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Regional Port Productivity in APEC

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Abstract: The regional growth of the goods and services trade has placed greater pressure on the ports of the Asia-Pacific Economic Cooperation (APEC) members, especially in the developing countries. The purpose of this study is to apply the generalized metafrontier Malmquist productivity index (gMMPI) to compare the port productivity of developed countries (DCs) and developing countries (LDCs) in APEC. The results indicate that, first, the average rate of utilized capacity among the ports of APEC members was only 65.7% during 2002–2011, which means that another 34.3% of additional through put can be handled with the same level of resources. Second, the average productivity of the container ports in the DCs appeared to be higher than those located in the LDCs. The main sources of productive growth in the DCs were based on scale efficiency change (SEC), technical efficiency change (TEC), and potential technological relative change (PTRC), while the main source of productive growth in LDCs was based on SEC. Third, SEC appeared to be the dominant factor that affects the utilization of all ports.

Keywords: APEC; gMMPI; port productivity

1. Introduction

APEC (Asia-Pacific Economic Cooperation), as an organization, focuses on regional cooperation across the Asia-Pacific region, seeking to promote greater economic cooperation and integration within the region. APEC member nations comprise 39% of the world's population and are responsible for 56% of the world's GDP, with an average annual GDP growth rate of 2.79% in the past ten years, which is higher than the global rate. Between 1989 and 2014, the total trade in goods and services of the APEC members increased sevenfold, while the concurrent increase in world trade increased by 6.16 times [1]. This trade growth has brought a heavy burden on the major gateways of international trade. During the period from 2000–2013, within APEC, the compounded annual growth rate of container port traffic for developed countries (DCs) such as the US was 5.47%, whereas the growth rate of the developing countries (LDCs) was 10.71% in the same period [2]. In addition, the logistics costs for the United States in 2014 reached USD 1.45 trillion, accounting for 8.3% of the country's GDP, with a USD 43.4 billion increase compared to that of 2013 [3]. Among the developing countries in APEC, the logistics costs of China, Peru, and Mexico for the same year were 18.0%, 12.5%, and 12.0%, respectively [4]. This higher logistics costs can be attributed to their underdeveloped logistics systems. Walkenhorst and Yasui [5] have pointed out that a one percent reduction in the trade transaction costs yields an increase of USD 40 billion into the APEC economies. Therefore, APEC has committed itself to the enhancement of supply chain connectivity and the reduction of trade transaction costs among its member economies. Investing in the improvement of international gateways' efficiency is regarded as one of the major development plans of a nation. The purpose is to reduce the time and costs spent on the entire supply chain, as well as to minimize the uncertainties during the freight transport.

The importance of container ports to the economic growth of APEC members is rooted in the economic development and natural endowments within the region. From 1989 to 2014, the total growth of Intra-EU merchandise trade increased by a multiple of 4.45, while merchandise trade of intra-APEC in 2014 had increased over the 1989 level by 5.77 times [1]. Singapore, Hong Kong, and South Korea took advantage of this opportunity to strengthen their investment in the construction of logistics infrastructure as well as the improvement of efficiency, thereby becoming the central hubs for transshipment traffic. However, the underperformance of the logistics service sector of many developing countries affected their logistics efficiency and led to a loss in competitiveness [6]. In recent years, many scholars have conducted research on the theory, methods, and application of port performance evaluation. Indicators such as total factor productivity (TFP), data envelopment analysis (DEA), stochastic frontier analysis (SFA), free disposal hull, and revealed comparative advantage are often used to measure the efficiency of container ports [7–11]. The indicators of these methods can be used as a reference to develop strategies that improve port efficiency, resource allocation, and sustainable development.

Tongzon [12] applied the DEA model to investigate the value of efficiency for four Australian ports and 12 international ports. The results showed that the function or port size alone were not the key factors of port performance. Yuen, et al. [13] used the DEA model to analyze the performance of 21 ports between 2003 and 2007, including those located in China, Taiwan, Korea, and Singapore, and concluded that regional competitiveness can help to improve port efficiency. Figueiredo De Oliveira and Cariou [14] employed the data from 200 ports worldwide from 2007–2010, and utilized the non-parametric order-α frontier technique to estimate the value of efficiency, and the truncated bootstrapped regression to investigate factors that caused inefficiency. The findings suggested that the competition intensity among ports seemed to lead to a decline in port efficiency, and the difference in time between the equipment investment and the actual utilization of the equipment was the key factor. Tovar and Wall [15] applied directional technology distance functions to analyze the production technology and the technical efficiency of 20 Spanish port authorities from 1993 to 2012, and suggested that the Spanish ports should maximize the capacity of existing ports to provide services, rather than to over-invest in technology. Song and Cui [16] used the Malmquist index to study the changes in the productivity of Chinese container ports during the period 2006 to 2011. They claimed that the main source of productivity is technological development, rather than an improvement in technical efficiency.

A good port operation or logistics system can be a main driving factor in maintaining the economic development and retaining the competitiveness of a country [9,17]. However, the central question remains as to which indicators should be used to assess the performance of a port. In their study of institutional reforms, Cheon, Dowall and Song [11] examined the productivity of 98 major ports globally, using the MPI model and its compositions: scale efficiency change (SEC), technical efficiency change (TEC), and technological progress. The results showed that reform or restructuring of ownership and corporate structures is useful to TFP and can substantially enhance the productivity of large ports. Núñez-Sánchez and Coto-Millán [18] employed SFA to analyze the performance of 27 Spanish ports during the period 1990 to 1999 and claimed that TFP would improve due to technological progress and an increase in scale efficiency, as well as a decrease in the decline of technical efficiency. In their study of 14 Peruvian and Chilean ports with SFA, Chang and Tovar [19] discovered that Chilean ports are more productive than Peruvian ports, and claimed that the main source of this difference was the changes in technical efficiency and scale.

Port classification in heterogeneity received little attention in the existing literature [20]. Martínez-Budría, et al. [21] categorized the 26 Spanish ports during the period 1993 to 1997 into three categories according to their level of complexity, and used the BCC model of DEA for their evaluation. The results illustrated that the ports with a higher level of complexity have a higher relative efficiency, whereas the relative efficiency of the port with a lower level of complexity tends to exhibit negative growth. Bichou [7] decomposed the operation procedure of container ports and terminals into sub-processes and applied a network structure to analyze its efficiency. The results showed that the inconsistent efficiencies in the freight handling process between offshore stations and container yards led to a bottleneck in the workflow. Therefore, Bichou concluded that integration and management capabilities are the key factors influencing the productivity of container terminals. Using 21 countries in the G7 markets and emerging markets as a research sample, Wu and Goh [8] applied peer-assessment and self-assessment techniques to analyze the operations of container ports, and categorized the ports into three strategic groups: BRIC, Next-11, and G7.

