Measuring port evolution, growth and vulnerability:'Port Growth Performance Evaluation' approach

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Abstract

This study proposes a group of indicators in the analysis of port performance. Section one presents a new model of analysis to evaluate how the port cargo openness, the productivity level, the cargo expansion, and the technological change adaptability can affect directly on the marginal productivity growth rate and performance of a port. This new model, "The Port Growth Performance Evaluation model (PGPE-Model)" is intended to offer policy makers and researchers an additional analytical tool to study the impact of dynamic changes such as change in international trade trends an the impact of technology or competition on port performance from a new perspective. The PGPE-Model can be applied to the study of any production unit or a group of economic activity and not constrained by geographical area or development stage of the entities on study. The PGPE-Model is simple and flexible. Section two, summarizes the results on the performance of Singapore, Malaysia, South Korea, Japan and China. In an era of dynamic global change and supply change where production units change location, the PGPE-Model's strength is the ability to capture and measure the change, vulnerability and port performance.

Keywords: Ports performance, productivity, port dynamic, international trade, technology

JEL Classifications: R40

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1. Introduction

Studies on port performance have largely focused on derivation of key performance indicators and efficiency indicators. However, these are often received with caution simply because no two ports have similar operating environment, management competency and innovation, efficiency and institutional set up and, government support. As such comparing the port performance of Los Angeles, Rotterdam, Singapore, Melbourne with Shanghai would not be meaningful without transparency of data. Further, ports form part of the dynamic global supply chains. The dynamic nature and mobility of production centers (from procurement of primary and intermediate inputs for production to distribution final products) are constantly changing as firms adjust cost conditions competition between seaport operators. Ports exist within a grid. Thus performance standards and common measurements of performance should incorporate this grid. However, fundamental information such as efficiency and tariff rates are shrouded under commercial confidentiality.

A port may be efficient but not effectiveness. Being effective is to service the right customers at the right time not. It is not just about efficiency alone. For example easing congestion access to a port when is encroaches into scarce city real estate may not be an issue in other ports. Therefore, scoring very important to least important must be cautioned. Reference points must be established. This is allows port operators an insight into what customers are looking for and in response what to services to improve and infrastructure to invest. There primarily three kinds of users, chipping lines, shippers and receivers of products / cargo, and, global supply chain players,

Shippers and receivers of cargo focus on costs associated with delays and warehousing costs, reliability and safety. Shipping lines focus load factors, congestion at port, cost of operation and environmental taxes. Global supply chain players are concerned with multi-modal connectivity to the port, access and egress times from the port, communication flow and custom procedures. Time sensitive cargo requires quick turn around time which only some ports are able to deliver given its facilities. Port effectiveness and performance is a complex KPI subject to perception and subjective preferences but as a perceptual metric, it is best measured from the user perspectives which require the port to reconcile service gaps with differing priorities.

This study offers an alternative approach in the study of port performance measurement in a dynamic environment. The following section summarizes the literature followed by the introduction of the Port Growth Performance Evaluation model (PGPE-Model). An evaluation using port data from Singapore, Hong Kong, Shanghai, Busan, Tokyo and Port Klang follows. The final section concludes with a discussion of the results.

2. Literature Review

The analysis of ports performance has taken several approached, namely quantitative and qualitative. From a quantitative perspective, the uses of sophisticated mathematical and econometrics models on the study of ports productivity makes possible to measure with accuracy the different levels and behavior of ports performances respectively. The rapid development of ports performance models have been facilitated through the use of "*basic computational instruments*" (between the 1950s and 1960s) and through "*advance computational instruments*" (Middle of the 1980s up to the present). This enabled the use of sophisticated software which enabled large information management, application of difficult simulations and creation of high resolution graphs using 3-dimensional coordinate system.

This ultimately led to the formulation of large ports performance models. The PGPE-Model comprises of *the ports performance descriptive models* and *the ports performance analytical models*. Both of which can be categorized according to functions and database sizes. In terms of function, the two ports performance modeling approaches can either be descriptive or empirical. The *ports performance descriptive models* on the one hand show arbitrary information that is used to observe a long historical data behavior from a simple perspective. While *the ports performance analytical models* on the other hand is used to generate time-series graphs, cross-section graphs and scatter diagrams to show the trends and relationships between two or more variables from a multi-dimensional and dynamic perspective. The research leading to this study shows a strong link between the introduction of new ports performance models and the development of theories and methodology.

