi.org/10.22201/fca.24488410e.2021.1998

International seaports operate as trade facilitators in the global economy. They are strategic trade policy instruments in national economies and represent an important link between nations through the efficient and cost-effective movement of goods, people, and information (Sanchez & Lara, 2016).

Knowing the productivity performance of a port is important to adopt measures that allow the correction of detected inefficiencies and improve the port's strengths (Kim and Sachis, 1986). For González and Trujillo (2006), ports seek to maximize cargo transfer, and they consider that the cargo handling capacity of a port depends on its productivity.

Several authors have analyzed port productivity through different methodologies. In the case of calculating TFP through the Malmquist index, Schøyen and Odeck (2017) measured productivity changes through this index for major ports in Norway and the United Kingdom through 2009-2014. Their main findings indicate that productivity increased by approximately 0.6% per year for all the ports considered. Nwanosike, Tipi, and Warnock-Smith (2016) conducted a TFP study using this same methodology of Nigerian ports over 2000-2011 to compare productivity growth before and after the country's port reform. Baran and Górecka (2015) calculated efficiency and productivity using this index for major international ports throughout 1996-2012. Mokart and Shah (2013) measure the productivity of major Malaysian container ports using in the TFP measurement the Malmquist index with constant and variable returns, obtaining significant results in both approaches.

Halkos and Tzeremes (2012), on the other hand, calculate the TFP of Greek ports over the period between 2006-2010, incorporating, in addition, the bootstrap technique. Borafull (2010) calculates the TFP of the Spanish port system for the period between 1990-1999. The results show that the ports have seen productivity improvements, and technical progress has been the main determinant of productivity since 1997. On the other hand, Fu, Song and Guo (2009) analyze the TFP of 10 container terminals in Chinese ports from 2001-2006, using the Malmquist index. Cheon, Dowall, and Song (2009) calculate the productivity of ports internationally for the period 1991-2004 with the Malmquist index.

Other studies have calculated productivity through parametric methods, such as Chang and Tovar (2014). They obtained the efficiency and TFP of Peruvian and Chilean ports through Stochastic Frontier Analysis (SFA) from 2004-2010. Similarly, De (2006) conducted a study on TFP in major Indian ports using the SFA methodology. In turn, Lightfoot, Lubulwa and Malarz (2012) calculated the TFP of Australian ports with ordinary least squares in the years 1997-2010.

Specifically, studies on productivity in the APEC region have been conducted by various authors such as Yen-Chun, Chih-Hung, Goh, and Yung-Hsiang (2016), who used the Malmquist methodology to compare port productivity of developed and developing countries in APEC, disaggregating it into scale efficiency change, technical efficiency change and technological change. The results indicate that the average capacity utilization rate among APEC member ports was only 65.7% during 2002-2011, and the factor that most affected productivity was the change in scale efficiency.

APEC efficiency measurements include Kutin, Thuy and Valléec (2017), who conducted an efficiency study using DEA methodology of 50 ports in the ASEAN region using a CRS model. The findings can help port managers in the ASEAN region decide whether to increase container traffic. Chun-Chu (2008) conducted a study on efficiency using DEA methodology applying a CCR model and a BCC model in the period 1998 - 2001 in 10 ports in the Asia-Pacific region. The results show that, on average, the efficiency estimated with the CCR model is the lowest.

Hsuan-Shih and Ming-Tao (2005) calculated the efficiency of selected ports in the Asia-Pacific region using the DEA methodology for 1996, generally obtaining high-efficiency results for most ports.

This research aims to determine the Total Factor Productivity (TFP) of the 40 container terminals in major ports of Asia-Pacific Economic Cooperation (APEC) economies, during the period 2005-2015, through Stochastic Frontier Analysis (SFA). The research question posed is: Which factors determined Total Factor Productivity during 2005-2015? The hypothesis to be considered is that the variation in scale efficiency determines Total Factor Productivity in the ports of the APEC region for the period 2005-2015.

The paper is structured into six sections. The first section contains the introduction; the second deals with the theoretical and methodological foundations, developing the Stochastic Frontier Analysis methodology to obtain Total Factor Productivity; the third section presents the development of the model; the fourth section contains the results; while the fifth section contains the discussion of the results; finally, the sixth section presents the conclusions.

Theoretical and methodological foundations

This section analyzes the theoretical and methodological bases of Total Factor Productivity. It begins by defining productivity as the ratio between the quantity produced and the inputs used, whereas Total Factor Productivity is the ratio of net output to the associated sum of labor and capital factor inputs (Sumanth, 1994). There are several techniques to measure the change in Total Factor Productivity; the most common ones can be divided into 3 main categories (Girales 2013):

a. Index Numbers. Diewert (1976) defines index numbers as those that can be derived from some underlying production function. He also points out that the most commonly used indexes are those of Laspeyres, Paasche, Fisher and Törnqvist. Each of these indices uses a different functional form to aggregate the various inputs and results from the transformation process. In this technique, it is only necessary to know the data of inputs and outputs in single measures (indices) in terms of their relative prices, using various index number formulas.