Compared to previous research, this study has three major contributions. First, we noted that most of the past studies applied analytical methods to measure port efficiency in a pooled data set. They tended to conduct efficiency assessments and comparison analyses based on an assumption that all subjects were on the same level of technical capability. O'Donnell et al. [22] pointed out that the use of traditional frontier models should not be applied to compare companies of different characteristics or production technology. The level of production technology for each country differs according to their economy, infrastructure, and quality of service. It is suggested that it is necessary to categorize the subjects based on the countries' economic development, the characteristics of the ports, or the container lifting system before further comparison is conducted. Second, meaningful logistics indicators are considered to be able to directly affect a country's logistics decisions [23]. To our knowledge, the catch-up effect for port performance has only been considered in a few studies [11]. The catch-up effect represents the managerial capability to respond to the environmental challenges quickly. Using these indicators as a reference, policy makers can propose policies and action plans to improve port performance and supervise port development. Lastly, there are only a limited number of studies on port performance that have used countries, regional economies, or major trading groups as a unit of comparison, and our study thus helps to enhance the existing literature [8]. Hung, et al. [24] categorized Asian ports according to geographical location: East Asian, Northeast Asian, and Southeast Asian ports; and discovered that East Asian ports seemed to have a higher competitiveness than the other Asian ports.

Therefore, this study intends to adopt the generalized metafrontier Malmquist productivity index (gMMPI) to investigate the port productivity of the DCs and LDCs in APEC. The next section introduces the gMMPI. Section 3 illustrates the research methods and establishment of the models. The fourth section illustrates the regional productivity and its influential factors, and the last section includes the conclusions and discussion of implications.

2. gMMPI

Assuming that production technology represents the management capabilities of a port, inputs could be transferred into outputs through production technology. Under the context that $k = 1,..., K$ technology sets (groups) in time $t = 1, ..., T$, permitting that the quay length, the terminal area, and the number of tons that the facilities are able to handle are the input vectors, $x_t \in R^{+M}$, and the container throughput is the output vector, $y_t \in R^{+L}$. Then, S, the technology set of a given group that is formed by container ports is defined as:

$$S_t^k = \left\{ \left(x_t^k, y_t^k \right) : x_t^k \, can \, produce \, y_t^k \right\} \quad (1)$$

The output set P^K can be defined as:

$$P_t^k \left(x_t^k \right) = \left\{ y_t^k \left(x_t^k, y_t^k \right) \in S_t^k \right\} \quad (2)$$

This homogeneous, output-oriented technology set P^K includes a combination of all visible technical inputs and outputs. $x_t \in R^{+M}$ and $y_t \in R^{+L}$ are defined as non-negative input and output vectors. Therefore, with a set of given input vectors, we pursue the output vector of the maximum throughput. Based on these definitions, the distance function of the output surface of the *k*-th group would be [25]:

$$D_t^k\ (x_t^k, y_t^k\ ) = \inf_{\theta}\{\theta : (\frac{y_t^k}{\theta}) \in P_t^k(x_t^k\ )\ \} \tag{3}$$

In each output of the technology set, the efficiency frontier, formed by the units with the best performance, is defined as the group frontier. The ratio of actual productivity and frontier productivity is the distance function. Therefore, the technical efficiency of the output surface can be defined as [26]:

$$0 < D_t^k\ (x_t^k, y_t^k\ ) = \mathrm{TE}_t^k\ (x_t^k, y_t^k\ ) \leqslant 1 \tag{4}$$

We assume that, based on the educational and economic development of each country, the port operation is likely to apply a different technology. Thus, the ports can be divided into *k* technology subsets, *k* = 1, 2, ..., *K*, and the period *t* = 1,..., *T*, which are operated with a common technological set $T^*{}_t$ that can be found, for example, in the ports of DCs and LDCs. The set union of these *k* technology subsets is the output-oriented common technological set $P^*{}_t$:

$$P_t^*\ (x_t) = \{y : (x_t, y_t) \in T_t^*\} \tag{5}$$

The frontier of the common technological set is defined as the metafrontier. This implies that all the ports in the common technological set might have the potential to break out of the boundaries of the group frontier and reach the upper bound of maximum output. On the basis of the metafrontier, the distance function of the output surface of the common technological set is defined as:

$$D_t^*\ (x_t, y_t\ ) = \inf_{\theta}\ \{\theta : (\frac{y_t}{\theta}) \in P_t^*(x_t\ )\ \} \tag{6}$$

The technical efficiency of the output surface is defined as:

$$0 < D_t^*\ (x_t, y_t) = \mathrm{TE}_t^*\ (x_t, y_t) \leqslant 1 \tag{7}$$

We can use the metafrontier and group frontier based on the distance function to measure the correlation of the technical efficiencies:

$$D_t^*\ (x_t, y_t\ ) \leqslant D_t^k\ (x_t, y_t) \Rightarrow \mathrm{TE}_t^*\ (x_t, y_t) \leqslant \mathrm{TE}_t^k\ (x_t, y_t) \tag{8}$$

The ratio of the metafrontier and group frontier is defined as the technology gap ratio (TGR), and is measured as:

$$0 \leqslant \mathrm{TGR}_t^k\ (x_t, y_t) = \frac{D_t^k\ (x_t^k, y_t^k)}{D_t^*\ (x_t^*, y_t^*)} = \frac{\mathrm{TE}_t^k\ (x_t^k, y_t^k)}{\mathrm{TE}_t^*\ (x_t^*, y_t^*)} \leqslant 1 \tag{9}$$

TGR represents the status of the knowledge and management capability of port operation [27]:

$$\mathrm{TE}_t^*(x_t, y_t) = \mathrm{TK}_t^K\ (x_t, y_t) \times \mathrm{TGR}_t^K\ (x_t, y_t). \tag{10}$$

Applying the Quadratic Identity Lemma (Diewert [28]), the cross-period change in the distance function of the metafrontier as a logarithmic function can be written as:

$$\begin{aligned} &\ln D^{*}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t) - \ln D^{*}_{t}(y^{l}_{t}, x^{m}_{t}, t) \\ &= \tfrac{1}{2}\textstyle\sum_{l=1}^{L}\left[\frac{\partial \ln D^{*}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t)}{\partial \ln y^{l}} + \frac{\partial \ln D^{*}_{t}(y^{l}_{t}, x^{m}_{t}, t)}{\partial \ln y^{l}}\right] \times \left(\ln y^{l}_{t+1} - \ln y^{l}_{t}\right) \\ &+ \tfrac{1}{2}\textstyle\sum_{m=1}^{M}\left[\frac{\partial \ln D^{*}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t)}{\partial \ln x^{m}} + \frac{\partial \ln D^{*}_{t}(y^{l}_{t}, x^{m}_{t}, t)}{\partial \ln x^{m}}\right] \times \left(\ln x^{m}_{t+1} - \ln x^{m}_{t}\right) \\ &+ \tfrac{1}{2}\left[\frac{\partial \ln D^{*}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t)}{\partial t} + \frac{\partial \ln D^{*}_{t}(y^{l}_{t}, x^{m}_{t}, t)}{\partial t}\right] \end{aligned} \quad (11)$$

