Measurement of Digital Trade Efficiency in China and RCEP Countries: Based on the Super-Efficiency DEA-Malmquist Model

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Abstract: Against the backdrop of accelerating digital transformation of the international economic and trade landscape, Asia-Pacific digital trade under the framework of regional economic and trade agreements faces the dual challenges of differences in the level of digital economy development of member countries and synergistic efficiency improvement. This paper takes China and RCEP member countries as the research object, based on the panel data from 2015-2022, comprehensively uses the super-efficiency DEA model, Malmquist index method, and systematically analyses the digital trade efficiency in terms of static efficiency measurement and dynamic evolution trend. The study finds that: there are significant country differences in digital trade efficiency, institutional quality and technological endowment drive Singapore, Brunei and other developed economies to continue to lead, new infrastructure investment and industrial upgrading to promote the efficiency of China, Vietnam and other emerging markets to leap forward, Indonesia, Laos and other less developed countries subject to infrastructure gaps and institutional barriers lagging behind in efficiency; efficiency enhancement presents a double-wheeled technological progress-led and scale effects linkage, and the synergy between technology diffusion efficiency and market capacity constitutes a key growth pole, but external environment fluctuations and geo-economic shocks will significantly change the evolution path of efficiency through the technological conduction blockage, and the innovation of new trade modes has a strategic value to buffer the shocks.

Keywords: Digital Trade; Trade Efficiency; DEA Model; Malmquist Index

1. Introduction

Against the backdrop of accelerating digital transformation of the global economy, digital trade, as a key carrier of the digital economy, is reshaping the global economic and trade pattern at an unprecedented speed. This new trade model, which takes data resources as production factors, digital services as the core, and electronic processes as the characteristics, not only breaks through the time and space barriers of traditional trade, but also promotes the in-depth reconstruction of the global industrial chain supply chain by reducing the transaction costs and improving the circulation efficiency. Digital trade not only covers the cross-border circulation of digital products and services, but also includes the upgrading of traditional trade models through digital means.

It is noteworthy that the Asia-Pacific region has become the main position for the development of digital trade. UNCTAD's latest report shows that the Asia-Pacific region's digital services trade will grow at a rate of 12.4 per cent in 2023, driving the global market to exceed US$5.2 trillion, accounting for 63.5 per cent of total services trade. The Regional Comprehensive Economic Partnership Agreement (RCEP), which officially came into effect in 2022, covers ten ASEAN countries as well as China, Japan, South Korea, Australia and New Zealand, a total of 15 member countries, forming the world's largest free trade area. The RCEP agreement clearly proposes to strengthen cooperation in e-commerce, the digital economy and other areas, which provides institutional safeguards for the development of digital trade among member countries and policy support. As an important member of RCEP, China has actively promoted digital infrastructure construction, cross-border e-commerce development, and digital service exports in recent years, with the scale of digital trade imports and exports maintaining double-digit growth for three consecutive years, and cross-border e-commerce continuing to maintain a rapid growth rate of 9.8 per cent, demonstrating a strong resilience in digital trade. However, there are significant differences among RCEP member countries in terms of the level of development of the digital economy, technological foundation, policy environment, etc., and the efficiency of digital trade also shows a large imbalance as a result.

In this context, how to systematically measure the digital trade efficiency between China and RCEP member countries and deeply explore its influencing factors is of great value for promoting the integration of regional digital economy and enhancing the competitiveness of China's digital trade. This paper takes the measurement of digital trade efficiency as the core, and systematically analyses the digital trade efficiency in China and RCEP member countries from both static and dynamic dimensions with the help of the super-efficient DEA-Malmquist index. This not only expands the existing research perspectives on digital economy and international trade efficiency, but also provides a scientific methodological path for the quantitative assessment of digital trade efficiency. By measuring and comparing digital trade efficiency, it helps to identify China's relative advantages and shortcomings in regional cooperation, which in turn provides a quantitative basis for optimizing digital trade development strategies and enhancing international competitiveness. At the same time, this paper can also provide reference for RCEP member countries to formulate differentiated digital trade policies and promote the coordinated development of the digital economy in the region.

The subsequent chapters of this paper are arranged as follows: Chapter 2 reviews relevant studies on digital trade, trade efficiency, research methodology, etc.; Chapter 3 introduces the theoretical basis and model construction of the adopted DEA and Malmquist index; Chapter 4 constructs the input-output index system for measuring digital trade efficiency, and introduces the data sources Chapter 5 measures and compares the digital trade efficiency of China and RCEP countries, explains the efficiency differences and their causes; Chapter 6 summarizes the research findings and puts forward countermeasures and suggestions to enhance China's digital trade efficiency.

