

Potential Green Gains From the Integration of Economies: Evidence From Mainland, Hong Kong, Macao, and Taiwan in China

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ABSTRACT

The integration of economies always attracts much attention from policymakers and researchers. This paper introduces a novel approach to evaluate potential economic and environmental gains from integrating economies. Based on aggregate production technology and directional distance functions, the authors regard all decision-making units as a whole, allowing free resource reallocation among units. The level of resource misallocation is identified by a structural measure, which is obtained by the difference between overall potential improvement and individual technical inefficiency. Taking China as an empirical example, possible economic output expansions are estimated at 43.2% and 10.1% under convex and nonconvex production technologies, respectively; potential pollution reductions are around 28.4% and 5.1% under convex and nonconvex production technologies, respectively. A significant disparity of structural inefficiencies is detected, indicating a high level of resource misallocation in China. Economic cooperation is vital to promote potential green gains for all provinces in China.

KEYWORDS

Aggregate Directional Distance Function, Aggregate Production Technology, Economic Integration, Structural Efficiency

1. INTRODUCTION

The development of the economy has always been the focus of all countries. The economy plays a vital role in human society, which can improve social welfare, promote democratic politics, enhance military strength, and increase international influence. There is no doubt that the economy is crucial and significant. Unfortunately, with the acceleration of industrialization

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and urbanization, the whole world is also under severe environmental pressure, such as global warming, soil degradation, and desertification.

As the largest developing country in the world, China has made great progress in its economy and environment after the implementation of Reform and Opening Up, with an average growth rate of 14.76% in green GDP in the past 14 years (Xiang, 2021). On the other hand, with the rapid development, China is also confronted with a common dilemma of how to maintain rapid economic growth and simultaneously reduce the pollution that has accompanied growth (Greaney, Li and Tu, 2017). Air pollution (Sun and Cheng, 2021), excessive emissions of industrial wastewater, waste gas, and solid waste (Cheng, Dai and Ye, 2016) are serious in China, and bring great damage to society, for example, air pollution may cause the loss of highly-educated talent (Lai et al., 2021). To address those problems, the Chinese government issued a series of policies. For increasing the utilization rate of sustainable resources, National Renewable Energy Long-Term Planning was passed in 2007. Over the next few years, the Airborne Pollution Action Plan was unveiled by the central government, aiming to reduce the air pollution in the northern region surrounding Beijing by 25%, and 20% in the Yangtze River Delta. The government proposed carbon peaks and carbon neutralization in 2020, which planned to achieve “zero-emission” and a “balance of payments” of carbon dioxide emissions.

Improving the quality of the environment is of great importance, while the growth of the economy cannot be ignored. How to achieve the advance of a sustainable economy has become a new topic to research. Ziolo et al. (2020) studied the relationship between energy efficiency, sustainable economic development, and greenhouse gas emission reduction in OECD countries. For analyzing the determining impact of green growth on economic development, Fernandes et al. (2021) was committed to examining the role of sustainable technical expertise and sustainable innovation in green growth. Wang et al. (2021) found that green industrial innovation and product innovation can effectively improve the economic performance of enterprises in China. Moreover, it is found that cooperation and integration can promote both economic and environmental progress. In the past few decades, due to the cross-regional flow of production factors and resource allocation, the degree of globalization has been dramatically deepened. With the exchange and integration of globalization, there have been various economic cooperation organizations, such as the EU, NAFTA, APEC, OECD, and ASEAN. Economic cooperation and integration can bring a lot of benefits to the participants. The regions that are involved in those organizations can gain profits from technological advances (Urban et al., 2015), economic increases (Parrenas, 1998), and environmental improvements (Yoo and Kim, 2016).

It is concluded that economic integration can be a great solution to the dilemma that China is facing. To investigate the economic and environmental benefits brought by the cooperation and integration in China, this study invents a novel model to measure the potential green gains. 34¹ regions are included in the sample. It is noted that due to the relatively small economic aggregates in Hong Kong and Macau, the two special administrative regions are regarded as one unit, and the whole of China is regarded as one unit. The economic and environmental potential under the collaboration among the mainland of China, Hong Kong, and Macao will be estimated. Taiwan is also taken into consideration, measuring whether Taiwan would benefit from the future deeper cooperation and integration with the mainland of China.

The rest of the paper is organized as follows. Section 2 clarifies the literature review. Section 3 explains the model presented in the paper. Section 4 analyzes the empirical data and results. The final section is the conclusion and policy implications.

2. LITERATURE REVIEW

There have been a lot of studies on regional cooperation, with different methods. One of the major methods is a parametric method, but it is found to be less accurate than the non-parametric method. Alborzi et al. (2008) suggested that there are often no significant parametric distributions, and the non-parametric model is more adaptable for specific projects. Tran and Kodera (2013) researched

the differences between the two methods and found that the non-parametric method can avoid inconsistency problems compared to the traditional parametric model. With the widespread use of the non-parametric method, Wang and Zhang (2017) analyzed the influencing factors of cooperation in China. Formanek and Husek (2018) evaluated the importance of cross-border cooperation by Getis-type economic framework.