We reviewed 250 papers from five different journals[1] on ports performance models from 1997 to 2012. Studies adopted either benefit / cost, probabilistic or forecasting analysis approaches through the application of econometric methods and use of microeconomic and macroeconomic level secondary data. We observe an increasing dependency of ports productivity models on econometrics modeling, methods and techniques. Seventy-five percent of these studies were based on economic approach. Most focused on efficiency aspects. Technical ports performance models make up 65% and empirical ports performance models, 90%. Empirically (quantitative) studies outweigh qualitative studies by 85% to 15%. Further, 98% of the studies are based on the use of secondary data from various bibliographical documents (Coto-Millán and Pesquera, 2010). Around 60% of studies dealt with long run models while 40% short run models comprising of times series analysis (55%), cross-sectional data modeling (35%) and panel data modeling (45%). Only 25% of the studies adopted the institutional approach or multidisciplinary approach (entailing several disciplines such as history, economics, sociology, politics, technology and social sciences) in evaluating port performance modeling.

This study is of the view that the absence of non-quantitative variables can considerably increase the vulnerability in the analysis of ports performance. Therefore, it suggests that any ports performance model should take into consideration a wide range of factors, including unforeseen ones. These include factors such as natural disaster trends, climate changes, terrorism, crime expansion, education system, social events and phenomena, social norms and behavior. These are important in the ports performance modeling in order to formulate strong policies to improve the ports performance in the long run. However, it must be assumed that all these factors maintain steady transformation(s) through different historical periods of the port development stage.

The PGPE-Model will be employed here to analyze how the port cargo openness, the productivity level, the cargo expansion, and the technological change adaptability can affect directly on the marginal port productivity growth rate performance, regardless of port size through, (i) incorporating port cargo openness, the productivity level, the cargo expansion level and the technological changes adaptability level; and (ii) to quantify and analyze the marginal port productivity growth rate. We employ a mathematical and graph modeling approach to analyze the ports performance and suggest a set of new indicators to evaluate the port performance. It's advantage is flexible adaptation in analyzing without any restriction the weaknesses and strengths of any port efficiently. The PGPE-Model will test two following hypotheses:

1. The marginal port productivity growth performance is directly connected to the efficient coordination of the port cargo openness, the productivity level, the cargo expansion level, and the technological changes adaptability level simultaneously;

2. The profit of any port is dependent on how fast and flexible in utilizing human capital in adapting to changes in new technologies of ports.

[1] Transportation Research Part B: Methodological; Transportation Research Part E: Logistics and Transportation Review; Rresearch in Transportation Economics; Journal of Transportation Economics and Policy; Maritime Economics and Logistic.

3. The PGPE-Model Framework

The PGPE-Model is involves on a series of steps in its application to study the ports performance:

Step-1 Derivation of the total volume cargo of the port per year (**Ψ**) and the total volume cargo of the port per year growth rate (**ΔΨ**)
Step-2 Derivation of the total volume of exports/imports cargo operations under the national level (**λ**)
Step-3 Derivation of the port cargo openness (**Op**) and the port cargo openness growth rate (**ΔOp**)
Step-4 Derivation of the TFP port level (**T**) and TFP port level growth rate (**ΔT**)
Step-5 Derivation of the marginal port productivity growth rate (Π^*)
Step-6 Measurement of the port cargo openness/FTP growth rate (**ΔOp:ΔT**) sensitivity analysis
Step-7 The plotting of ports growth diamond graph

Step-1: Derivation of the Total Volume Cargo for the Port per Year (Ψ) and the Total Volume Cargo of the Port per Year Growth Rate (ΔΨ)

Initially, the total volume cargo of the port per year (Ψ) is equal to the total exports cargo volume (α') plus the total imports cargo volume (β'). If we build the total volume cargo of the port per year (Ψ) then we can proceed to find the total volume cargo of the port per year growth rate (ΔΨ). The ΔΨ can show how the cargo of any port is growing across different periods of time in our case is year by year.

$$\boldsymbol{\Psi} = \alpha' + \beta' \tag{1}$$

$$\boldsymbol{\Delta\Psi} = \frac{(\Psi')_{\text{final year}} - (\Psi o)_{\text{last year}}}{(\Psi o)_{\text{final year}}} * 100\% \tag{2}$$

Analysis of ΔΨ Results

The results of **ΔΨ** reflect two possible scenarios:

(i) If ΔΨ rate is high, then the port experiences strong trade cargo growth
(ii) If ΔΨ rate is low, then the port experiences weak trade cargo growth

Step-2: Derivation of the Total Volume of Exports/Imports Cargo Operations under the National Level (λ)

The second indicator in our model is called "The total volume of exports/imports cargo operations under the national level (**λ**)". This indicator is responsible to evaluate how much exports volumes and imports volumes are crossing across a port every year. The calculation of is equal to:

Total Exports (γ) + **Total Imports** (Λ) = **Total Trade** (Ļ) **(3)**

The Total Volume Cargo of the Port per Year (**Ψ**)/ **Total Trade** (Ļ) *100% = λ **(4)**

Step-3: Derivation of the Port Cargo Openness (Op) and the Port Cargo Openness Growth Rate (ΔOp)