2. Literature Review

2.1 Literature Review of Digital Trade Research

In recent years, with the accelerated evolution of digital technology and the deep adjustment of the global economic structure, digital trade, as a new type of business that integrates information and communication technology and international trade, has increasingly become a key force in promoting the reconstruction of the global value chain and the high-quality development of the economy. Ma et al. [1] find that digital trade promotes the leap of new quality productivity through the innovation of platform, system and economic and trade rules, especially playing an important role in improving the quality of workers and optimizing the allocation of labour resources and factors. Li et al. [2] find that the level of digital trade significantly contributes to the growth of high-quality economic development, and Internet penetration plays a key role in regulating it. In addition, digital trade also profoundly affects the green development path of enterprises. With a quasi-natural experiment in a cross-border e-commerce pilot zone, Chen and Wang [3] find that digital trade significantly improves firms' ESG performance, which is mainly achieved by promoting digital transformation and green innovation. In terms of international rules, Mei and Zhu [4] emphasize that, in the context of systemic openness, China should actively participate in international digital trade rulemaking, especially in the framework of the Belt and Road Initiative to deepen cooperation. In terms of regional cooperation, Chen [5] analyses the institutional innovation and implementation challenges of the China-ASEAN Free Trade Area (CAFTA) Version 3.0 digital trade rules, and suggests promoting the implementation of the rules through standard docking, institutional coordination and legislative improvement. At the same time, digital trade barriers have become an important constraint on the climb of the global value chain. Chen et al. [6] find that barriers significantly increase the costs of intermediate and final products, inhibiting the upgrading of the value chain of medium- and high-technology manufacturing and modern service industries. From the perspective of developing countries, the theoretical and empirical model constructed by Hou et al. [7] based on cross-country panel data shows that digital trade effectively promotes the upgrading of industrial structure by enhancing forward embeddedness and reducing backward dependence, and shows a significant threshold incremental effect. In general, the current academic research on digital trade has been systematically explored from policy promotion, rule evolution to environmental effects, structural upgrading and other dimensions.

2.2 Literature Review on Trade Efficiency Research

Against the background of deepening trade globalization and continuous promotion of regional cooperation mechanisms, trade efficiency, as an important indicator for measuring the quality and potential of foreign trade, has received extensive attention from the academic community. Studies have generally adopted the stochastic frontier gravity model (SFA) to assess the level of efficiency and the influence mechanism among different trade objects. Qian and Jin [8] empirically found, based on provincial data, that factor market distortions significantly reduce the efficiency of China's foreign trade, and that distortions in the capital and labour markets are the core constraints, and that optimizing factor allocation becomes the key to improving trade efficiency. Similarly, Zhu et al. [9] based on SFA model empirical evidence on digital service trade between China and RCEP countries show that the level of economic development and common language can enhance efficiency, while the digital trade restriction index and geographical distance form a significant resistance. In the context of 'Belt and Road' cooperation, Wang et al. [10] find that although the efficiency of trade between China and Belarus is gradually improving, there is still significant room for improvement due to factors such as geographic distance, its own population size and tariff policy. In the regional economic cooperation mechanism, Hu et al. [11] analyse based on the SFA model and conclude that the level of digital economy development of RCEP member countries has a significant pull effect on China's export trade efficiency, of which digital innovative development contributes the most; however, there is no cross-country system to measure the trade efficiency itself. Focusing on digital trade, Wang and Li [12] construct a model to measure the efficiency and potential of digital trade between China and 27 countries, and find that the overall efficiency is low but the potential is huge, and the level of the Internet and cultural affinity are the main driving factors; however, they did not focus on the RCEP region, and the model failed to reflect the trend of efficiency change dynamically. In the area of trade in services, Huo et al. [13] analyse the efficiency of China's trade in services with EU countries, and find that efforts should be made to promote the development of knowledge-intensive services, and to improve economic freedom and government effectiveness in order to promote efficiency. From a comprehensive point of view, the current trade efficiency research has carried out in-depth analysis in the regional, product type and institutional dimensions; the research mostly analyses the differences in trade efficiency from a static point of view, lacks the examination of the evolution path of efficiency, and the distinction between technological progress and scale efficiency is not clear enough, making it difficult to reveal the driving mechanism.

On this basis, this paper introduces the super-efficiency DEA-Malmquist model, which fills in the dynamic and systematic measurement of digital trade efficiency of RCEP member countries, deepens the empirical exploration of the mechanism of influencing factors of efficiency, and provides new perspectives and quantitative bases for promoting the regional digital economy cooperation and enhancing the competitiveness of China's digital trade.

3. Research Methods

3.1 Data Envelopment Analysis (DEA) Model

Data Envelopment Analysis (DEA) is a non-parametric efficiency evaluation method based on linear programming, applicable to complex systems with multiple inputs and multiple outputs. The relative efficiency values of each decision-making unit (DMU) are measured by constructing a production frontier. Compared with traditional parametric methods, DEA does not require a predefined form of the production function and is able to deal directly with nonlinear relationships among multidimensional variables, providing a high degree of objectivity and flexibility [14]. This study takes digital trade efficiency measurement as the core objective, and the input indicators cover digital infrastructure, human capital input, and policy environment input, and the output indicators include trade scale and digital trade quality. The BCC (Banker-Charnes-Cooper) model is adopted, allowing variable returns to scale (VRS), and technical efficiency (TE) is decomposed into pure technical efficiency (PTE) and scale efficiency (SE), i.e., TE = PTE × SE. The specific planning is as follows:

$$\min[\theta - \varepsilon(1^T S^- + 1^T S^+)]$$
$$\begin{cases} \sum_{j=1}^{n} X_j \lambda_j + S^- = \theta X_0 \\ \sum_{j=1}^{n} Y_j \lambda_j - S^+ = Y_0 \\ \lambda_j \geq 0, \sum_{j=1}^{n} \lambda_j = 1 \\ S^- \geq 0, S^+ \geq 0 \end{cases} \tag{1}$$

where theta is the efficiency value, is the weight coefficient, and and are the slack variables, denoting input redundancy and output deficiency, respectively.