b. Non-parametric distance functions. These approaches handle the aggregation process based directly on the amount of information on inputs and outputs and minimal assumptions about the overall shape of the technology (i.e., the transformation process). They are based on the calculation of quotients of distance functions obtained by linear programming. They make it possible to measure the TFP growth experienced by any unit that transforms productive factors and break down this growth into technological and technical efficiency changes. The most common distance functions for measuring productivity growth are based on the notion of the Malmquist productivity index, which was introduced as a theoretical concept by Caves, Christensen and Diewert (1982). Later Färe et al. (1992) demonstrated how the Malmquist productivity index could be estimated using Data Envelopment Analysis (DEA).

c. Econometric approaches. Like non-parametric distance functions, econometric methods can also estimate a productivity index using only information on quantities of inputs and outputs and a set of minimal assumptions, mainly on the general shape of the technology and the distribution of random noise and the inefficiency term. Econometric approaches can also break down Total Factor Productivity into its components: technological change and change in technical and scale efficiency. The most common econometric approaches are Corrected Ordinary Least Squares (COLS) or the Stochastic Frontier Analysis (SFA) model.

The Solow model

The Solow growth theory, in which the pattern of productivity growth reflects the so-called technological progress (i.e., the Solow residual), was the first deterministic methodology proposed for estimating TFP and has been used to estimate TFP at both the aggregate and sectoral levels. Solow (1957) was the one who contributed to establishing Total Factor Productivity as an operational concept based on the production function. In his article "Technical change and the aggregate production function," published in 1957, he describes the model based on production theory, specifically on the Cobb-Douglas curve, whose standard form considers two factors of production: capital and labor.

The Solow residual method considers TFP as a variable that is not directly observable, representing the part of production that the productive actors cannot explain. The residual method establishes that, to calculate the TFP, it is necessary to make an assumption regarding the production function, that is, to use a mathematical approximation to how the factors are combined in the production of goods and services to estimate the residual that will represent the TFP subsequently. Solow's residual is based on the Cobb-Douglas production function with constant returns to scale and calculates neutral or

http://dx.doi.org/10.22201/fca.24488410e.2021.1998

"Hicks-neutral" technological change, which implies an equal increase in the capital and labor variables. Solow's (1957) residual method indicates that Q represents the output while K and L represent the inputs of capital and labor in "physical units" so that the aggregate production function can be written as follows:

$$Q = F(K,L;t) \tag{1}$$

Solow (1957) mentions that technical change is neutral. In other words, a shift in the production function does not alter income distribution for a given capital-labor relation. In that case, the production function takes the special form:

$$Q = A\,(t)\, f\,(K,L) \tag{2}$$

Equation 2 is differentiated regarding time and divided by Q to obtain:

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + A\left(\frac{\partial f}{\partial K}\right) * \left(\frac{\dot{K}}{Q}\right) + A\left(\frac{\partial f}{\partial L}\right) * \left(\frac{\dot{L}}{Q}\right) \tag{3}$$

The dots indicate the derivatives regarding time. Now define $W_k = \left(\frac{\partial Q}{\partial K}\right) * \left(\frac{K}{Q}\right)$ and $W_L = \left(\frac{\partial Q}{\partial L}\right) * \left(\frac{L}{Q}\right)$ the relative forms of capital and labor, and substitute them into Equation 3 (note that $\partial Q/\partial K = A\,\partial f/\partial K$, etc.) and hence the result:

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + w_k\left(\frac{\dot{K}}{K}\right) + w_L\left(\frac{\dot{L}}{L}\right) \tag{4}$$

Then the rate of technological progress in two periods is given by:

$$\frac{\Delta A}{A} = \frac{\Delta Q}{Q} - w_k * \left(\frac{\Delta K}{K}\right) - w_L * \left(\frac{\Delta L}{L}\right) \tag{5}$$

Where:

$\frac{\Delta A}{A}$ = Rate of growth of technical progress

$\frac{\Delta Q}{Q}$ = Output growth rate

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$\frac{\Delta K}{K}$= Capital stock growth rate

$\frac{\Delta L}{L}$ = Growth rate of labor stock

w_k y w_L = Remuneration of capital and labor

Some authors, including Summer (1986), Hall (1988, 1990), Mankiw (1989), Evans (1992), Chen (1997), Zheng, Liu, and Bigsten (1998), Kumbhakar and Lovell (2000), and Songqing, Hengyun, Huang, Ruifa, and Rozelle (2009), have argued that the Solow residual is flawed in several ways. For example, they mention that it is very limiting because it is only an accounting approach to the sources of growth and that the estimation of technological change is not adequate to calculate it only in the presence of constant returns to scale due to market imperfections; another criticism they mention is that it misinterprets productivity improvements attributed only to technical progress. Nonetheless, this assumption is only valid if companies are technically efficient, thus operating at their production frontiers and taking advantage of the full potential of technology, which is not always the case. Therefore, technological progress cannot be the only source of productivity growth, and it will be possible to increase it by improving technical efficiency. Moreover, they mention that measuring TFP with the Solow residual only allows the calculation of technological change in a Hicks-neutral way. However, technological change is often not neutral since, on many occasions, some factors of production benefit more than others; moreover, some groups adopt new technologies earlier than others. Limiting ourselves to a single type of technological change does not reflect the reality of the competitive effects of the market.

Measurement of TFP using parametric methods

An alternative way of analyzing TFP growth is to disaggregate it into its components: technological progress and efficiency improvement. Following the common approach in stochastic frontier analysis (SFA), it is assumed that inefficiencies can generate a gap between actual output and the production frontier, given the current state of technology.