In case of the port cargo openness formula is equal to:

$$\Psi / GDP_{real\ prices} = \mathbf{O_P} \quad \mathbf{(5)}$$

In the case of the port cargo openness, this indicator will show the type of international trade policy any country carry such as import substitution industrialization (protectionism) and export oriented (free trade) (Ruiz Estrada, 2004). Hence, we are evaluating how a port is open to the rest of the world. The **ΔOp** is equal to the port cargo openness rate in a given period (**Op**') minus the port cargo openness rate of the previous period ($\mathbf{Op_o}$) divided by the port cargo openness rate of the previous period ($\mathbf{Op_o}$).

$$\mathbf{\Delta Op} = (Op' - Op_o) * 100\% / Op_o \quad \mathbf{(6)}$$

Analysis of ΔOp Results:

(i) If **ΔOp** rate is high, then the country experiences strong openness growth
(ii) If **ΔOp** rate is low, then the country experiences weak openness growth

Step-4: Derivation of the TFP Port Level (T) and the TFP Port Level Growth Rate (ΔT)

In the case of TFP port level is based on a several number of variables such as education (V_1): we are taking the minimum academic level requested by the port authorities; training (V_2): Number of training programs annually; diet (calories): average national level of calories (V_3); physical condition (V_4): basic medical annual checkup per worker; life expectation (v_5): average national life expectation; years of experience (V_6): average years of working experiences among all staff; ratio of local and foreign workers (V_7): we compare the percentage between local and foreign workers; working place security (V_8): labor guaranty in the long run; technological management (V_9): basic uses of technology in the working place of each worker; incentives programs (V_{10}): allowance and commissions; salaries skills (V_{11}): time and amount of money; retirement programs (V_{12}): social welfare programs; management system (V_{13}): centralized or des-centralized management systems; working hours (V14): number of hours per worker monthly.

$$\mathbf{T} = f(V_1, V_2, V_3, V_4, V_5, V_6, V_7, V_8, V_9, V_{10}, V_{11}, V_{12}, V_{13}, V_{14})$$
$$\mathbf{T'} = f'(V_1, V_2, V_3, V_4, V_5, V_6, V_7, V_8, V_9, V_{10}, V_{11}, V_{12}, V_{13}, V_{14})$$
$$\cdot$$
$$\mathbf{T^i} = f^i(V_1, V_2, V_3, V_4, V_5, V_6, V_7, V_8, V_9, V_{10}, V_{11}, V_{12}, V_{13}, V_{14}) \quad \mathbf{(7)}$$

Hence, the TFP Port Level Growth Rate (**ΔT**) is equal to the T in a given period (**T**') minus the TFP of the previous period ($\mathbf{T_o}$) is divided by the T of the previous period ($\mathbf{T_o}$).

$$\mathbf{\Delta T} = \frac{T' - To}{To} * 100\% \quad \mathbf{(8)}$$

Step-5: Analysis of the Marginal Port Productivity Growth Rate (Π^*)

The marginal port productivity growth rate (Π^*) is based on the uses of three co-factors that we like to applied multidimensional partial differentiation simultaneously. The variables are using to measure the Π^* is based on the labor demand growth rate (α); the equipment and machinery demand growth rate (β) = ratio of container crane(s) by Km^2; the ratio of capacity of storage by KM^2 (θ) = ratio of storage space by Km^2; the ratio of disembarkation by KM^2 (Ω) = ships space disembarkation; the shipping supply (γ) = the ratio of maintenance services, fuel supply, water and foodstuffs number of suppliers. The construction of the marginal port productivity growth rate (Π^*) is to evaluate the fast changes and adaptability of labor and capital in the process of the port growth expansion (see Figure 1).