3.2 Super-Efficient DEA Model

The traditional DEA model is unable to further distinguish the efficiency advantage for efficient DMUs with efficiency value of 1 on the frontier. For this reason, this paper introduces the super-efficiency DEA model proposed by Andersen and Petersen [15], which enables the ranking comparison of efficient units by excluding the evaluated DMUs from the reference set and reconstructing the production frontier so that the efficiency value of the efficient DMUs breaks through the upper limit of one. Its mathematical form is as follows:

$$\min[\theta - \varepsilon(1^T S^- + 1^T S^+)]$$
$$\begin{cases} \sum_{j=1,j\neq k}^{n} X_j \lambda_j + S^- = \theta X_k \\ \sum_{j=1,j\neq k}^{n} Y_j \lambda_j - S^+ = Y_k \\ \lambda_j \geq 0, \sum_{j=1}^{n} \lambda_j = 1 \\ S^- \geq 0, S^+ \geq 0 \end{cases} \tag{2}$$

A larger value of super-efficiency indicates a more significant efficiency advantage for DMUs, while the efficiency value of units that do not reach the frontier remains unchanged. The model is particularly applicable in the field of digital trade and can accurately identify efficiency benchmarks in RCEP member countries.

3.3 Malmquist Index Decomposition

In order to explore the dynamic evolution mechanism of digital trade efficiency in RCEP countries, this paper adopts the Malmquist productivity index proposed by Färe et al. [16] to measure the change of digital trade efficiency (TFP) based on panel data. The index decomposes TFP changes into technical efficiency change (effch) and technical progress rate (techch) through the ratio of distance function, and further effch can be subdivided into pure technical efficiency (pech) and scale efficiency (sech):

$$M_t^{t+1} = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} = \text{effch} \times \text{techch} \tag{3}$$

If M>1, it indicates an upward trend in efficiency; M=1 indicates stable efficiency; and M<1 reflects declining efficiency. This decomposition method can reveal the intrinsic motivation of digital trade efficiency improvement, such as technological innovation or scale optimization.

4. Indicator Construction

This study aims to assess the efficiency of digital trade between China and RCEP countries, which needs to take into account the dual objectives of scale expansion and quality upgrade. Therefore, based on transaction cost theory and endogenous growth theory, combined with the factor-driven and technology-penetrating characteristics of digital trade, the selected indicators can reflect traditional factor inputs (infrastructure, labour force) and capture the unique attributes of digitization (ICT product exports), which is in line with the needs of the heterogeneous development stages of RCEP countries for measurement.

Digital infrastructure: the degree of perfection of digital communication network directly determines the cost and efficiency of information interaction among trading entities. In this study, the number of fixed telephone subscriptions (per 100 people) and the number of fixed broadband subscriptions (per 100 people) are selected as quantitative indicators, the former measures the penetration of traditional communication channels, and the latter focuses on the coverage density of high-speed Internet, which together portray the 'breadth' and 'depth' of a country's digital infrastructure. The two together portray the 'breadth' and 'depth' of a country's digital infrastructure.

Human capital input: endogenous growth theory emphasizes that human capital accumulation drives technological progress through knowledge spillovers. This study adopts the total labour force as a proxy variable, which connotes not only the size of the labour force, but also implicitly the potential support of educational input and skill structure for digital trade.

Policy environment: Economic freedom and foreign direct investment (FDI) reflect institutional openness and market attractiveness. Research shows that economic freedom significantly promotes the openness and competitiveness of the digital trade ecosystem by lowering market entry barriers and transaction costs [17], while net FDI inflows promote digital business model innovation through technology transfer and localised cooperation among multinational corporations (MNCs).

Trade size and quality: The WTO's extended EBOPS 2010 classification, which defines the value of exports of digital services trade as the value of cross-border transactions covering new types of services such as cloud computing, digital finance, etc. [18], is a useful indicator to capture the process of 'scaling up' of digital trade. The ratio of high-tech exports and the ratio of ICT exports measure 'quality upgrading' from the perspective of technological value-added: the former focuses on knowledge-intensive manufactured goods such as aerospace and biomedicine, reflecting the country's ability to climb up the global value chain; the latter refers to communication equipment, semiconductors, and other digital technology carriers, and the increase in its ratio implies the transformation of trade structure into a technology-driven one. The specific evaluation indicator system is shown in Table 1.

Table 1. Evaluation Index System of Digital Trade Efficiency

	Primary indicators	Secondary indicators	Sources of data
Input indicators	Digital infrastructure	Fixed-line telephone subscriptions (per 100 persons)	World Bank
		Fixed broadband subscriptions (per 100 persons)	World Bank
	Human capital input	Total labour force	World Bank
	Policy environment	Degree of economic freedom	The Heritage Foundation
		Net inflow of FDI (current prices BOP)	World Bank
Output indicators	Trade scale	GDP per capita	World Bank
		Exports of digital services trade	UNcomtrade
	Quality of digital trade	Percentage of exports of finished goods from high-tech exports	World Bank
		Export of information and communication technology (ITC) products	World Bank

This study mainly uses the World Bank database as the core data source, but Myanmar was excluded from the sample due to the missing rate of more than 60% of the core indicators, so Myanmar is not included in this study. Compared with Feng's [19] six-dimensional system of 'scale of digital innovation skills', this study simplifies the indicator hierarchy and focuses on the data availability of RCEP countries. Unlike Wang [20], who focuses on the customs environment of 'Belt and Road' countries, this indicator emphasises the institutional impact of policy openness on digital trade. At the same time, the introduction of 'the proportion of ICT product exports' replaces the traditional e-commerce turnover indicator, which is more in line with the evolution of trade patterns driven by digital technology.