In this framework, technological progress (represented by a time trend) shifts the production frontier upward for all states. At the same time, an improvement in technical efficiency moves states toward the production frontier (Cardarelli and Lusinyan, 2015). The first authors who started using parametric approaches were Aigner and Chu (1968), Seitz (1971), Timmer (1971), Afriat (1972), and Richmond (1974). However, it was the contributions of Aigner, Lovell, and Schmidt (1977) and Meeusen and Van Den Broeck (1977) that developed the conceptualization of the stochastic frontier, from which the methodological reference of this line of study on efficiency was consolidated, based on a function of efficient behavior, whether of production or costs.

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$$y = X\beta + \varepsilon \tag{6}$$

Y = is the vector of outputs

β‘= is a vector of the parameters to be estimated

X = is the vector of all its inputs

ε = is the stochastic disturbance term

Where the error term is assumed to have two components, $\varepsilon = \nu - u$ for production functions and $\varepsilon = \nu + u$ for cost functions.

Kumbhakar and Lovell (2000) later measured the Total Factor Productivity using stochastic frontier analysis, breaking it down into technological change, change in technical efficiency and change in scale efficiency.

$$TFP_{it} = TE_{it} + TP_{it} + (E-1)\sum_j \frac{E_j}{E} x_j \quad \text{j= 1,2} \tag{7}$$

Where:

TFP_{it}= Represents the change in TFP

TE_{it} = Represents the change in technical efficiency

TP_{it} = Is the technological change

E_j (j =1,2) = Represents the elasticity of output relative to each input (capital and labor)

$(E-1)\sum_j \frac{E_j}{E} x_j$ = is the scale efficiency component

Estimation and breakdown

A stochastic frontier production function can be defined by (Kumbhakar and Lovell, 2004):

$$y_{it} = f(x_{it},t,\beta) \exp(v_{it} - u_{it}) \tag{8}$$

Where yit is the vector of the firm's output (i=1,2,.....N) in period t (t=1,2,...T)

The stochastic production frontier has two parts: deterministic and stochastic; f(xit,t,β) is the deterministic part of the production frontier with the vector of the technology parameter β to be estimated, xit is the vector of inputs, t is a time trend; v is the stochastic part, which captures the random effects, -u is the technical inefficiency term. When representing production functions, the translog and Cobb-Douglas functional forms are the most common in applied economics literature. The authors recommend a series of criteria that allow discrimination between the different functional forms to be used, noting that while both are similar in terms of parameter linearity and regularity, the translogarithmic form is superior in flexibility (Coelli et al., 2005). For this research, the change in Total Factor Productivity is calculated with the Stochastic Frontier Analysis methodology, disaggregating the difference in technical efficiency and technological change from a panel data model with a translogitmic specification of the production function proposed by Kumbhakar and Lovell (2004).

$$ln\, y_{it} = \beta_0 + \sum_n \beta_n \, lnx_{nit} + \beta_t t + \frac{1}{2}\sum_n \sum_j \beta_{nj} lnx_{nit} \, ln\, x_{jit} + \frac{1}{2}\beta_{tt} t^2 + \sum_n \beta_{nt} \, lnx_{nit} t + v_{it} - u_{it} \tag{9}$$

Where:
y_{it} = the observable output in period t
X_{it} = the set of production factors
t = a temporal factor component
β = the unknown parameters to be estimated
v_{it}= the random noise error component
u_{it}= the error component of technical inefficiency

Panel data production frontier model

Panel data models for measuring efficiency with econometrics were pioneered by Pitt and Lee (1981), Jondrow, Materov, Lovelland, and Schmidt (1982), Schmidt and Sickles (1984), and Battese and Coelli (1988), where efficiency was taken as invariant and constant over time. Subsequently, Cornwell, Schmidt, and Sickles (1990), and Kumbhakar (1990) were the first authors to propose a stochastic production frontier for a panel data model with time-varying efficiency and Battese and Coelli (1992) continued working according to this same model.

Kumbhakar (1990) developed the following parametric time function:

$$\beta(t) = [1 + \exp\{\gamma t + \delta t^2\}]^{-1} \tag{10}$$

The Kumbhabar model contains two additional parameters that must be estimated with maximum likelihood γ and δ. The function $\beta(t)$ satisfies the properties $0 \leq \beta(t) \leq 1$ and $\beta(t)$ and can

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increase or decrease monotonically and be concave or convex depending on the signs and magnitudes of the two parameters γ and δ for both fixed and variable effects panel data model.

Battesi and Coelli (1992) propose a model for estimating time-varying efficiency using maximum likelihood to estimate all parameters:

$$\beta(t) = \exp\{-\gamma(t - T)\} \tag{11}$$

Here, the unknown parameter represents the rate of change in technical inefficiency. The technical inefficiency effects in earlier periods are a deterministic exponential function of the inefficiency effects in the final period.

The change in efficiency is represented according to Kumbhakar and Lovell (2004) as follows:

$$\Delta TE = \hat{u}_i \,.\, \hat{\gamma} \,.\, \exp\{-\hat{\gamma}(t - T)\} \tag{12}$$

Where:

$\hat{u}_i$ = the estimator for the calculation of inefficiency

$\exp\{-\hat{\gamma}(t - T)\}$ = the time-varying technical efficiency

$\hat{\gamma}$ = parameter to be estimated

$(t - T)$ = the effect of time

The interpretation of the change in efficiency component is that it captures the movement of unit i toward the frontier. When the result is greater than zero, ΔTE>0, it means that there was an improvement in efficiency over time. On the contrary, when the result is less than zero ΔTE<0, it means that efficiency worsened over time, and when the result is equal to zero ΔTE=0, the units did not show any change in the period analyzed.