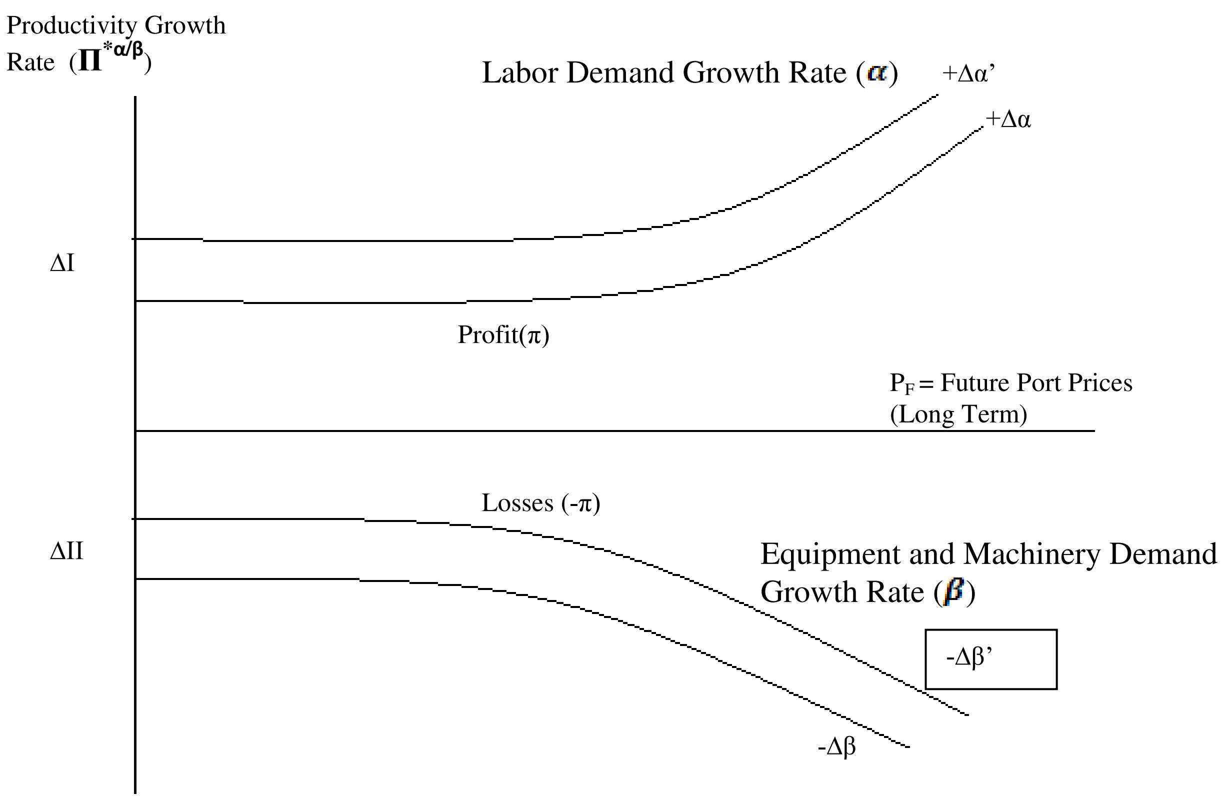
$$\Pi_1 \equiv \left(\frac{\left(\dfrac{\Sigma\ \lambda'_1\ [\alpha'_1 + \beta'_1]^{\theta+1}}{1 - \lambda'_1} \right)^{\text{☼}t+1}}{\left(\dfrac{\Sigma\ \lambda^{o}_1\ [\alpha^{o}_1 + \beta^{o}_1]^{\theta+1}}{1 - \lambda^{o}_1} \right)^{\text{☼}t}} \right)^{\text{☼}gt} \times 100\% \qquad \textbf{(9)}$$

$$\Pi_2 \equiv \left(\frac{\left(\dfrac{\Sigma\ \lambda'_2\ [\theta'_2 + \Omega'_2]^{\theta+1}}{1 - \lambda'_2} \right)^{\text{☼}t+1}}{\left(\dfrac{\Sigma\ \lambda^{o}_2\ [\theta^{o}_2 + \Omega^{o}_2]^{\theta+1}}{1 - \lambda^{o}_2} \right)^{\text{☼}t}} \right)^{\text{☼}gt} \times 100\% \qquad \textbf{(10)}$$

$$\Pi_i \equiv \left(\frac{\left\{ \dfrac{\Sigma \lambda'_i \; [\gamma'_i + \Omega'_i]^{\theta+1}}{1 - \lambda'_i} \right\}^{☼t+1}}{\left\{ \dfrac{\Sigma \; \lambda^{o}_i \; [\gamma^{o}_i + \Omega^{o}_i]^{\theta+1}}{1 - \lambda^{o}_i} \right\}^{☼t}} \right)^{☼gt} \times 100\% \qquad \textbf{(11)}$$

$$\Pi^{*} = \Pi_{1} + \ldots + \Pi_{i} \qquad \textbf{(12)}$$

Figure 1 The Marginal Port Productivity Growth Rate



Source: Ruiz Estrada and Chin (2012)

To prove the marginal port productivity growth rate (**Π***), we will propose a mathematical framework to support the analysis. However, we are going to applied statistical data to calculate the marginal port productivity growth rate (Π*) on different ports. Hence, the main idea is to analyze the behavior the marginal port productivity growth rate (**Π***) by parts under the application of a large number of partial derivatives see bellow.