5. Empirical Analysis

5.1 Static Efficiency Analysis of RCEP Countries' Trade Based on DEA-BBC Model

This paper takes the data of RCEP countries from 2015 to 2022 as a sample, and uses the DEA-BBC model to measure the efficiency of digital trade using the DEA2.1 software, and the comprehensive efficiency (TE), pure technical efficiency (PTE), scale efficiency (SE) efficiency, and the average efficiency during the sample period are shown in Figure 1 and Table 2.

Table 2. Evaluation Results of Digital Trade Efficiency of RCEP Countries based on Standard DEA

Country	2015				2016			
	TE(CRS)	PTE(VRS)	SE	RTS	TE(CRS)	PTE(VRS)	SE	RTS
Australia	0.926	0.993	0.933	↑	0.824	0.950	0.867	↑
Korea	1.000	1.000	1.000	→	0.912	0.968	0.942	↑
Philippines	1.000	1.000	1.000	→	0.992	1.000	0.992	↓
Cambodia	1.000	1.000	1.000	→	0.894	1.000	0.894	↑
Laos	1.000	1.000	1.000	→	1.000	1.000	1.000	→
Malaysia	1.000	1.000	1.000	→	1.000	1.000	1.000	→
Japan	1.000	1.000	1.000	→	0.852	0.940	0.906	↑
Thailand	0.447	0.879	0.509	↑	0.617	0.911	0.677	↑
Brunei	1.000	1.000	1.000	→	1.000	1.000	1.000	→
Singapore	1.000	1.000	1.000	→	1.000	1.000	1.000	→
New Zealand	1.000	1.000	1.000	→	0.953	0.980	0.972	↑
Indonesia	0.328	0.865	0.380	↑	0.445	0.829	0.537	↑
Vietnam	0.572	0.858	0.667	↑	0.560	0.830	0.675	↑
China	0.757	0.942	0.803	↑	0.743	0.929	0.799	↑
Average	0.859	0.967	0.878	——	0.842	0.953	0.876	——
Country	2017				2018			
	TE(CRS)	PTE(VRS)	SE	RTS	TE(CRS)	PTE(VRS)	SE	RTS
Australia	0.870	0.974	0.893	↑	0.886	0.983	0.901	↑
Korea	0.886	0.930	0.953	↑	0.998	1.000	0.998	↓
Philippines	0.980	0.980	1.000	↓	0.962	0.971	0.991	↓
Cambodia	0.844	1.000	0.844	↑	0.976	1.000	0.976	↑
Laos	0.989	1.000	0.989	↓	1.000	1.000	1.000	→
Malaysia	0.979	0.979	0.999	↓	1.000	1.000	1.000	→
Japan	1.000	1.000	1.000	→	0.989	0.994	0.995	↑
Thailand	0.440	0.782	0.563	↑	0.416	0.801	0.519	↑
Brunei	1.000	1.000	1.000	→	0.963	0.973	0.990	↓
Singapore	1.000	1.000	1.000	→	1.000	1.000	1.000	→
New Zealand	0.978	0.998	0.980	↑	1.000	1.000	1.000	→
Indonesia	0.347	0.805	0.431	↑	0.504	0.815	0.618	↑
Vietnam	0.626	0.842	0.744	↑	0.670	0.890	0.753	↑
China	0.772	0.932	0.829	↑	0.853	0.950	0.898	↑
Average	0.836	0.944	0.873	——	0.873	0.955	0.903	——
Country	2019				2020			
	TE(CRS)	PTE(VRS)	SE	RTS	TE(CRS)	PTE(VRS)	SE	RTS
Australia	0.922	0.986	0.935	↑	1.000	1.000	1.000	→
Korea	0.962	0.974	0.987	↑	1.000	1.000	1.000	→
Philippines	1.000	1.000	1.000	→	1.000	1.000	1.000	→
Cambodia	1.000	1.000	1.000	→	1.000	1.000	1.000	→
Laos	0.670	0.822	0.815	↑	0.596	0.793	0.752	↑
Malaysia	0.959	0.967	0.992	↑	1.000	1.000	1.000	→
Japan	0.960	0.995	0.965	↑	0.881	0.962	0.915	↑
Thailand	0.601	0.843	0.713	↑	1.000	1.000	1.000	→
Brunei	0.945	0.973	0.971	↑	0.780	0.962	0.811	↑
Singapore	0.933	0.946	0.987	↑	1.000	1.000	1.000	→
New Zealand	0.970	0.981	0.988	↓	0.925	0.975	0.948	↑
Indonesia	0.426	0.817	0.522	↑	0.399	0.803	0.497	↑
Vietnam	0.755	0.894	0.845	↑	0.871	0.928	0.938	↑
China	0.880	0.965	0.912	↑	0.916	0.973	0.941	↑
Average	0.856	0.940	0.902	——	0.883	0.957	0.915	——
Country	2021				2022			
	TE(CRS)	PTE(VRS)	SE	RTS	TE(CRS)	PTE(VRS)	SE	RTS
Australia	1.000	1.000	1.000	→	0.971	0.998	0.973	↑
Korea	0.994	0.999	0.995	↑	0.984	1.000	0.984	↑
Philippines	1.000	1.000	1.000	→	1.000	1.000	1.000	→