Technological change

Technological change is associated with displacing the production possibilities frontier of the sector or industry to which it belongs. The following translog function involves, in addition to the independent effect of t, the interaction between the trend term and the production inputs through which the non-neutral technological change can be calculated (Kumbhakar and Lovell, 2004). The output is assumed to be a function of two inputs: capital (K) and labor (L).

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$$\ln y_{it} = \beta_L lnL_{it} + \beta_K lnK_{it} + \frac{1}{2}\beta_{LL}(lnL_{it})^2 + \frac{1}{2}\beta_{KK}(lnK_{it})^2 + \beta_{LK}(lnL_{it})(lnK_{it}) + \beta_t t + \frac{1}{2}\beta_{tt}t^2 + \beta_{Lt}(lnL_{it})t + \beta_{Kt}(lnK_{it})t + v_{it} - u_{it} \tag{13}$$

$$\Delta TC_{it} = \frac{\partial lnf(x_{it},t;\beta)}{\partial t} = \hat{\beta}_t + \hat{\beta}_{tt}t + \hat{\beta}_{Lt} L_{it} + \hat{\beta}_{Kt} K_{it} \tag{14}$$

Technological progress is represented by the derivative of the production function relative to time. The technological change ΔTC_{it}, can be positive or negative, reflecting that it shifts up or down the production frontier. When the result is greater than zero $\Delta TC_{it} > 0$ it means there was technological progress. On the contrary, when the result is less than zero $\Delta TC_{it} < 0$, there was technological regression, and when the result is equal to zero $\Delta TC_{it} = 0$, the frontier remains constant during the analyzed periods, and therefore the technology did not change.

Model development

This research presents a model for panel data where a translog production function with the specification of Kumbhakar and Lovell (2004) is used. The change in Total Factor Productivity is calculated by disaggregating it into technological change, change in technical efficiency and change in scale efficiency for 2005-2015 using the Stochastic Frontier Analysis (SFA) methodology.

The study sample is based on container port terminals in the APEC region, where those that had a mobilization of more than one million teus per year in 2015 are identified, according to the World Shipping Council report and the Port Industry Statistics - American Association of Port Authorities. The selection was composed of 40 ports, as shown in Table 1.

Table 1
Ports in the APEC region, 2015

	Country	Port	Millions of Teus
1	Australia	Melbourne	2.63
2	Australia	Sidney	2.33
3	Canada	Metro Vancouver	3.05
4	China	Guangzhou	17.22
5	China	Qingdao	17.47
6	China	Shenzhen	24.20
7	China	Tianjin	14.11
8	China	Dalian	9.45

http://dx.doi.org/10.22201/fca.24488410e.2021.1998

9	China	Xiamen	9.18
10	China	Ningbo	20.63
11	China	Lianyungung	5.01
12	China	Suzhou	5.10
13	China	Yingkou	5.92
14	China	Shanghai	36.54
15	Korea	Busan,	19.45
16	Korea	Inchon	2.36
17	Korea	Kwangyang	2.32
18	United States	Long Beach	7.19
19	United States	Los Angeles	8.16
20	United States	Oakland- San Francisco	2.27
21	United States	Seattle-Tacoma	3.53
22	Philippines	Manila	4.23
23	China	Hong Kong	20.07
24	Indonesia	Tanjung Priok, Jakarta,	5.20
25	Indonesia	Tanjung Perak, Surabaya	3.12
26	Japan	Tokyo	7.52
27	Japan	Osaka	4.93
28	Japan	Nagoya	2.631
29	Malaysia	Port Kelang	11.89
30	Malaysia	Tanjung Pelepas	9.10
31	Mexico	Manzanillo	2.45
32	Mexico	Lazaro Cardenas	1.05
33	Peru	Callao	1.9
34	Singapore	Singapore	30.92
35	Thailand	Laem Chabang	6.82
36	Thailand	Bankgok	1.55
37	Taiwan	Kaohsiung,	10.26
38	Taiwan	Keelung	2.66
39	Vietnam	Ho Chi Minh	5.31
40	Vietnam	Haiphong	3.87

Source: World Shipping Council y AAPA, 2017

Variables description

The variables to be worked with are identified to calculate the change in Total Factor Productivity and its components. The first step was to conduct a literature review to select the methodologies and variables applied in the port sector (see Table 2).