The labor demand growth rate ($\boldsymbol{\alpha}$)

$$\alpha' = \frac{\Delta\alpha^{*\,t+1}}{\Delta\alpha^{*\,t}} \quad \textbf{(13)}$$

$$\int_{i:0}^{\infty} [\, \frac{\pi_i^{\,n+1}\,(\Delta\alpha')}{n+1} \,]^0 \text{ x } (\Delta\lambda^*)^{\,t+1} \ldots\ldots \int_{i:0}^{\infty} [\, \frac{\pi_i^{\,n+1}\,(\Delta\alpha')}{n+1} \,]^1 \text{ x } (\Delta\lambda^*)^{\,t+1} \ldots . R_+ \not\forall \neq 0 \quad \textbf{(14)}$$

The equipment and machinery demand growth rate ($\boldsymbol{\beta}$)

$$\alpha' = \frac{\Delta\beta^{*\,t+1}}{\Delta\beta^{*\,t}} \quad \textbf{(15)}$$

$$\int_{i:0}^{\infty} [\, \frac{\pi_i^{\,n+1}\,(\Delta\beta')}{n+1} \,]^0 \text{ x } (\Delta\lambda^*)^{\,t+1} \ldots \int_{i:0}^{\infty} [\, \frac{\pi_i^{\,n+1}\,(\Delta\beta')}{n+1} \,]^1 \text{ x } (\Delta\lambda^*)^{\,t+1} \ldots . R_+ \not\forall \neq 0 \quad \textbf{(16)}$$

Thus, we prove that the profit (π) is represented by

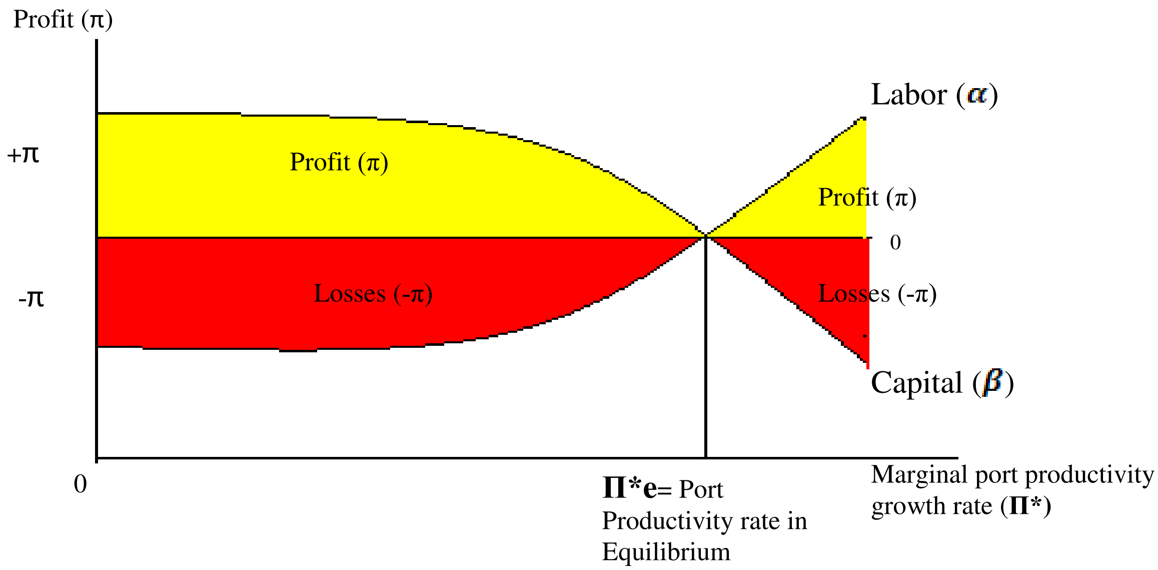
$$\pi_i\,(\Delta\Psi') \rightarrow \Delta\Psi^* = f\,(\Pi_1, \Pi_2, \Pi_3) \ldots\ldots \mathbb{R} \neq 0 \quad \textbf{(17)}$$

$$\pi_i'(\Delta\Psi) = \left\{ \left[\frac{\Delta\pi_i^{\,t+1}}{\pi_i^{\,t}} \right]^{k+1} / \left[\frac{\Delta\pi_i\,(\Delta\alpha')^{-1}}{\Delta\pi_i\,(\Delta\beta')} \right] \right\} \quad \textbf{(18)}$$

$$\alpha = \{\, x|x \;\; \varepsilon\; \mathbb{R}_+ \not\forall\; \pi_i\, ^* \}$$
$$\beta = \{\, x|x \;\; \varepsilon\; \mathbb{R}_+ \not\forall\; \pi_i\, ^* \}$$

Finally, we can prove that the profit and losses of any port is strongly related about the optimum combination between labor ($\boldsymbol{\alpha}$) and capital ($\boldsymbol{\beta}$). It is possible to be observed in the figure 2 that in the initial state of any port the profit is directly connected to the high intensity of capital ($\boldsymbol{\beta}$) at the short run, but in the long run the profit is going to be directly connected to the intensive uses of labor ($\boldsymbol{\alpha}$).

Figure 2 Ports Profit Analysis



Step-6: Measurement of the Port Cargo Openness/FTP Growth Rate (ΔOp:ΔT) Sensitivity Analysis

This indicator measures the vulnerability of any port growth performance under the analysis of the port cargo openness growth (ΔOp) and FTP growth rate (ΔT) simultaneously. The main objective is to compares the trend of port cargo openness growth rate (ΔOp) and FTP growth rate (ΔT) behavior together.