Cambodia	1.000	1.000	1.000	→	1.000	1.000	1.000	→
Laos	0.306	0.884	0.346	↑	0.343	0.959	0.357	↑
Malaysia	0.926	0.947	0.979	↑	1.000	1.000	1.000	→
Japan	1.000	1.000	1.000	→	0.954	1.000	0.954	↑
Thailand	0.515	0.841	0.613	↑	0.614	0.943	0.651	↑
Brunei	0.875	0.969	0.903	↑	1.000	1.000	1.000	→
Singapore	1.000	1.000	1.000	→	1.000	1.000	1.000	→
New Zealand	1.000	1.000	1.000	→	1.000	1.000	1.000	→
Indonesia	0.457	0.822	0.556	↑	0.545	0.833	0.654	↑
Vietnam	0.881	0.939	0.938	↑	1.000	1.000	1.000	→
China	1.000	1.000	1.000	→	1.000	1.000	1.000	→
Average	0.854	0.957	0.881	——	0.886	0.981	0.898	——

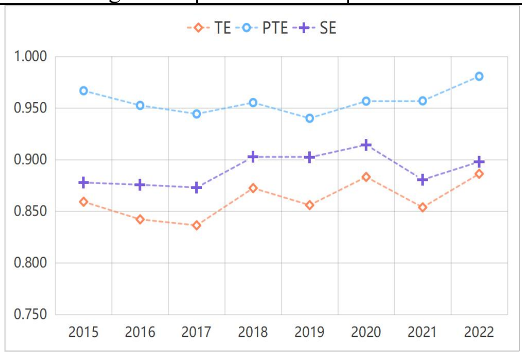

Figure 1. Average Digital Trade Efficiency of RCEP Countries, 2015-2022

The digital trade efficiency of RCEP countries measured based on the DEA model shows that technical efficiency (TE) and scale efficiency (SE) present significant country-specific differences and dynamic evolution characteristics. Horizontally, the average value of technical efficiency (TE) fluctuates and rises from 0.859 in 2015 to 0.886 in 2022, with an average annual growth rate of 0.4%, indicating the gradual optimization of the overall efficiency of digital trade under the RCEP framework. In stages, the accelerated growth rate after 2019 is closely related to the release of policy dividends such as tariff cuts and synergies in digital trade rules after the formal signing of the RCEP agreement. the efficiency of some countries briefly declines in late 2020 due to the global epidemic, but most countries resume growth after 2021, showing the restorative effect of policy adjustments on efficiency. Pure technical efficiency (PTE) as a whole remains high, with an average value of >0.94, and there are small fluctuations in some countries. The SE values of China and Vietnam continue to rise, reflecting that they have achieved marginal cost reductions by expanding the scale of their digital service exports, while Thailand's SE value has been below 0.7 for a long period of time, which is related to its high dependence on the traditional trade model and lagging behind in digital transformation.

From a country perspective, there is a clear differentiation in efficiency tiers. Singapore, Brunei and other economies belong to the efficient and stable type, the TE value is close to 1 for a long time, its advantage stems from the highly open market environment and perfect digital infrastructure (broadband subscription rate of more than 90/100 people), forming a 'system-technology' double-wheel drive mode. China and Vietnam belong to the type of catching up and upgrading, TE value jumped from 0.757 and 0.572 in 2015 to 1.000 in 2022, which is highly correlated with the landing of 'new infrastructure' policy during the 14th Five-Year Plan period and the FDI-led ICT industry upgrading in Vietnam. The upgrading of Vietnam's FDI-led ICT industry chain is highly correlated. Indonesia and Laos, on the other hand, belong to the inefficient volatility type, with TE values below 0.6 for a long period of time, and efficiency bottlenecks caused by weak infrastructure (Indonesia's fixed-line telephone subscription is only 8 per 100 people) and institutional barriers (Economic Freedom Index (EFI) <60).

The Rewards to Scale (RTS) state is dominated by increasing returns to scale, presenting the risk of localized decreasing returns to scale. About 67 per cent of the observations in the sample are 'Increasing RTS', suggesting that most countries are still in the period of rising returns to scale in digital trade, and that expanding factor inputs can further unlock efficiency potential. South Korea and Japan have multiple occurrences of 'Decreasing RTS' in 2020-2022, suggesting that the marginal returns of their digital infrastructure inputs are declining, and they need to shift to quality upgrading to break through the efficiency ceiling.

5.2 Static Efficiency Analysis of RCEP

Countries' Trade Based on Super-Efficient DEA Model

Although the standard DEA model can identify efficiency frontier surface countries, it cannot further distinguish the efficiency differences among effective decision-making units (DMUs). For this reason, the data of each indicator from 2015 to 2022 are substituted into MaxDEA6.6Pro software, and the digital trade efficiency of RCEP member countries is further measured by using the super-efficient DEA model, and the results are shown in Table 3.