Table 2
Literature review

Author	Methodology	Variables
Kumtong, Saosaovaphak and Chaiboonsri (2017)	O'Donnell, Rao, and Battese (2008) productivity index	*Outputs:* teus *Inputs:* number of ships, ship-handling capacity, workers, and terminal area
Chang and Tovar (2014)	Stochastic Frontier Analysis	*Outputs:* teus, general cargo, breakbulk cargo. *Inputs*: workers, stock of net fixed assets, number of berths, and machinery
Halkos, G. and Tzeremes, N. (2012).	Malmquist	*Output:* volume of goods in tons and total passengers *Inputs:* fixed assets and employees
Baran and Górecka (2015)	Malmquist	*Output*: teus *Inputs:* berths, terminal area, terminal area, length of quay
Lightfoot, Lubulwa, and Malarz (2012).	Stochastic Frontier Analysis	*Output*: teus *Inputs:* working hours and hours of crane use
Ding, Jo, Wang, and Yeo, (2015)	Malmquist	*Output*: teus *Inputs:* structure, shipping lines, number of terminal operators, registered capital, and shipping routes
Park (2010)	Econometric model	*Output:* teus/berth *Inputs:* berths and length of berths
Kennedy, Lin, Yang and Ruth (2011)	Stochastic Frontier Analysis	*Output*: teus *Inputs:* total terminal area, quay length, total number of cranes

Source: created by the author based on the literature reviewed

In this study, the selection of variables was based on the factors of production and the tests to which the model was subjected. The port infrastructure data represent very well the capital inputs (K). In this case, the length of the quay measured in meters is considered. As for labor input (L), the number of workers at each port's container terminal is considered. In terms of output, the number of teus handled annually at each port in the APEC region is used.

The availability of information can be a limitation for this type of analysis since the databases are usually disaggregated by country and not by port. However, for this research, data were obtained from the World Shipping Council and Port Industry Statistics - American Association of Port Authorities, in addition to the official port sites of each of the ports analyzed.

Below, the descriptive statistics for the years 2005 and 2015 are presented (see Tables 3 and 4), where the means and standard deviation of the selected variables are shown. In the case of teus and dock length, growth was observed during the period analyzed. The number of workers has a different behavior

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since there is a decrease in the mean during the period, mainly due to the increase in the use of machinery in the container terminals.

Table 3
Descriptive statistics for 2005

Variable	Obs.	Media	Dev. Stat.	Min.	Max.
Teus	440	3.556	1.588013	.103	23.192
Length Pier	440	3,366.00	160.1709	550	6,114.00
Workers	440	175	40.4663	20	350

Source: created by the author based on the results from the SPSS statistic

Table 4
Descriptive statistics for 2015

Variable	Obs	Media	Dev. Stat.	Min.	Max.
Teus	440	5.197	7.588013	.106	36.516
Length Pier	440	4,095.00	160.1709	550	6,114.00
Workers	440	152	40.4663	15	310

Source: created by the author based on the results from the SPSS statistic

Specification of the panel data model

The panel data model comprises 40 APEC container terminals over an 11-year period (2005-2015).

To determine the type of panel data model to be used, the Haussman test is performed. It is assumed that the random and fixed effects estimators do not differ substantially (the estimators are considered the same). So, the null hypothesis is: there is no systematic difference between the coefficients; if the prob chi2 > 0.05, the null hypothesis is accepted, which indicates that the random estimator should be used, otherwise if Prob chi2 < 0.05, the null hypothesis is rejected, and the fixed effects estimator would be used.

Once the Hausman test was carried out (see Table A1 in the appendix), it was observed that the Prob chi2 value 0.1003 > 0.05, therefore, the null hypothesis was accepted, and the variable effects estimator was selected.

For Greene (2005), stochastic frontier analyses using panel data have been based on traditional fixed and random effects models. Greene proposes extensions that avoid two shortcomings of these approaches. First, conventional panel data estimators assume that technical or cost inefficiency is time-invariant. Second, fixed and random effects estimators force time-consistent cross-unit heterogeneity into the same term used to capture inefficiency.

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Green’s (2005) proposal for panel data models is to separate the individual heterogeneity component from the technical efficiency component. He called this proposal True Fixed Effects. In these models, a specific intersection is incorporated for each decision unit, and time-varying inefficiency can be obtained.

The paper follows a translogarithmic specification to estimate the production function and thus obtain the component of non-neutral technological change. In addition, the random effects model proposed by Greene (2005) is applied because it is considered that in the analyzed period, it is possible that the inefficiency term is time-varying and, therefore, the heterogeneous effects of each port should be considered in the estimation.

Model testing

Once the type of panel data model to be used to estimate the production frontier has been determined, the following tests are used to validate the model: specification of the Ramsey model, the White test for heteroscedasticity, the multicollinearity test, the unit root test, the cointegration test, and the skewness test.

Ramsey test of model specification

The Ramsey specification test (1969) allows for determining whether there is an error in the specification of the model and detects relevant variables that are omitted or irrelevant variables that are included. The null hypothesis is that the model has no omitted variables. In this case, after the test, it is observed in Table A2 of the appendix that a value of 0.145 > 0.05 was obtained, and the F value obtained is 1.23, being lower than the F value in the table, which has a critical F value of 1.927. Therefore, the null hypothesis is accepted, and it is verified that a relevant variable has not been omitted from the model.

White test for heteroscedasticity

There are several tests to detect heteroscedasticity problems; one of them is the White test, where the null hypothesis is that there is no heteroscedasticity, that is, that the variance of the errors is constant. Once the model has been run, the null hypothesis is rejected if the chi-square obtained is greater than the chi-square in the table. (Gujarati and Porter, 2010). In the results obtained from this test (see Table A3 in the appendix), it can be seen that the chi2 value = 12.01, which is lower than the table value, which in this case is 16.9190 at 5% for 9 degrees of freedom, and a p-value of 0.2357 > 0.05 was obtained. Therefore, it is concluded that the null hypothesis is accepted, and the homoscedasticity assumption is validated.