After it is weighted by the distance elasticity of input and output, the logarithmic form is calculated for the ratio of the changes in the input and output. The proportion of the input distance elasticity is used to replace the input distance elasticity to ensure that the proportionality property is satisfied [29]. Thus, gMMPI can be expressed as follows:

$$\begin{aligned} &\ln gMMPI_{t,t+1}(y^{l}_{t+1}, y^{l}_{t}, x^{m}_{t+1}, x^{m}_{t}) = \\ &\left[\ln D^{*}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t) - \ln D^{*}_{t}(y^{l}_{t}, x^{m}_{t}, t)\right] \\ &- \tfrac{1}{2}\left[\frac{\partial \ln D^{*}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t)}{\partial t} + \frac{\partial \ln D^{*}_{t}(y^{l}_{t}, x^{m}_{t}, t)}{\partial t}\right] \\ &+ \tfrac{1}{2}\textstyle\sum_{m=1}^{M}\left[\frac{(-\sum_{m=1}^{M}\xi^{*m}_{t+1} - 1)\xi^{*m}_{t+1}}{\sum_{m=1}^{M}\xi^{*m}_{t+1}} + \frac{(-\sum_{m=1}^{M}\xi^{*m}_{t} - 1)\xi^{*m}_{t}}{\sum_{m=1}^{M}\xi^{*m}_{t}}\right] \times \left(\ln x^{m}_{t+1} - \ln x^{m}_{t}\right) \end{aligned} \quad (12)$$

where $\xi^{*m}_{t+1} = \frac{\partial \ln D^{*}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t)}{\partial \ln x^{m}}$; $\xi^{*m}_{t} = \frac{\partial \ln D^{*}_{t}(y^{l}_{t}, x^{m}_{t}, t)}{\partial \ln x^{m}}$.

Therefore, Equation (12) can be decomposed as TEC*, TC* and SEC*:

$$\text{gMMPI}_{t,t+1} = \text{TEC}^{*}_{t,t+1} \times \text{TC}^{*}_{t,t+1} \times \text{SEC}^{*}_{t,t+1} \quad (13)$$

Equation (12) can also be rewritten as:

$$\begin{aligned} &\ln \text{gMMPI}_{t,t+1}(y^{l}_{t+1}, y^{l}_{t}, x^{m}_{t+1}, x^{m}_{t}) \\ &= \left[\ln D^{k}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t) - \ln D^{k}_{t}(y^{l}_{t}, x^{m}_{t}, t)\right] - \tfrac{1}{2}\left[\frac{\partial \ln D^{k}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t)}{\partial t} + \frac{\partial \ln D^{k}_{t}(y^{l}_{t}, x^{m}_{t}, t)}{\partial t}\right] \\ &+ \left[\ln \text{TGR}^{k}_{t+1}\left(y^{l}_{t+1}, x^{m}_{t+1}, t\right) - \ln \text{TGR}^{k}_{t}\left(y^{l}_{t+1}, x^{m}_{t+1}, t\right)\right] - \tfrac{1}{2}\left[\frac{\left[\frac{\partial \ln D^{*}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t)}{\partial t} + \frac{\partial \ln D^{*}_{t}(y^{l}_{t}, x^{m}_{t}, t)}{\partial t}\right]}{\left[\frac{\partial \ln D^{k}_{t+1}(y^{l}_{t+1}, x^{m}_{t+1}, t)}{\partial t} + \frac{\partial \ln D^{k}_{t}(y^{l}_{t}, x^{m}_{t}, t)}{\partial t}\right]}\right] \\ &+ \tfrac{1}{2}\textstyle\sum_{m=1}^{M}\left[\frac{(-\sum_{m=1}^{M}\xi^{*m}_{t+1} - 1)\xi^{*m}_{t+1}}{\sum_{m=1}^{M}\xi^{*m}_{t+1}} + \frac{(-\sum_{m=1}^{M}\xi^{*m}_{t} - 1)\xi^{*m}_{t}}{\sum_{m=1}^{M}\xi^{*m}_{t}}\right] \times \left(\ln x^{m}_{t+1} - \ln x^{m}_{t}\right) \end{aligned} \quad (14)$$

Further, Equation (14) can be simplified as:

$$\text{gMMPI}_{t,t+1} = \text{TEC}^{k}_{t,t+1} \times \text{TC}^{k}_{t,t+1} \times \text{PTCU}^{k}_{t,t+1} \times \text{PTRC}^{k}_{t,t+1} \times \text{SEC}^{*}_{t,t+1} \quad (15)$$

In Equation (15), a gMMPI value greater than 1 indicates a growth in productivity. TEC is the ratio that measures the cross-period change of the distance between actual productivity levels with respect to the maximum productivity level. In other words, it is the measurement of the factor intensity of production efficiency [30]. A value greater than 1 means that the output level is close to the potential output level of the group, or an improvement in production efficiency. TC is the rate of technological change used to measure input and output. TC > 1 indicates technical progress. TC < 1, on the other hand, indicates technological recession. The pure technological catch-up (PTCU) refers to the ratio of TGR in time *t* and time *t + 1*. If PTCU is greater than 1, then the current technical production level is catching up with the potential production level, indicating that the technical gap faced by the port would reduce over time, and manifests as a *catch-up* effect. The potential technological relative change (PTRC) refers to the ratio of the group frontier technological change and the metafrontier technological change. It measures the improving speed of potential technology based on the existing production technological change. If its value is greater than 1, then the improved speed of potential technology is greater than that of current technology. Lastly, SEC is affected by the input and elasticity of scale. SEC > 1 represents an optimal size that can help to improve productivity [31].

3. Methodology

To investigate the port performance of APEC member countries, and to explore the factors that influence their performance, we conducted the following steps:

- Grouping: We grouped the APEC economies according to their state of economic development.
- Major ports: We defined the major ports of each economy.
- Measurement model: We measured the function between inputs and outputs.
- Analysis: We analyzed the port productivity of the DCs and LDCs.