(**ΔOp: ΔT**) = ΔOp : ΔT **(19)**

<u>Results of (**ΔOp: ΔT**) Sensitivity Analysis</u>

The (ΔOp: ΔT) sensitivity analysis reflects several possible scenarios:

(i) If ▲ΔOp:▲ΔT then the ports growth performance has good performance
(ii) If ▼ΔOp:▼ΔT then the ports growth performance has poor performance
(iii) If ▲ ΔOp:▼ΔT then the ports growth performance has inconsistent performance
(iv) If ▼ ΔOp : ▲ΔT then the ports growth performance has inconsistent performance

(ΔOp): port cargo openness growth rate ▲ : increase
(ΔT) : FTP growth rate ▼: decrease

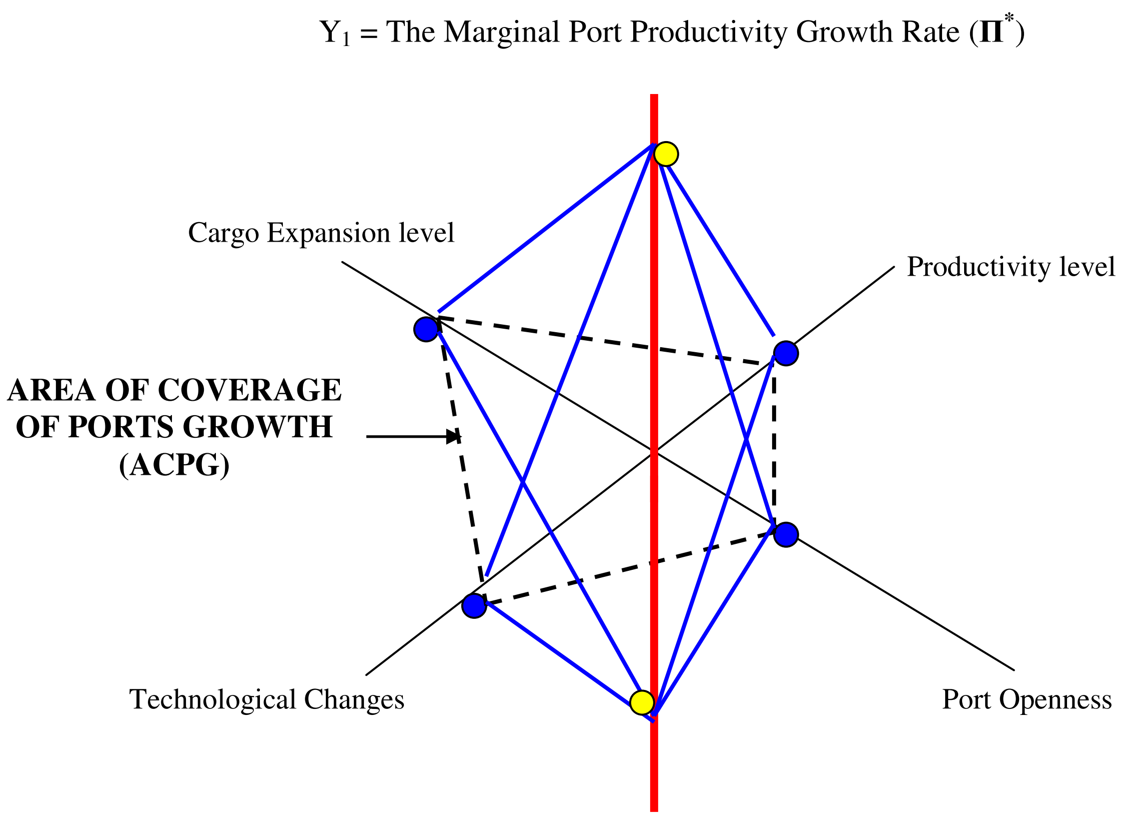
Step-7: Plotting of Ports Growth Diamond Graph

The Ports Diamond Graph (Ruiz Estrada and Chin, 2011) presents a general idea about the current port development based on a new concept of graphic representation (see Figure 3). This new concept of graphic representation consists of six axes, each of which has only positive values. In the case of this research, the value in four of the axes is represented by the degree of ports growth (openness, productivity, cargo expansion, technological changes). These indexes are independent variables. There can be joined together to create a general area. This general area is called "area of coverage of ports growth performance (**ACPG**)". This area shows the dimension of ports growth performance from a general perspective. For comparison purposes, **ACPG** can be applied to different years for one port or two ports. The analysis of the **ACPG** is based on the comparison of two periods. In the case of this research study, two periods (i.e. first period and second period) are compared. The total **ACPG** may present three possible scenarios, namely:

(a) Expansion (**ACPG**' first period < **ACPG**" second period)
(b) Stagnation (**ACPG**' first period = **ACPG**" second period)
(c) Contraction (**ACPG**' first period > **ACPG**" second period)

The fifth and sixth axes are represented by the dependent variables Y_1 (port growth rate) and Y_2 (income growth rate). They are positioned in the center of the graph which is the meeting point of the other four axes.