Multicollinearity test

This test is performed to verify if the model has a high correlation. Several tests detect multicollinearity problems, one of which is the VIF (Variance Inflation Factor) test. This test calculates centered or uncentered variance inflation data for the independent variables specified in a linear regression model (Gujarati & Porter, 2010). Values greater than 10 are considered indicative of multicollinearity. According to the results shown in Table A 4 of the appendix, it can be demonstrated that there is no evidence of multicollinearity, with a value of 1.33 (Bruin, 2006).

Stationarity analysis

Different authors accept several tests for testing stationarity and order of composition in panel data; one of them is the Levin, Lin, and Chu (2002) test, which is the one used in the present research. This test considers a common autoregressive parameter for all panels, including an intercept or an intercept and trend. The null hypothesis used in the test is: ho = the panels have a unit root, and the alternative hypothesis: ha = the panels are stationary.

The contrast was performed for each of the variables: lny (logarithm of y, which is the dependent variable number of teus handled annually), lnk (logarithm of k, which is the independent variable dock length) and lnl (logarithm of l, which is the independent variable of the number of workers). In the first instance, the calculation was performed in levels without trend, resulting in a unit root. The contrast was performed with first differences; in this case, the panels no longer presented a unit root, so they had an order of composition I(1), i.e., they were stationary in first differences (see Table A5 in the appendix).

Cointegration test

Once the unit root test has been performed, by obtaining the stationarity of the variables in the same order of composition I(1), the aim is to observe whether there is long-run equilibrium, in other words, whether they are cointegrated. There are tools to examine whether the variables are cointegrated; one of them is the cointegration test for panel data developed by Pedroni (2004), which consists of analyzing the coefficients associated with the explanatory variables, where the intercepts and trends can vary for each cross-sectional unit, thus indicating that there is a cointegration vector for each unit of analysis. In this test, the null hypothesis is that there is no cointegration versus the alternative hypothesis that there is cointegration. According to the results obtained (see Table A6 in the appendix), the null hypothesis of no cointegration is rejected for the variables analyzed I(1) with a significance level at 5%; therefore, it is concluded that all panels are cointegrated and that there is a long-run equilibrium.

Asymmetry test (Skewness)

The Skewness test serves to specify whether inefficiency can be measured in the stochastic frontier model. In this case, the negative sign shows that the residuals are correctly fitted for the maximum likelihood implementation. On the stochastic frontier, if the sign is not negative, it is not possible to distinguish between inefficiency and stochastic error (Waldman, 1982). In the test (see Table A7 in the appendix), the Skewness test result was -0.5605371, obtaining the expected sign.

Production function model

The following are the results of the production function model using maximum likelihood estimation (see Table 5).

Table 5
SFA production function model

Stock. Frontier normal/half model			Number of obs =		440
			Wald chi2 =		229.75
			Prob > chi2 =		0.000
lnY	Coef.	Std. Err.	z	P>z	
lnL	0.557099	0.0257557	21.63	0.000	
lnK	0.6358347	0.0343544	18.51	0.000	
lnL2	-0.0537163	0.0119536	-4.49	0.001	
lnK2	-0.0850208	0.0147142	-5.78	0.002	
t2	0.0199149	0.0019572	10.18	0.007	
lnLK	0.1677688	0.0233009	7.2	0.045	
_cons	0.4816761	0.0205502	23.44	0.004	
/lnsig2v	-7.110676	0.5478525	-12.98	0.000	
/lnsig2u	-3.609345	0.2292352	-15.75	0.000	
igma_v	0.6566085	0.0575254			
sigma_u	0.99344928	0.1177844			
sigma2	1.418163	0.1824608			

lambda	1.513067	0.1661375

Log Likelihood-ratio test of sigma_u= 0: chibar2 (01) = 12.16 Prob>chibar2 = 0.000

Source: created by the author based on STATA statistical calculations

As seen in Table 5, the parameters are different from zero, and the lambda value is close to 2, which means that the stochastic frontier model is the appropriate one to calculate the inefficiency. In addition, the value of sigma_u is very close to one, indicating that the residual accounts for the inefficiency in the model. At the end of Table 5 is the likelihood test, which allows for verification of whether the restrictions are valid or not. In this case, rejecting the null hypothesis indicates that the restrictions are correct and that inefficiency can be calculated with the model. All these tests together provide evidence that the time-varying effects panel data model with time-varying efficiency can be used to be able to estimate a production frontier, as well as to perform the corresponding calculations for the change in technical efficiency, change in scale efficiency, technological change, and the change in Total Factor Productivity.

Results

Table 6 shows that, on average, TFP had a value of 0.051 for the entire study period, indicating a developing growth in productivity in APEC ports as a whole. The port of Lianyungang in China achieves the highest productivity, explained specifically by technological change. Conversely, the port of Lázaro Cárdenas in Mexico has the lowest productivity, where the decline in technological change in the years under study has the greatest impact on the fall of this indicator.