Table 3. Evaluation Results of Digital Trade Efficiency in RCEP Countries Based in Super-Efficient DEA Model

Country	2015				2016			
	TE(CRS)	PTE(VRS)	SE	RTS	TE(CRS)	PTE(VRS)	SE	RTS
Australia	0.926	0.993	0.933	↑	0.824	0.950	0.867	↑
Korea	1.164	1.239	0.939	↓	0.912	0.968	0.942	↑
Philippines	1.346	1.378	0.976	↓	0.992	1.027	0.967	↓
Cambodia	1.060	1.306	0.811	↑	0.894	1.030	0.868	↑
Laos	1.752	3.072	0.570	↓	1.161	1.641	0.708	↓
Malaysia	1.064	1.067	0.997	↑	1.022	1.024	0.998	↓
Japan	1.727	2.871	0.602	↓	0.852	0.940	0.906	↑
Thailand	0.447	0.879	0.509	↑	0.617	0.911	0.677	↑
Brunei	1.226	1.627	0.754	↓	2.011	2.285	0.880	↓
Singapore	1.008	1.010	0.999	↑	1.064	1.103	0.964	↓
New Zealand	1.186	20.331	0.058	↓	0.953	0.980	0.972	↑
Indonesia	0.328	0.865	0.380	↑	0.445	0.829	0.537	↑
Vietnam	0.572	0.858	0.667	↑	0.560	0.830	0.675	↑
China	0.757	0.942	0.803	↑	0.743	0.929	0.799	↑
Average	1.040	2.746	0.714	——	0.932	1.103	0.840	——

Country	2017				2018			
	TE(CRS)	PTE(VRS)	SE	RTS	TE(CRS)	PTE(VRS)	SE	RTS
Australia	0.870	0.974	0.893	↑	0.886	0.983	0.901	↑
Korea	0.886	0.930	0.953	↑	0.998	1.003	0.995	↓
Philippines	0.980	0.980	1.000	↓	0.962	0.971	0.991	↓
Cambodia	0.844	1.077	0.783	↑	0.976	1.061	0.920	↑
Laos	0.989	1.818	0.544	↓	1.115	1.302	0.857	↓
Malaysia	0.979	0.979	0.999	↓	1.003	1.075	0.932	↓
Japan	1.011	1.077	0.938	↓	0.989	0.994	0.995	↑
Thailand	0.440	0.782	0.563	↑	0.416	0.801	0.519	↑
Brunei	1.520	17.338	0.088	↓	0.963	0.973	0.990	↓
Singapore	1.003	1.006	0.997	↑	1.058	1.093	0.968	↓
New Zealand	0.978	0.998	0.980	↑	1.004	1.004	1.000	↑
Indonesia	0.347	0.805	0.431	↑	0.504	0.815	0.618	↑
Vietnam	0.626	0.842	0.744	↑	0.670	0.890	0.753	↑
China	0.772	0.932	0.829	↑	0.853	0.950	0.898	↑
Average	0.875	2.181	0.767	——	0.885	0.994	0.881	——

Country	2019				2020			
	TE(CRS)	PTE(VRS)	SE	RTS	TE(CRS)	PTE(VRS)	SE	RTS
Australia	0.922	0.986	0.935	↑	1.029	1.092	0.942	↓
Korea	0.962	0.974	0.987	↑	1.102	1.534	0.718	↓
Philippines	1.018	1.075	0.947	↓	1.133	1.395	0.812	↓
Cambodia	1.205	1.230	0.980	↑	1.015	1.058	0.960	↑
Laos	0.670	0.822	0.815	↑	0.596	0.793	0.752	↑
Malaysia	0.959	0.967	0.992	↑	1.301	1.474	0.882	↓
Japan	0.960	0.995	0.965	↑	0.881	0.962	0.915	↑
Thailand	0.601	0.843	0.713	↑	2.519	2.523	0.998	↓
Brunei	0.945	0.973	0.971	↑	0.780	0.962	0.811	↑
Singapore	0.933	0.946	0.987	↑	1.195	1.396	0.856	↓
New Zealand	0.970	0.981	0.988	↓	0.925	0.975	0.948	↑
Indonesia	0.426	0.817	0.522	↑	0.399	0.803	0.497	↑
Vietnam	0.755	0.894	0.845	↑	0.871	0.928	0.938	↑
China	0.880	0.965	0.912	↑	0.916	0.973	0.941	↑
Average	0.872	0.962	0.897	——	1.047	1.205	0.855	——

Country	2021				2022			
	TE(CRS)	PTE(VRS)	SE	RTS	TE(CRS)	PTE(VRS)	SE	RTS
Australia	1.079	1.439	0.750	↓	0.971	0.998	0.973	↑
Korea	0.994	0.999	0.995	↑	0.984	1.047	0.940	↑
Philippines	1.005	1.019	0.986	↑	1.124	1.202	0.935	↓
Cambodia	1.215	1.233	0.985	↑	1.875	1.979	0.947	↓
Laos	0.306	0.884	0.346	↑	0.343	0.959	0.357	↑
Malaysia	0.926	0.947	0.979	↑	1.026	1.280	0.802	↓
Japan	1.094	1.401	0.780	↓	0.954	1.043	0.915	↑
Thailand	0.515	0.841	0.613	↑	0.614	0.943	0.651	↑
Brunei	0.875	0.969	0.903	↑	1.368	6.919	0.198	↓
Singapore	1.066	2.470	0.431	↓	1.111	1.035	1.073	↓
New Zealand	1.140	2.417	0.471	↓	1.180	1.185	0.996	↑
Indonesia	0.457	0.822	0.556	↑	0.545	0.833	0.654	↑
Vietnam	0.881	0.939	0.938	↑	1.209	1.301	0.929	↓
China	1.038	1.074	0.967	↓	1.504	1.835	0.820	↓
Average	0.899	1.247	0.764	——	1.058	1.611	0.799	——