This study focused on the APEC region. APEC is an association of Asia-Pacific nations founded in 1989, and currently comprises 21 member economies. Its policies are made through consensus decision making, voluntarily applied by its members, allowing the members to achieve the same goal with different rates of progression. Past research on port performance evaluations tended to assume that all ports have the same management capability and infrastructure, analyzing and comparing all samples in a single pool. However, appropriate grouping can help identify the sources of inefficiency and possible improvement measures. Researchers often apply economic development, geographical location, or organization as a grouping reference [11,32,33]. Using the World Economic Outlook as a reference [34], this study grouped the 20 economies into DCs and LDCs (we omitted Papua New Guinea due to the lack of data). Australia and another seven countries were classified as DCs, while China and another 11 countries were classified as LDCs. For the decision-making units (DMU) of the gMMPI model, we adopted the international container ports of the APEC economies that were listed as the world's top 100 ports with the largest average container throughput. Due to the lack of availability of actual data, only 54 container ports of eight DCs and 12 LDCs were included in the final sample (Table 1), with a study period from 2002–2011.

3.1. Input and Output

Many studies have proposed appropriate performance indicators for port ranking. Land (size of the terminal area), equipment (facilities, buildings, and cargo lifting equipment), labor (the expenses of employees of the port authorities, stevedores, and other types of labor), and management capability are considered to be significant factors affecting container port productivity [8,35]. According to past studies, container terminal area, the berth length, and the number of equipment such as quayside gantries, yard gantries, and straddle carriers, are usually used as input variables, while container throughput is used as the main output variable [8–11,36–41].

We adopted publications put forth by the Containerization International [42], the American Association of Port Authorities [43], CI-online [44], and The World Bank [2] as the main sources of information to construct these variables. This study applied the definition of variables proposed by Cullinane and Wang [45], and Wu and Goh [8], merging three indicators (quayside cranes, yard gantry cranes, and straddle carriers) into a single variable "amount of equipment". The variable "amount of equipment" is independent of the volume of throughput the equipment could handle or the operational efficiency of the equipment. For example, there is a big difference in the volume of containers that Panamax, Post Panamax, and Super-Post Panamax can handle per hour. Therefore, the processing capacity of equipment was seen as an input variable in this study (see Table 1). The length of berths (m) was defined as the total length of all container berths. The greater this number, the more number of berths can be provided by the port simultaneously. The size of terminal area (ha) referred to the usage area of the container port. The larger the area, the more favorable the port is for future expansion of the container storage area and the enrichment of equipment. Equipment processing capability (ton) was defined as the total container volume in metric tons that could be handled by cranes and large-scale equipment, as they were seen as important equipment that could affect the loading and discharging efficiency of containers. Container throughput was defined as the total volume of containers handled by a port per year (TEU), a globally essential indicator of container port output evaluation.

Table 1. Descriptive statistics for input and output variables.

Country	Container Port	Quay Length (m)		Terminal Area (ha)		Capacity (ton)		No. of Containers (TEU)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
DCs									
Australia	Melbourne	3502	346	147	9	3826	449	2,009,312	351,533
	Sydney	2748	677	94	8	2983	98	1,560,629	297,501
Canada	Montreal	3936	389	89	11	2252	429	1,267,170	132,077
	Vancouver BC	4199	475	162	8	2689	573	2,035,916	475,754
Hong Kong	Hong Kong	9580	2154	306	51	18,269	2734	22,411,998	2,050,206
Japan	Kobe	7930	1111	190	17	4421	127	2,346,579	172,044
	Nagoya	3632	236	131	16	4536	730	2,453,011	338,648
	Osaka	4295	245	123	13	2456	104	1,993,501	266,954
	Tokyo	4242	462	126	34	4201	613	3,829,302	512,319
	Yokohama	5504	319	199	15	4607	280	2,968,394	391,328
New Zealand	Auckland	1063	60	41	1	2122	286	736,744	130,685
Singapore	Singapore	14,960	4603	415	107	30,134	12,292	24,689,970	4,613,651
South Korea	Busan	12,687	1476	384	60	12,519	3270	12,233,596	2,309,898
	Gwangyang	2985	1257	213	309	2112	1361	1,605,088	459,862
	Incheon	2010	468	47	5	1005	193	1,405,936	530,070
Taiwan	Kaohsiung	6487	523	148	18	3210	393	9,255,783	804,964
	Keelung	3362	249	39	7	1820	170	2,026,099	228,724
	Taichung	1864	201	88	17	2341	602	1,246,608	73,814
United States	Charleston	3102	0	186	10	2221	472	1,600,481	320,806
	Houston	1525	0	78	0	1456	345	1,602,306	271,445
	Long Beach	7456	475	450	45	4810	582	6,023,136	992,943
	Los Angeles	8732	1176	574	140	5746	1822	7,406,072	1,031,546
	New York/New Jersey	8251	685	571	30	8439	1128	4,740,355	746,186
	Oakland	6869	398	307	25	2884	389	2,176,142	213,793
	Savannah	2676	315	476	16	3071	1820	2,154,801	639,155
	Seattle	3858	412	206	15	1382	266	1,825,555	249,212
	Tacoma	2680	453	219	35	2622	895	1,732,205	253,691
	Virginia	3894	602	449	58	2217	415	1,860,089	235,735
LDCs									
Brunei	Muara	765	0	9	2	117	1	88,668	16,864
Chile	San Antonio	1163	27	46	5	616	47	693,283	143,197
China	Dalian	2744	1175	160	60	4122	1407	3,526,890	1,688,175
	Fuzhou	1354	320	94	42	1341	421	988,561	345,955
	Guangzhou	3848	1878	306	211	3833	2156	7,712,190	4,559,065
	Lianyungang	540	0	16	0	404	29	2,052,150	1,555,327
	Nanjing	410	0	20	0	782	61	754,954	332,160
	Ningbo	2460	679	76	0	1454	20	7,887,450	4,617,521
	Qingdao	4756	1151	118	17	4005	897	8,058,170	3,555,060
	Shanghai	6899	2825	621	319	14,343	7734	21,114,820	8,514,188
	Shenzhen	9046	3842	297	81	10,872	4564	16,877,284	5,990,716
	Tianjin	3089	761	132	39	3720	2229	6,517,142	3,206,334
	Xiamen	1721	676	57	11	1044	171	4,027,106	1,642,391
	Yantai	1156	705	58	28	1263	995	1,266,185	793,099
Indonesia	Tanjung Perak	2094	444	92	30	2232	649	1,994,987	586,062
	Tanjung Priok	2907	451	155	19	4661	852	3,699,082	921,677
Malaysia	Penang	1052	129	75	11	1885	325	886,004	176,179
	Port Klang	5662	907	161	22	10,547	1678	6,620,973	1,947,519
	Tanjung Pelepas	2376	683	126	19	4367	1817	4,801,387	1,966,480
Mexico	Manzanillo	1669	875	27	7	1037	421	1,143,002	439,051
Peru	Callao	3821	568	42	15	694	351	950,638	363,796
Philippines	Manila	7768	549	183	29	3148	625	2,809,480	298,604
Russia	St. Petersburg	2154	250	68	35	2483	1012	1,423,794	687,832
Thailand	Bangkok	3958	430	106	57	3570	1693	1,335,638	148,976
	Laem Chabang	8420	2671	337	140	6658	2199	4,168,238	1,086,971
Vietnam	Ho Chi Minh	3842	1844	167	89	2991	1600	2,683,834	1,221,260