Table 6
Total Factor Productivity of APEC Ports, 2005-2015

Ports	Technological Change	Technical Efficiency Change	Efficiency Change Scale	TFP change
Lianyungang, China	0.448	-0.064	0.042	0.425
Shanghai, China	0.461	-0.085	0.019	0.394
Oakland- San Francisco, USA	0.184	-0.056	0.138	0.266
Suzhou, China	0.255	-0.062	0.036	0.229
Manzanillo, Mexico	0.156	-0.027	0.015	0.144
Kwangyang, Korea	-0.028	0.006	0.143	0.121
Seattle-Tacoma, USA	0.108	-0.034	0.032	0.106
Ho Chi Minh, Vietnam	0.059	-0.020	0.051	0.090

Laem Chabang, Thailand	0.116	-0.044	0.004	0.075
Guangzhou, China	0.028	-0.015	0.061	0.074
Xiamen, China	0.016	-0.010	0.048	0.054
Dalian, China	0.043	-0.019	0.029	0.053
Tianjin, China	-0.009	-0.001	0.061	0.051
Yingkou, China	-0.002	-0.003	0.053	0.049
Ningbo, China	-0.077	0.026	0.098	0.046
Qingdao, China	-0.019	0.004	0.056	0.041
Tanjung Pelepas, Malaysia	0.045	-0.024	0.017	0.038
Keelung, Taiwan	0.076	-0.041	-0.001	0.034
Nagoya, Japan	0.000	-0.005	0.037	0.032
Tanjung Perak, S. Indonesia	-0.015	0.002	0.044	0.031
Port Kelang, Malasia	0.011	-0.010	0.019	0.020
Busan, Korea	-0.049	0.011	0.055	0.017
Sidney, Australia	-0.024	0.004	0.035	0.015
Shenzhen, China	-0.063	0.024	0.054	0.015
Tokyo, Japan	-0.077	0.022	0.068	0.014
Hong Kong, China	-0.041	0.013	0.039	0.010
Singapore	-0.012	0.000	0.022	0.010
Callao, Peru	-0.049	0.016	0.033	-0.001
Metro Vancouver, Canada	-0.028	0.006	0.019	-0.002
Bankgok, Thailand	-0.063	0.025	0.034	-0.005
Melbourne, Australia	-0.065	0.022	0.037	-0.006
Kaohsiung, Taiwan	-0.041	0.012	0.021	-0.008
Long Beach, USA	-0.068	0.027	0.030	-0.012
Osaka, Japan	-0.103	0.027	0.060	-0.017
Los Angeles, U.S.A.	-0.021	0.003	-0.004	-0.022
Manila, Philippines	-0.080	0.028	0.026	-0.025
Haiphong, Vietnam	-0.082	0.019	0.036	-0.027
Tanjung Priok, J. Indonesia	-0.058	0.018	-0.004	-0.044
Inchon, Korea	-0.245	0.099	0.033	-0.113
Lazaro Cardenas, Mexico	-0.199	0.040	0.016	-0.143
Average	0.012	-0.002	0.040	0.051

Source: created by the author based on calculations made with the SFA methodology

In general, technical efficiency is the biggest problem in the ports, which indicates the need to optimize resources better to increase efficiency. Nevertheless, the port of Inchon in Korea scored the highest value for this indicator.

The efficiency of scale, on average, had a positive growth, which means that the ports are working at an optimal scale, not necessarily the desired one. The port of Kwangyang in Korea stands out in this section with an increase of 14.3%. On average, technological change reflects an insignificant increase since only 14 ports showed technological progress during the study period, with the port of Shanghai standing out at 46.10%. Since 2003, this port has been under the management of the Shanghai International Port Group (SIPG), which replaced the Shanghai Port Authority, achieving its potential by receiving large investments to increase infrastructure, equipment, and facilitation in port operations (I.G, 2014).

In the case of Mexico's ports, only Manzanillo's TFP grew, mainly due to technological change. This is explained by the improvements implemented in the infrastructure and acquisition of machinery at the container terminal through increased private investment in recent years (API Manzanillo, 2018). On the other hand, the port of Lazaro Cardenas has an average TFP drop of -0.143 due to its technological backwardness.

Overall, it is observed that the TFP of all APEC ports is determined firstly by the increase in scale efficiency with 4% and secondly by the technological progress of ports globally with 1.2% during 2005-2015.

Discussion of results

Several authors have studied TFP in ports, but few works have done so using Stochastic Frontier Analysis, as in this article.

Chang and Tovar (2014) calculate the efficiency and Total Factor Productivity of Peruvian and Chilean ports through Stochastic Frontier Analysis (SFA) in the period 2004-2010. The results show that Peruvian terminals had an average TFP of 2.4%, mainly due to the increase in technical and scale efficiency. In the case of Chilean terminals, TFP decreased by an average of 2.0% during the years under analysis, mainly due to the reductions shown in the technological change component. This paper has two similarities to these authors: a) in both investigations; the SFA methodology is used, implementing a translogarithmic production function; b) the change in Total Factor Productivity is also disaggregated into technological change, change in technical efficiency, and change in scale efficiency. The results are closer to those obtained in the Peruvian terminals since, in this research, in the years analyzed, there was an average TFP growth of 5.1%, mainly due to the change in scale efficiency.