In the standard DEA, countries such as Japan, Brunei and Singapore are judged to be fully efficient (TE=1), but the super-efficiency model shows that their efficiency values are significantly higher than 1. In the case of Japan, for example, its super-efficiency TE in 2015 was 1.727, and its PTE was as high as 2.871, suggesting that there is a significant redundancy in its technical efficiency. This redundancy stems from Japan's technological accumulation in the fields of artificial intelligence and industrial automation, which makes the marginal output per unit of input far exceed the industry average. Highly technologically efficient countries such as Japan therefore need to guard against efficiency decay due to lagging technological upgrades. Similarly, Brunei's 2015 super-efficiency TE=1.226, but its SE=0.754, reflecting the lack of scale efficiency, suggests that although its investment scale reaches the frontier surface, there is a structural imbalance in resource allocation. Therefore, countries with low SE such as Brunei and Singapore should optimize their investment structure, focusing on high value-added areas rather than blind expansion. The Philippines' 2015 super-efficiency TE=1.346 is significantly higher than the standard DEA of 1.0, indicating that the current level of output can still be maintained even if inputs are increased by 34.6%, a phenomenon that coincides with its stage characteristic of rapid expansion of digital infrastructure but lagging application efficiency. Therefore, countries with significant redundant resources, such as the Philippines and Cambodia, can integrate resources through RCEP digital trade rules, such as establishing cross-border data sharing platforms, to enhance the elasticity of resource allocation.

5.3 Dynamised Efficiency Analysis Based on Malmquist Index

On the basis of static efficiency analysis, in order to further explore the dynamic trend of digital trade efficiency between China and RCEP member countries, this paper adopts the Malmquist index method, by decomposing digital trade efficiency (tfpch) into technical progress rate (techch) and comprehensive technical efficiency (effch), and further decomposing comprehensive technical efficiency into pure technical efficiency (pech) and scale efficiency (sech) to comprehensively analyse the intrinsic drivers of efficiency changes. Table 4 shows the Malmquist index and decomposition results of digital trade efficiency between China and RCEP member countries in 2016-2022.

Table 4. Malmquist Index and Decomposition of Digital Trade Efficiency in RCEP Countries from 2016 to 2022

Country	tfpch	effch	techch	pech	sech
Australia	1.010	0.985	1.032	1.018	1.076
Cambodia	1.109	1.235	0.917	1.171	1.089
Japan	0.951	1.006	1.032	0.899	1.496
Singapore	1.021	1.102	0.934	1.446	0.882
Vietnam	1.119	1.116	1.012	1.081	1.034

Korea	0.983	1.001	0.989	0.930	1.194
Laos	0.824	0.911	1.232	0.754	1.118
Thailand	1.438	1.438	1.069	1.209	1.085
New Zealand	1.006	0.942	1.512	0.759	1.571
China	1.111	1.054	1.058	1.016	1.040
Philippines	0.983	0.931	1.066	0.908	1.280
Malaysia	1.011	1.059	0.960	1.061	1.009
Brunei	1.074	1.002	1.099	1.000	1.028
Indonesia	1.101	1.007	1.085	0.982	1.026
Average	1.053	1.056	1.071	1.017	1.138

In terms of digital trade efficiency (tfpch), RCEP members show significant heterogeneity. High-growth types (tfpch >1.10) include Thailand, China, Vietnam and Cambodia. The average annual growth of digital trade efficiency in these countries is more than 10%, mainly relying on the dual drive of technological progress and scale effect. Medium-low (1.00 ≤ tfpch ≤ 1.10) covers Australia, Malaysia, Brunei and Indonesia. The efficiency growth of these countries relies on a single factor, for example, Brunei's techch (1.099) is high but sech (1.028) is lagging behind, suggesting that its technological introduction has not been effectively translated into economies of scale. The efficiency decline type (tfpch <1.00) is represented by Japan (0.951), the Republic of Korea (0.983) and Laos (0.824). Japan's tfpch (0.899) slips severely despite a positive techchch (1.032), reflecting the failure of its digital management model to adapt to regional competition; Laos's effch (0.911) diverges from techch (1.232), indicating that technological inputs are not matched with localized demand.

Shown in Figure 2, China as a core player in digital trade within the RCEP framework, has a techch contribution of 47.6 per cent, significantly higher than the regional average. This is due to the implementation of the 'Digital China' strategy, the 2017 'New Generation Artificial Intelligence Development Plan' to promote the popularity of 5G and big data technologies, and the digital payment coverage rate exceeding 85% by 2020, reducing cross-border transaction costs. techch (1.040) grew at an average annual rate of 4.0%, higher than that of Vietnam (1.034) and Thailand (1.085). Thailand (1.085). Platforms such as Alibaba International Station and Pinduoduo TEMU are expanding the RCEP market, increasing the penetration rate of e-commerce in ASEAN to 32% by 2022, and accelerating the release of the scale effect. pech (1.016) indicates the improvement of management capacity, such as the digital reform of the General Administration of Customs' "Single Window", which has compressed the time limit for customs clearance to 1.8 hours, a 60% increase compared with 2016. 60% higher than in 2016. From the time dimension, China's efficiency evolution has been characterized by phased fluctuations (see chart). 2016-2017 was a period of rapid growth, with the tfpch jumping from 1.134 to 1.449, an increase of 27.7%, hitting a historical peak. techchch (1.044 to 1.426) contributed as much as 98.4%, benefiting from the 'Internet Plus' initiative, which has been a key driver of China's efficiency development. The deepening of the 'Internet Plus' strategy, the 2016 '13th Five-Year Plan for the Development of E-commerce' to promote cross-border e-commerce comprehensive pilot zones to expand to 13, Ali Cloud international version of the online accelerated technology output. techchch plummeted to 0.923 in 2018, reflecting a record peak in the U.S.-China trade. 0.923, reflecting the U.S.-China trade friction led to technology cooperation blocked, Huawei and other enterprises encountered supply chain restrictions; 2019 effch (1.025) and techch (1.014) synergistically repaired, thanks to the introduction of the 'Outline of the Strategy for the Development of the Digital Economy' and the acceleration of the RCEP negotiations. 2020 tfpch reached 1.104 (techchch=0.983 and effch=1.123) in 2021-2022, stabilising in the 1.03-1.04 range. sech (1.212) in 2020 is significantly higher due to the popularity of the 'no-touch trade' model, the General Administration of Customs' In 2020, sech (1.212) will increase significantly, owing to the popularity of the 'no-touch trade' model and the General Administration of Customs' "two-step declaration" reform, which will compress customs clearance time by 30 per cent.