3.2. Model

For the SFA, we adopted the setting of the translog production function [46,47] and panel data setting proposed by Battese and Coelli [48]. The group frontier of this study was constructed as:

$$\begin{aligned} \ln y_{it}^{g} &= \beta_0^g + \beta_1^g \left(\ln L_{it}^g\right) + \beta_2^g \left(\ln M_{it}^g\right) + \beta_3^g \left(\ln N_{it}^g\right) + \tfrac{1}{2}\beta_4^g \left(\ln L_{it}^g\right)^2 \\ &+ \tfrac{1}{2}\beta_5^g \left(\ln M_{it}^g\right)^2 + \tfrac{1}{2}\beta_6^g \left(\ln N_{it}^g\right)^2 + \beta_7^g (T) + \beta_8^g (T)^2 \\ &+ \beta_9^g \left(\ln L_{it}^g)\right) \left(\ln M_{it}^g\right) + \beta_{10}^g \left(\ln L_{it}^g\right) \left(\ln N_{it}^g\right) + \beta_{11}^g \left(\ln N_{it}^g\right) \left(\ln M_{it}^g\right) \\ &+ \beta_{12}^g \left(\ln L_{it}^g)\right) (T) + \beta_{13}^g \left(\ln M_{it}^g\right) (T) + \beta_{14}^g \left(\ln N_{it}^g\right) (T) - U_{it}^g + V_{it}^g \end{aligned} \tag{16}$$

where $U_{it}^{g} = \{\exp\left[-\eta\left(t-T\right)\right]\} U_i^g, i = 1, 2, \ldots N; t = 1, 2, \ldots, 10$.

Here, g denotes the group frontier, i represents the ith port, t is the time period, Y stands for the throughput, L is the length of the container berths, M refers to the terminal area, and N is the total volume in tons that can be handled by the equipment. V_{it}, are assumed to be iid $N(0, \sigma_v^2)$ random errors, independently distributed of the U_{it}. U_{it} is a technical inefficiency variable, which is assumed to be truncated at zero of $N(\mu, \sigma^2)$ and a non-negative random variable. β, η, μ, and σ^2 are parameters to be estimated.

4. Results

Table 2 shows the results of applying the stochastic frontier production function proposed by Battese and Coelli (1995) to estimate the parameters. Based on the stochastic production model of all the ports of APEC countries, within the estimated values of the 14 parameters in Equation (15), the estimated value of the nine parameters was significant at α = 10%. Thus, the estimate can be accepted. A likelihood ratio test (LR test) was adopted to investigate whether there were significant differences between the production technologies of the DCs and LDCs. The calculation method of the LR test was $\lambda = -2[\ln[L(\text{H0})] - \ln[L(\text{H1})]]$. Here, $\ln[L(\text{H0})]$ was the estimated value of the likelihood function of all the ports, whereas $\ln[L(\text{H1})]$ was the total likelihood function value of the DC and LDC groups. The results had a significance level of 5%, indicating that significant technological differences exist between DCs and LDCs, and metafrontier data are needed for subsequent analyses of efficiency and productivity because the metafrontier distance function method is a better option for analysis. There was heterogeneity in the management and operational capacity among the ports in the APEC region. This result conforms to the concept proposed by Tovar and Rodríguez-Déniz [20].

4.1. Model of Productivity Analysis

The dynamics and composition of the gMMPI are shown in Table 3, with the mean of each indicator presented in a two-year interval. During the study period of 2002–2011, the mean of gMMPI of all APEC economies was 0.6570, which means that the average annual capacity utilization of the container ports of APEC economies was 65.7%; thus, an additional 34.3% of the throughput can be handled by these ports within the context of the same factor input. This result is slightly higher than the results for Trujillo and Tovar [49], who found that the average capacity utilization of European ports was 60%. Tovar and Wall [15] also suggested the over-investment to be replaced by the maximization of current capacity utilization. The gMMPI decreased by 6% during the period 2003–2004 due to the influence of the decline in SEC and PTRC values. The value of PTCU increased in the same period, suggesting that the speed of enhancement of potential technologies was higher than that of existing technologies. During 2004–2006, gMMPI seemed to have rebounded slightly, mainly due to the sharp recoil of SEC, and because the factor inputs had almost reached the optimal size. During the period 2007–2009, productivity continued to increase, mainly because the model had reached the optimum size (SEC > 1). From 2009–2011, productivity was affected by PTCU, PTRC, TEC, and SEC, indicating a recession. PTCU was greater than 1 only during the 2003–2004 period, while SEC was greater than 1 during 2007–2009. The remaining three indicators were all less than 1 during all the periods, indicating a potential for an improvement in APEC policies.

Table 2. Estimates for parameters of the stochastic frontier model.

	DCs			**LDCs**			**APEC**			**Metafrontier**
Constant	16.170	***	(1.449)	14.895	***	(1.162)	17.470	***	(0.967)	12.965
L	−0.076		(0.602)	−0.510		(0.596)	−0.365		(0.457)	−0.063
M	−0.171		(0.675)	−0.849		(0.703)	0.910	**	(0.375)	0.652
N	−0.265		(0.645)	0.662		(0.703)	−1.410	***	(0.458)	−0.776
$(\ln L)^2$	0.588	***	(0.176)	0.158		(0.122)	0.065		(0.095)	0.168
$(\ln M)^2$	0.130		(0.118)	−0.388		(0.248)	0.025		(0.081)	−0.046
$(\ln N)^2$	0.602	***	(0.124)	−0.029		(0.162)	0.258	***	(0.083)	0.221
$(\ln L)(\ln M)$	−0.067		(0.079)	0.122		(0.106)	−0.002		(0.065)	−0.004
$(\ln L)(\ln N)$	−0.532	***	(0.142)	−0.143		(0.094)	0.030		(0.065)	−0.093
$(\ln M)(\ln N)$	0.007		(0.083)	0.217		(0.178)	−0.121	*	(0.069)	−0.008
t	0.136	*	(0.073)	1.029	***	(0.097)	0.880	***	(0.059)	0.673
t^2	−0.016	***	(0.003)	−0.010	*	(0.006)	−0.009	**	(0.003)	0.022
$(\ln L)t$	0.015		(0.012)	−0.049	***	(0.015)	−0.053	***	(0.009)	−0.103
$(\ln M)t$	−0.006		(0.008)	0.004		(0.018)	−0.002		(0.008)	0.017
$(\ln N)t$	−0.016	*	(0.009)	−0.040	**	(0.016)	−0.029	***	(0.009)	−0.003
σ^2	0.340	***	(0.043)	2.13	***	(0.480)	0.956	***	(0.075)	
γ	0.955	***	(0.010)	0.975	***	0.007	0.954	***	(0.007)	
μ	1.139	**	(0.163)	2.882	***	(0.456)	1.910	***	(0.153)	
η	0.008		(0.006)	−0.068	***	(0.006)	−0.056	***	(0.006)	
Observations	280			260			540			
Log likelihood function	426.773			−60.819			−68.537			
Likelihood ratio test	868.982 ***									

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Figures in parentheses are standard errors.