Figure 3: The Port Growth Diamond Graph



4. PGPE-Model and the Performance of selected Asian Ports

The PGPE-Model was applied initially to twelve ports such as the port of Singapore, Hong Kong, Busan, Shanghai, Tokyo, and port Klang at Malaysia respectively (see Table 1). The period of study is between 1970 and 2010. In this period of time was chosen because we are interested to evaluate if exist a strong linkage between the marginal port productivity growth rate and four main variables of analysis. These main four variables in analysis are the port cargo openness, the productivity level, the fast cargo expansion, and the technological change adaptability. The results show that the marginal port productivity growth directly is depend on the efficient coordination of the port cargo openness, the productivity level, the fast cargo expansion, and the fast technological change adaptability.

According to the PGPE-Model results is possible to observe that the most high marginal port productivity growth rate among the twelve ports in analysis is the port of Singapore (see Table 1 and Figure 4). It is followed by the port of Hong Kong, Busan, Shanghai, Tokyo, and Klang respectively. The last place among the twelve ports in the analysis was port Klang at Malaysia. We can observe a high ports openness, but low cargo expansion, a low productivity, and slow technological change adaptability (see Table 1 and Figure 5). The lower marginal port productivity growth rate in port Klang request the help from the central government of Malaysia to supply high levels of subsidies to reduce the high cargo costs according to the PGPE-Model.

Figure 4: Port Growth Diamond for Singapore

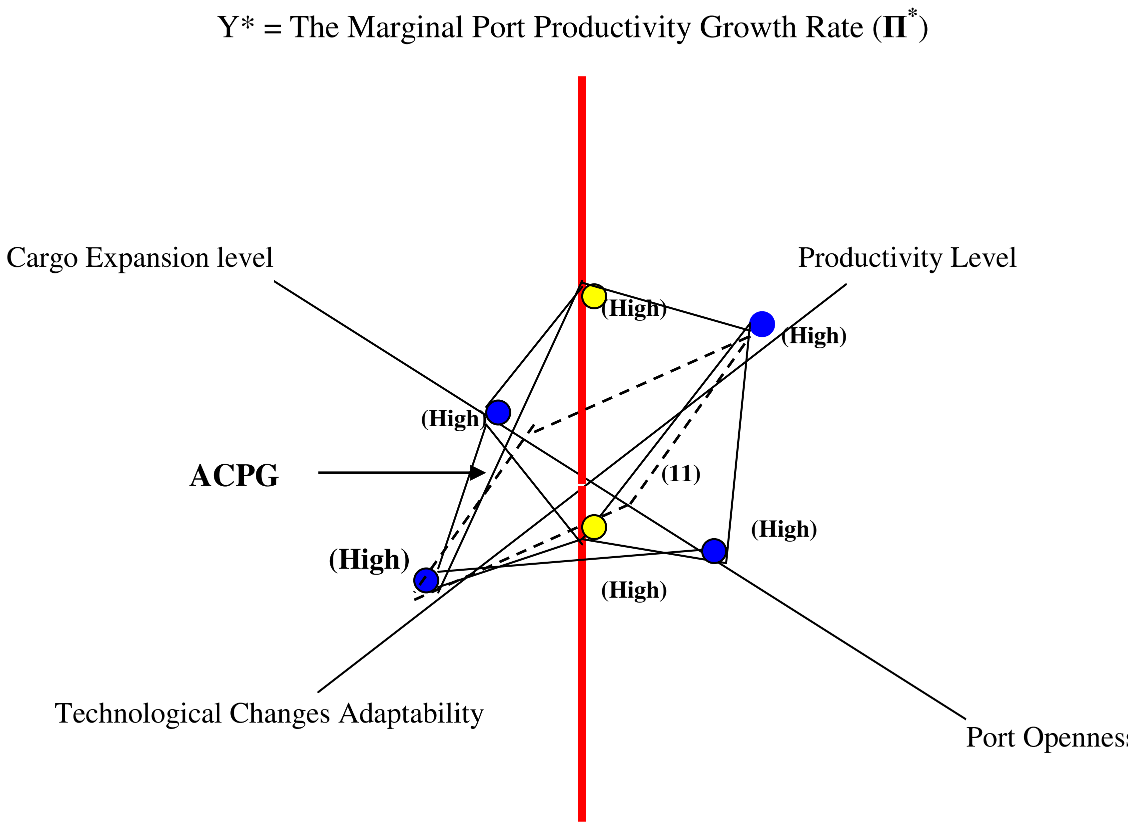


Figure 5: Port Growth Diamond for Port Klang (Malaysia)