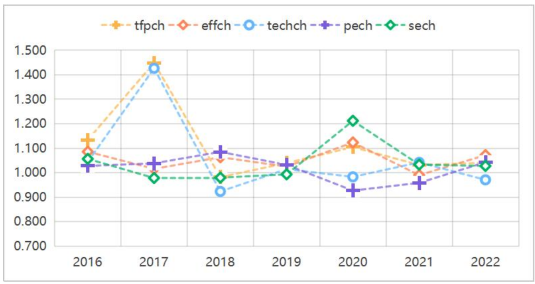

Figure 2. Decomposition of Time Series Data of China's Digital Trade Malmquist Index from 2016 to 2022

6. Conclusion and Recommendation

This paper measures the digital trade efficiency between China and the RCEP member countries by combining the standard efficiency DEA model and the super-efficiency DEA, and uses the Malmquist index method to deeply analyse the dynamic trend of the efficiency, and draws the following conclusions:

Among the RCEP member countries, Singapore, Brunei and other economies have maintained high efficiency for a long time by virtue of perfect digital infrastructure and open institutional environment; China and Vietnam have achieved efficiency leap through 'new infrastructure' policy and industrial chain upgrading, and the TE value will reach 1.000 in 2022; Indonesia, Laos and other countries are constrained by weak infrastructure and institutional barriers, and their efficiency has been below 0.6 for a long time, which has become the short board of regional synergistic development.

Malmquist index decomposition shows that the improvement of digital trade efficiency (tfpch) relies on the rate of technological progress (techch) and scale efficiency (sech). China's techch grew at an average annual rate of 1.058%, with a contribution rate of 47.6%, and the application of technologies such as 5G and artificial intelligence significantly reduced trade costs; Thailand and Vietnam achieved sech improvement through cross-border e-commerce scale expansion, but Japan and South Korea need to shift to quality-driven due to the risk of diminishing returns to scale.

The dynamic evolution of efficiency is significantly affected by policies and external shocks. China's efficiency presents 'technology-driven - policy repair - management complementary' stage characteristics: 2016-2017 technology dividend release to promote the tfpch peak of 1.449; in 2018, the U.S.-China trade friction led to techchch decline to 0.449. The friction between China and the United States in 2018 led to a decline in techch to 0.923; in 2020, the 'no-touch trade' model against the trend to improve sech to 1.212, highlighting the resilience of digital management.

After the entry into force of the RCEP agreement, tariff cuts and mutual recognition of digital rules will promote the efficiency repair of most countries in 2021-2022, but the technological gap and market fragmentation still constrain the overall efficiency improvement.

Based on the above conclusions, this paper puts forward the following recommendations:

1. Deepen autonomous technological innovation to break through efficiency growth bottlenecks. Increase R&D investment in core technologies such as artificial intelligence and blockchain, and establish a 'technology early warning-policy response' mechanism to reduce external supply chain risks. Promote technical cooperation within the framework of RCEP, and jointly build cross-border data centers and digital technology transfer platforms to narrow the technological gap between member countries.

2. Optimize digital infrastructure and unleash the potential of economies of scale. Focus on supporting broadband network coverage and ICT equipment penetration in inefficient countries such as Laos and Cambodia, where the number of fixed-line phone subscriptions is less than 10 per 100 people according to World Bank data, and which need targeted assistance through the 'Digital Silk Road' special fund. Meanwhile, cross-border e-commerce platforms are encouraged to expand into the Southeast Asian market and explore differentiated overseas strategies, so as to avoid diminishing returns on scale due to homogeneous competition.

3. Strengthening institutional openness and enhancing management efficiency. Promote China's 'Single Window' digital customs clearance model to compress trade process timeliness; promote the implementation of RCEP digital provisions, establish a 'negative

list' mechanism for cross-border data flow, and reduce systemic transaction costs. For countries with diminishing returns to scale such as Japan and South Korea, we will guide them to shift from 'scale expansion' to 'value-added services', such as the development of digital finance, intellectual property rights trading and other high-value-added businesses.

4. Improve the regional coordination mechanism to solve the problem of efficiency imbalance. Establish an RCEP digital trade efficiency monitoring platform, and regularly release national techch and sech indices to provide data support for policy adjustment. Set up a pilot 'digital FTA' to explore the docking of rules between ASEAN and China's eastern coastal provinces, so as to enhance the overall efficiency level through technology sharing and resource integration.

Through the above measures, China can further play a pivotal role in the RCEP digital trade network, promote the balanced development of regional efficiency, and achieve high-quality sustainable growth.

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