The mean of gMMPI of DCs was 0.6695, higher than that of APEC, suggesting that the productivity of DCs is higher than that of LDCs. Apparently, the productivity frontier of DCs was closer to the metafrontier than that of LDCs, indicating that on average, DCs had a greater potential for better productivity than LDCs. Indicators that had a positive effect on productivity included TEC, SEC, and TC, while PTCU and PTRC seemed to have a negative impact. However, affected by the decline of PTCU, PTRC, and SEC, gMMPI showed a continuous decrease from 2002–2007. During 2007–2009, the values of TC, TEC, and SEC were greater than 1, causing an increase in gMMPI. During 2009–2011, influenced by PTCU, PTRC, and SEC, the rate of utilized capacity started to fall. TEC was greater than 1 during all study periods, TC was greater than 1 during 2007–2011, and SEC was greater than 1 during 2007–2009.

The mean of gMMPI of the ports in LDCs was 0.6436. PTCU and PTRC seemed to have positive impacts on productivity, while the impact of TC, TEC, and SEC appeared to be negative. From 2003–2006, the productivity maintained progress, mainly driven by the growth in TC and SEC. After a short decline, the gMMPI started to rise during 2007–2009 due to the increase in the mean of TC and SEC. Similar to DCs, port productivity started to decline in 2009. A possible explanation may be that when influenced by the subprime mortgage crisis, the ports were unable to adjust their factor input in time, resulting in a substantial decline in the container throughput capacity. PTCU was greater than 1 right through 2002–2008, indicating the group frontier of LDCs is gradually moving closer to the metafrontier over time. This suggested that the increased speed of potential technologies was higher than that of the current technologies.

Table 3. Decomposition of the generalized metafrontier Malmquist productivity index (gMMPI): 2002–2011.

		PTCU	PTRC	TC	TEC	SEC	gMMPI
APEC	2002–2003	0.9912	1.0083	0.8071	0.9497	0.9698	0.7329
	2003–2004	1.0031	0.9871	0.8241	0.9460	0.8811	0.6710
	2004–2005	0.9689	0.9665	0.8421	0.9421	0.9632	0.6978
	2005–2006	0.9413	0.9452	0.8564	0.9379	0.9994	0.6914
	2006–2007	0.9392	0.9237	0.8710	0.9335	0.9142	0.6253
	2007–2008	0.9004	0.9021	0.8862	0.9289	1.0169	0.6611
	2008–2009	0.8832	0.8807	0.9000	0.9240	1.0539	0.6641
	2009–2010	0.8617	0.8607	0.9128	0.9189	0.9893	0.5970
	2010–2011	0.8564	0.8410	0.9272	0.9135	0.9673	0.5723
Average		0.9273	0.9239	0.8696	0.9327	0.9728	0.6570
DCs	2002–2003	0.8999	0.9065	0.9216	1.0122	1.0008	0.7649
	2003–2004	0.8925	0.8844	0.9377	1.0121	0.9529	0.7206
	2004–2005	0.8702	0.8651	0.9536	1.0120	0.9709	0.7055
	2005–2006	0.8364	0.8437	0.9692	1.0119	0.9913	0.6855
	2006–2007	0.8506	0.8223	0.9859	1.0118	0.8874	0.6145
	2007–2008	0.7970	0.8007	1.0036	1.0117	1.0451	0.6760
	2008–2009	0.7803	0.7784	1.0208	1.0116	1.0738	0.6735
	2009–2010	0.7630	0.7579	1.0381	1.0115	0.9817	0.5956
	2010–2011	0.7716	0.7383	1.0560	1.0114	0.9763	0.5896
Average		0.8291	0.8219	0.9874	1.0118	0.9867	0.6695
LDCs	2002–2003	1.0896	1.1180	0.6837	0.8824	0.9366	0.6984
	2003–2004	1.1223	1.0978	0.7018	0.8748	0.8038	0.6177
	2004–2005	1.0752	1.0758	0.7221	0.8667	0.9549	0.6896
	2005–2006	1.0544	1.0546	0.7348	0.8582	1.0081	0.6979
	2006–2007	1.0347	1.0329	0.7471	0.8492	0.9431	0.6370
	2007–2008	1.0117	1.0113	0.7597	0.8397	0.9866	0.6451
	2008–2009	0.9940	0.9908	0.7698	0.8297	1.0325	0.6540
	2009–2010	0.9679	0.9714	0.7777	0.8191	0.9976	0.5986
	2010–2011	0.9477	0.9516	0.7886	0.8079	0.9577	0.5537
Average		1.0330	1.0338	0.7428	0.8475	0.9579	0.6436

4.2. Trend

Figure 1 illustrates the trend of gMMPI and the five major sources of productivity changes during 2002–2011. It can be seen that the gMMPI of DCs was higher than that of LDCs during 2002–2005, suggesting a higher productivity of DCs than LDCs. However, during 2005–2007, the rate of utilized capacity of LDCs exceeded that of DCs. It was not until 2007 that the gMMPI of DC was higher than that of the LDCs. PTCU and PTRC showed a downward trend and fell below 1, indicating a weakening in the technological catch-up effect and technological development potential of DCs and LDCs. TC showed an upward trend; however, only that of DCs was greater than 1, suggesting its production function had moved upward. The TEC of DCs remained greater than 1, whereas that of LDCs continued to decline, representing that the throughput of DCs was closer to its potential output level. During the study period, the TC and TEC of DCs were greater than that of LDCs, while PTCU and PTRC of LDCs were greater than that of DCs. Moreover, DCs and LDCs were interchangeable in the leading position of the SEC.