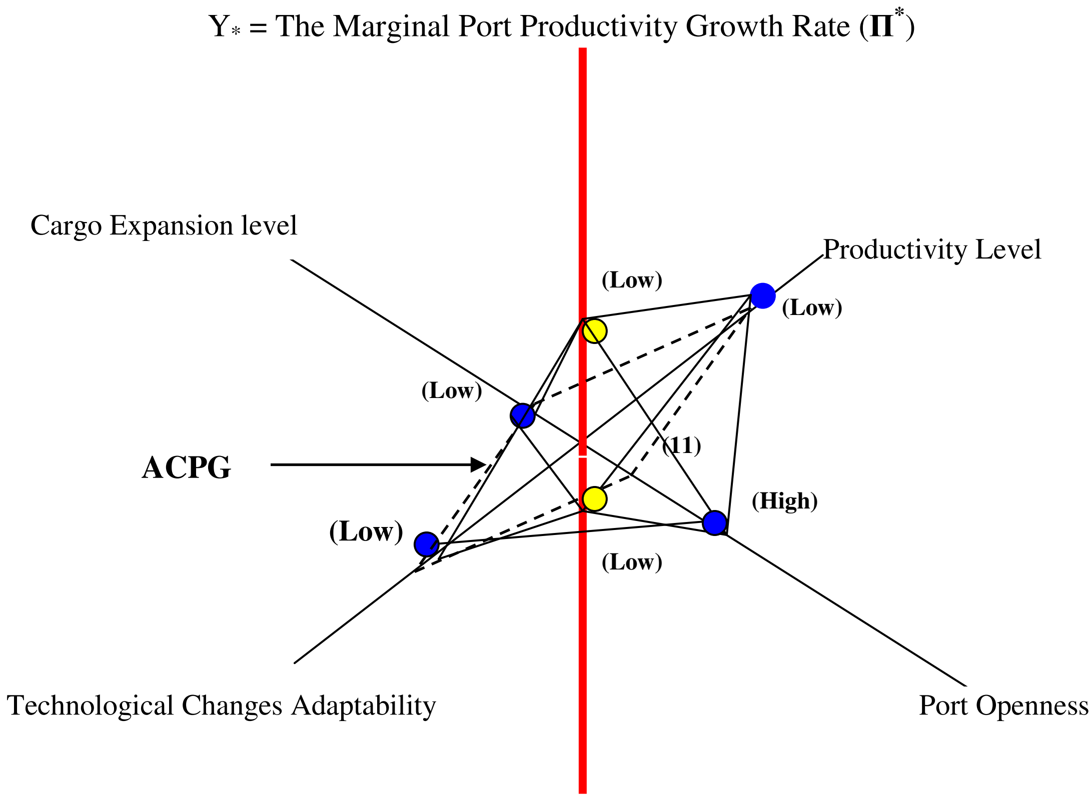


Table 1: PGPE-Model Results

Port	Port Openness	Productivity Level	Cargo Expansion	Technology Change Adaptability	The Marginal Port Productivity Growth Rate
Singapore	**0.97**	**0.95**	**0.99**	**0.99**	**0.975**
Hong Kong	**0.95**	**0.91**	**0.95**	**0.99**	**0.95**
Shanghai	**0.90**	**0.89**	**0.99**	**0.90**	**0.92**
Busan	**0.95**	**0.91**	**0.89**	**0.93**	**0.92**
Tokyo	**0.85**	**0.92**	**0.91**	**0.95**	**0.90**
Port Klang	**0.55**	**0.35**	**0.37**	**0.35**	**0.40**

Source: Asian Development Bank; Busan Port Authority; International Maritime Information Webside; Research in Transportation Economics; Hong Kong Marine Department; Japanese Ministry of Internal Affairs and Communications; Port Knalng Authority; Singapore Port Authority; World Bank ; World Port Source.

5. Conclusion

This study incorporates factors such as port cargo openness, the productivity level, the cargo expansion, and the technological change adaptability in evaluating port performance. The Port Growth Performance Evaluation model (PGPE-Model) was proposed to evaluate the above factors can directly affect marginal productivity growth rate and performance of a port. The objective is to offer policy makers and researchers a different perspective in incorporating dynamic changes such as change in international trade trends, the impact of technology or competition in evaluating port performance. The versatility of the PGPE-Model is such that it can be applied to any production unit or a group of economic activity. It is not constrained by geographical area or development stage of the entities. It is thus simple and flexible. In an era of globalization where changes take place in short cycles and production units change location, the main advantage of the PGPE-Model is the ability to capture and measure the change, vulnerability and port performance.

The main conclusion is that to generate a high marginal port productivity rate is necessary to have a efficient coordination of the port cargo openness, the high productivity levels, the ability to expand cargo quickly, and the ability of the port to adapt to technological change. The second finding is that marginal port productivity level is based on how the human capital factor can be adapted to these new changes in maritime and ports technologies.

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