In the same direction, De (2006) conducted a study on Total Factor Productivity in major Indian ports using the SFA methodology, where it was concluded that technological change has the greatest influence on TFP. Among the similarities found with this author's results is that the SFA methodology is used in both works. Differences include: (a) in the Indian ports study, it is technological change that determines TFP growth, while in this work, it is the increase in scale efficiency that specifies to a greater extent the increase in TFP; b) De (2006) uses a Cobb Douglas production function, and in this research, there is a translog function; c) TFP in Indian ports is disaggregated into technological change and change in technical efficiency, while in this study, in addition to these two components, change in scale efficiency is considered.

Through parametric methods, Lightfoot, Lubulwa, and Malarz (2012) calculated TFP using a simple Cobb Douglas function, and an augmented Cobb Douglas function as a function of time at major ports in Australia over the period 1997-2010. The main differences observed include: a) these authors have an analysis of TFP using an ordinary least squares econometric model with a Cobb Douglas production function, while this paper uses a Stochastic Frontier Analysis with a translogarithmic production function; b) they globally calculate TFP. In this study, the calculation of TFP is disaggregated into technological change, change in technical efficiency, and change in scale efficiency.

To summarize, three aspects stand out in this paper: a) the study is carried out through Stochastic Frontier Analysis using panel data; b) TFP is disaggregated into change in technical efficiency, change in scale efficiency, and technological change; and c) increase in scale efficiency followed by technological change are essential elements in the determination of TFP growth. This constitutes pioneering work in measuring TFP through the SFA methodology in the port area.

Conclusions

This article determined the Total Factor Productivity (TFP) of 40 container terminals in major ports of Asia-Pacific Economic Cooperation (APEC) member economies during 2005-2015. The dependent variable used is the number of *teus* mobilized annually, and the independent variables are dock length and personnel employed. The model developed is a panel data model with variable effects and the translogarithmic production function proposed by Kumbhakar and Lovell (2004) is considered. Thus, TFP growth is obtained with each component: technological change, change in efficiency, and scale efficiency, applying the Stochastic Frontier Analysis (SFA) methodology.

The results show that productivity growth averaged 5.10% during the period under review and that the port of Lianyungung in China achieved the highest level of TFP. Meanwhile, the port of Lazaro Cardenas had the lowest productivity these years. In terms of technological change, the port of Shanghai in China has made the greatest technological progress. In terms of technical efficiency, the port of Inchon in Korea was the best performer in this indicator.

Among Mexican ports, the port of Manzanillo had the highest TFP (0.144) for the years studied, which is mainly determined by technological change. Meanwhile, the port of Lazaro Cardenas, with productivity of -0.143, ranks last in the APEC economies. The hypothesis posed in this paper is fulfilled, as it was mainly the change in scale efficiency that determined Total Factor Productivity in the APEC region for the period 2005-2015.

The results suggest that TFP growth in APEC ports may especially benefit from policies that promote investment in the inputs analyzed in this research: human capital and infrastructure. Likewise, since progress in productivity is not significant, it suggests the implementation of public policies aimed at strengthening innovation and technology, as this indicator is of little significance in the determination of TFP in APEC ports -besides the fact that it is necessary to address the problems of technical efficiency. In addition, productivity is a key element in the economic impact and development of the economies that make up this region.

Finally, three aspects of the present research are highlighted: a) the study is conducted through Stochastic Frontier Analysis using panel data on ports in the APEC region during the period 2005-2015; b) TFP is disaggregated into change in technical efficiency, change in scale efficiency, and technological change; and c) an increase in scale efficiency followed by technological change are essential elements in determining TFP growth in APEC ports. This constitutes pioneering work in measuring TFP through the SFA methodology in the study of ports.

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Annex

Table A1
Hausman test

.106 Hausman fixed random	
Test:	Ho: difference in coefficients not systematic
chi2(2) =	4.6
Prob>chi2 =	0.1003

Source: created by the author based on the results from the statistical Stata

Table A2
Specification test

Ramsey Model	
. estat ovtest	
Ho: model has no omitted variables	
F (9, 329) =	1.23
Prob > F =	0.145

Source: created by the author based on the results from the statistical Stata

Table A3
Heteroscedasticity test

White’s test for Ho: homoscedasticity against
Ha: unrestricted heteroscedasticity
chi2(9) = 12.01
Prob > chi2 = 0.2357

Source: created by the author based on STATA statistical calculations

Table 4
VIF test

Multicollinearity		
Variable	VIF	1/VIF
lny	1.5	0.6655
lnk	1.42	0.7023
t	1.07	0.9365

Mean VIF	1.33

Source: created by the author based on STATA statistical calculations

Table A5
Levin-Lin-Chu unit root test

Ho: Panels contain unit roots		Number of panels = 40
Ha: Panels are stationary		Number of periods = 10
Variable	Statistic	p-value
D.lny	-39.4048	0.0000
D.lnL	.7.3817	0.0000
D.Lnk	-20.2809	0.0000

Source: created by the author based on STATA statistical calculations

Table A6
Pedroni cointegration test

. xtcointtest pedroni lny lnl lnk

Ho: No cointegration	Number of panels = 40	
Ha: All Panels are cointegrated	Number of periods = 10	
	Statistic	p-value
Modified Phillips-Perron t	-7.3452	0.001
Phillips-Perron t	-5.8764	0.023
Augmented Dickey-Fuller t	-5.3243	0.000

Source: created by the author based on STATA statistic calculations

Table A7
Skewness test

Skewness	-0.5605371
Variance	0.798205
Kurtosis	5.089777

Source: created by the author based on STATA statistical calculations