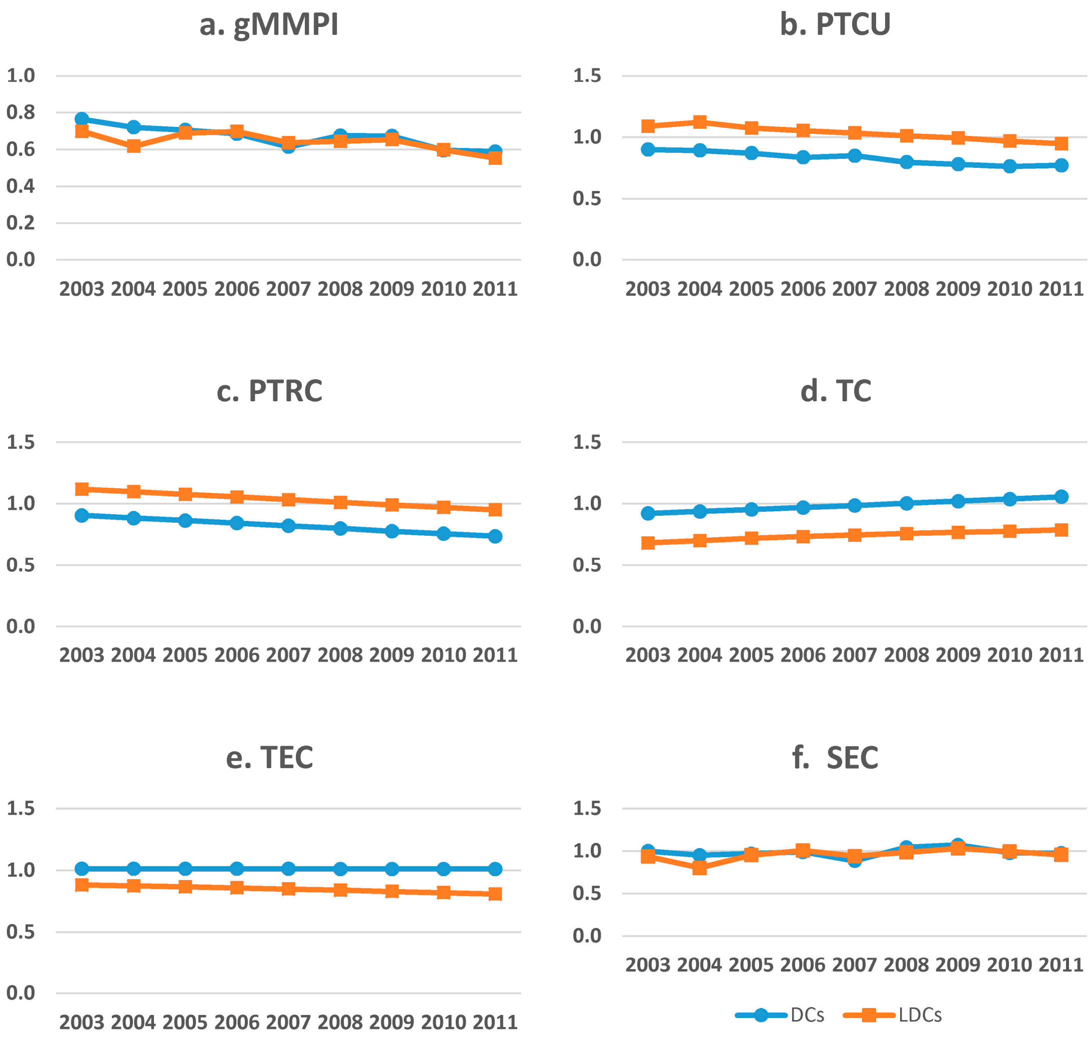

Figure 1. Trends for gMMPI and its compositions. (**a**) gMMPI; (**b**) PTCU; (**c**) PTRC; (**d**) TC; (**e**) TEC; (**f**) SEC.

4.3. Sources of Impact

Table 4 shows the relationship between the gMMPI of the APEC region and its five decompositions. First, productivity was obtained from SEC, which had the strongest impact on the overall productivity for APEC, DCs, and LDCs. Second, SEC, PTRC, and TEC were the main source of gMMPI growth of DCs. PTCU seemed to have a small positive impact, while TC had a negative impact. Third, in the LDCs group, SEC showed a significant, positive impact on the growth of productivity. PTRC, TEC, and PTCU were found to be statistically significant with regard to the changes in productivity, albeit on a much smaller scale. TC was found to have no effect. TC and TEC were found to have a negative correlation. A low level of technological progress seemed to co-exist with the changes in high technical efficiency, and vice versa [16,50]. This result concurs with Cheon, Dowall and Song [11] and Núñez-Sánchez and Coto-Millán [18], who suggested that the correlations between the frontier-shift effect and technical efficiency were negative. The main reason may be that a swift adjustment was not easy to apply to quasi-fixed inputs, making it difficult to select the optimal factor inputs alongside the given outputs [51].

Table 4. Relationship between gMMPI and its compositions.

Decomposition	APEC		DCs		LDCs	
	gMMPI		gMMPI		gMMPI	
PTCU	0.131	***	0.242	***	0.201	***
PTRC	0.206	***	0.634	***	0.236	***
TC	−0.005		−0.482	***	0.071	
TEC	0.287	***	0.612	***	0.292	***
SEC	0.840	***	0.715	***	0.871	***

Notes: *** $p < 0.01$.

5. Conclusions and Discussion

APEC has continued its effort to promote the integration of regional economies and connectivity of its supply chain. As a result, container ports, as the interface between the land and sea, have started to play an increasingly important role. LDCs tend to have a greater likelihood to benefit from regional integration through the increase of existing economic resources, or from access to new economic resources. However, in face of unprecedented, intensive competition and environmental flux, determining a method to improve a country's port productivity has become a major challenge to policymakers [52]. Discrete distance functions seemed to be a potentially useful tool for policy makers, allowing management with measurable indicators, and making it possible to improve productivity without increased investment [15]. Cullinane and Song [53] recommended an appropriate grouping of ports to be conducted before comparison to identify the source impact of efficiency and measures for improvement. Therefore, we grouped the countries in the APEC region into DCs and LDCs in our study and applied gMMPI to analyze productivity and its source of impact on the ports of DCs and LDCs within the APEC region. The results are summarized as follows.

First, different functional relationships were found between the inputs and outputs, suggesting a significant difference in the operational capability of the ports of the DCs and LDCs. Second, during the study period, the average productivity of container ports in DCs was found to be higher than that of LDCs, mainly due to TEC and SEC. However, in recent years, container port productivity of LDCs has started to gradually approach or exceed that of DCs. Third, in the composition of gMMPI, PTRC and PTCU of LDCs were greater than that of DCs; TC and TEC of DCs were greater than that of LDCs; and the SEC of the two groups led interchangeably. Fourth, there seemed to be a great difference in the source of port productivity between DCs and LDCs. DCs relied more on SEC, TEC, and PTRC, while LDCs relied more on SEC. Finally, SEC was found to play a dominant role in port productivity, on average.

5.1. Implications for Practice

SEC is an essential influential factor for port performance. This indicates that the adjustment of production inputs can be applied to improve the rate of capacity utilization. Both DCs and LDCs were found to show an increase in the returns to scale during 2008–2009; investment in new equipment could help container ports achieve optimal production scale. If all input factors were doubled, the proportion of increase in the throughput is likely to be more than double. However, since the global financial crisis, the returns to scale for both groups have decreased, and it is necessary to reduce the factor inputs commensurately. An effective adjustment in production scale is essential to the overall development strategy and resource allocation of a country's ports, which relies on the country's geographical location, factor endowment, industries, and competition of hinterland and regional ports. For example, when faced with competition from Singapore and Port Klang and Tanjung Pelepas of Malaysia adopted inter-regional flows as its strategy to adjust factor inputs, and became the fastest-growing port and transshipment center [54]. Compared to import/export ports, a transit port tends to have significantly better performance [55]. However, Malaysia has not proposed an effective integration policy for its national ports, such as Port Klang, Tanjung Pelepas, and Penang [56], leading to the situation wherein some of the increased market share of Tanjung Pelepas come from other Malaysian ports. This suggests that the ports in a nation should consider internal needs, industry development, and competitive rivalry when developing strategies to enhance service capability. With comprehensive planning in strategy, national level policy-makers may transform each port into either an exclusive port with segmentation or a port with dedicated functions. Supplemented with the improvement of peripheral facilities to serve certain industries, transshipment ports dedicated to certain industries may be formed. For example, Mexico ranks sixth among the world's car-producing nations and sixteenth among fishery producers [57,58]. Port Manzanillo may adjust its service and facilities depending on the demands of the automobile and fishery industries. The Philippines' electronics industry specializes in manufacturing assembly. With the use of the free trade zone's tax benefits, warehousing and storage, as well as highly efficient logistics, Port Manila may turn the Philippines into a regional center for semiconductor industry specializing in distribution/maintenance. In addition, all the ships based on size entering and exiting the port may be separated into different routes to reduce the lead time for adjusting the lifting equipment.

National level policy-makers could execute performance evaluation, positioning, strategies, and management practice of their ports and harbors by leveraging the advantages and disadvantages of multi-indicators. We noticed that the TC of DCs continued to grow; however, it seemed to have a negative relationship with gMMPI. This finding suggests that DCs have invested too much in new equipment, causing ineffective and inadequate utilization of the given production technologies. TEC stayed greater than 1, suggesting an improvement in efficiency. DCs can maintain their port efficiency through improvement of management and operating practices and diffusion of new technologies and knowledge [11,16]. However, their PTRC and PTCU seemed to be getting worse. The drop in PTRC indicates the distance between the stochastic frontier and the metafrontier has a tendency of expanding over time. The reduction in PTCU shows that the speed of enhancement of potential technologies is lower than that of the current technologies, indicating less possibility in technological development of DCs. It reaffirms the findings that TC and productivity maintain a negative relationship. This suggests that the DCs need to focus on the improvement of technical efficiency in terms of continuous innovation. Appropriate staff training may improve efficiency. For example, we can choose senior employees with outstanding business performance or colleagues with high working efficiency, and train them to be mentors. The mentors may coach new employees to enhance their overall performance. Second, we can also encourage staff to learn multiple skills in order to increase the flexibility of human resource deployment.

Although the TC of LDCs continues to rise, TEC showed a downward trend. However, according to Table 4, the main source of productivity is the improvement of technical efficiency, rather than technological progress. Diffusion of new technological knowledge, maximization of output, learning by doing, reform of port labor, and port optimization can be adopted to improve TEC [11,16]. TC is determined by the adoption of new technologies or innovations such as new cargo lifting equipment and computer management systems [59]. Even though both PTRC and PTCU showed downward trends, their values remained close to 1. This result suggests an expansion in the potential technological development of the port, as well as space for improvement, giving signs of the catch-up effect. This indicates that LDCs have a better ability to cope with changes in the economic environment. Ports in the DCs are rather labor-intensive. The management of these ports may be more flexible, which means that they can be more responsive, e.g., last-minute adaptation of services. Further, such ports can provide cargo consolidation services, classifying and repackaging the cargoes from adjacent countries for shipping worldwide.

5.2. Implications for Theory

In most of the existing literature on port performance, samples were first put into a single pooled data set [9,12,13], and then compared and analyzed in groups [11,24,60]. DCs such as Singapore, Hong Kong, and Taiwan in Asia; the United States and Canada in America; and Denmark, Finland and Germany in Europe are often seen as the benchmarks, indicating that as long as port equipment is designed based on the actual needs of the cargo, it is able to achieve outstanding operational efficiency [8]. Our study discovered significantly different input–output functions faced by DCs and LDCs. Investment in land, equipment, and labor is certainly important. However, transferring input into an output of port management capabilities and combining it with good overall planning are important sources of impact to achieving outstanding performance. Thus, we propose the metafrontier distance function as a more suitable analysis tool. This is similar to the classification concept of Tovar and Rodríguez-Déniz [20], who argued that heterogeneity exists in operational-setting-based operations as well as geography-based or port-based operations. Further, gMMPI and its compositions, TC, TEC, PTCU, PTRC, and SEC, were used to analyze country logistics productivity within a region. These indicators can help research to capture the implications of productivity regionally.

5.3. Limitations and Future Research Direction

The time window of the data we analyzed is a 10-year period. A further test of the robustness of the results might be possible using a larger span of data. It will be interesting to see if the relationships we observed hold across other time periods as well. A limitation is that this study only focuses on APEC. Future research may include EU members, as APEC members are different from the EU countries in terms of being able to voluntarily implement common policies and achieve the goal at their own pace. The metafrontier method can be used to explore how the regional integration of policies influences container port productivity. In comparison with regional competition and a turbulent environment, importance has not been attached to the non-intended factors of inefficiency that can affect port performance. These factors include the trade openness index, industrial value addition, and capita per worker. Future studies can further develop multi-input and -output models for emissions and throughput, based on this study.

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Abbreviations

The following abbreviations are used in this manuscript:

APEC	Asia-Pacific Economic Cooperation
DCs	Developed countries
DEA	Data envelopment analysis,
gMMPI	generalized metafrontier Malmquist productivity index
LDCs	Developing countries
PTCU	Pure technological catch-up
PTRC	Potential technological relative change
SEC	Scale efficiency change
SFA	Stochastic frontier analysis
TC	Technical change
TEC	Technical efficiency change
TFP	Total factor productivity
TGR	Technology gap ratio

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