Traditionally, most studies focus on the economic benefits brought by cooperation. Bobocka (1994) analyzed the influence of economic potential and effectiveness by examining the participation of the Czech Republic, the Polish Republic, and the Hungarian Republic in the process of integration in Europe. Laporte (1998) researched the economic cooperation in West Africa and found that practical regional cooperation is an essential factor in promoting trade between developing countries. Kim (2002) studied the relations between regional integration and the Korean peninsula, showing that they would benefit from their cooperation. Ahn and Cheong (2007) discussed the need for closer cooperation from the perspective of finance and trade. Zhai (2018) researched the macroeconomic impact on China's BRI, which could bring considerable benefits to the world economy in terms of welfare and trade. Similarly, Mahmood and Mostafa (2018) measured the prospect of economic cooperation between BRICS countries and its possible impact on economic growth and development, suggesting that Kazakhstan should further develop its relationship with BRICS countries to promote financial needs. Campos, Coricelli and Moretti (2019) estimated that without European integration, the per capita income of countries joining the EU would decline by about 10% in the first ten years after joining the EU. Cui and Song (2019) also studied the impacts of BRI on the world economy and international trade, implying the significant economic potential for cooperation.

With the great concern of the development of the sustainable economy, some studies also concentrated on the green economic gain from regional cooperation. Ivanova and Angeles (2006) argued regional economic integration must be complemented by creating regional frameworks for ecological management, and they also advised trade and environmental policy could reinforce each other. Zhang (2008) found that Asia's economic progress brought unprecedented environmental results, suggesting that Asia should implement the right policy, which includes national, local, and regional cooperation to increase its environmental quality. Pjerotić (2008) regarded trade liberalization as the most important factor of sustainable economic growth in the regional cooperation of SEE countries. Lubell, Hillis and Hoffman (2011) discussed the impact of collaboration on the resilience, and sustainability of many different social-ecological systems. Ruggiero et al. (2015) analyzed the level of collaboration between EU countries and EU policies in energy, which was based on sustainable development; they concluded that the EU should focus on energy cooperation. Gu, Renwick and Xue (2018) recognized that the cooperation within the BRICS group of countries could promote green economic growth in Africa. Paroussos et al. (2019) researched international climate collaboration. They found that critical benefits of the club structure are enhanced technological diffusion and the provision of low-cost climate finance, which can reduce the cost of developing countries' energy transition. Khan et al. (2020) discussed the positive effect of green economic growth and environmental sustainability in SAARC member states. Li, Gong and Choi (2021) found that trade cooperation between Korea and China plays an essential role in their technological progress, which has a significant promotion effect on China's green total factor productivity. Kalantaripor and Najafi (2021) found regional cooperation can improve green production, by using the spatial panel data econometric approach.

However, there are still some problems with regional cooperation. It is challenging to coordinate the interests of all regions. Comprehensive cooperation is hard to implement. Liberatore (1991) studied that due to the characteristic of the single European Market project, the EC environmental policies have been weak in formulation and implementation. Iredale (1999) discussed the problems occurring in regional cooperation, such as the "brain waste" or "wasted skills" occurring. Narine (1999) criticized the attempts of ASEAN at its institutional expansion because of the lack of political, economic, and military resources. Ulachovic (2004) checked the advantages and disadvantages of the cooperation between Belarus and the EU and found Belarus is unlikely to get any resources

spared from the EU, which is preoccupied with itself. Dent (2007) researched the idea submitted by APEC and recognized there are still a lot of obstacles to realizing an FTAAP, such as the fragile multilateral trading system. Cressati, Pascolini and Spizzo (2010) examined the European grouping of territorial cooperation and discussed the transformation of one of its communities with a loose structure created in a very different socio-economic context. Medrano (2012) summarized the main findings and analytical contributions of the EU and claimed that most states and their citizens in European Integration are reluctant to further transfers of competencies and sovereignty which makes the diversity of visions on European integration matter. Peritz (2018) showed that domestic politics obstructed the policy enforcement on deepening economic integration and highlighted the completion of the single market could be an obstacle. Hjaltadóttir, Makkonen and Mitze (2020) assessed the differences in the regions' engagement in inter-regional innovation cooperation, and they pointed out that in terms of the intensity of innovation cooperation, border regions are usually at a disadvantage compared with non-border areas.

Yet, there are few studies focusing on the economic cooperation between Taiwan and the mainland of China. Kao (1993) discussed the problems of economic relations between Taiwan and the mainland of China and proposed the prospects for future development. It is found that with the development of non-governmental contacts and exchanges, the trade between Taiwan and the mainland is expected to grow faster. Guo et al. (2006) illustrated the features of tourism flow, politics, economics, and trade between the mainland of China and Taiwan. They found the relationships between the mainland of China and Taiwan are unbalanced, existing some obstacles to tourism cooperation between the two sides, including transportation, politics, and culture. Hong and Yang (2011) opposed the agreement that Taiwan signed with China from a political perspective, though Taiwan could benefit from cooperation. Pan and Huang (2020) examined the passenger-cargo relationship and its socio-economic performance between Taiwan and the mainland of China direct flights. They proposed the essential factors affecting the direct cross-strait transportation, which are the nominal GDP and the growth rate of Taiwan and the mainland of China. In conclusion, a non-parametric model can be used to estimate the economic and environmental benefits brought by the regional cooperation. However, there is little research which is estimated by non-parametric methods on the potential benefit of the deeper integration among Hong Kong, Macau, Taiwan, and the mainland of China.

Therefore, this paper will use two non-parametric methods, Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH), to evaluate the potential gains under the integration of economies in China. DEA was proposed by Charnes and Cooper (1978) and is a common model to estimate the efficiency of production in many dimensions. Yunos and Hawdon (1997) proposed a DEA model to compare the performance of Malaysia's National Electricity Board with those of other countries in a similar stage of development, as well as with that of the UK. Tan and Hooy (2007) examined the knowledge-based development of nine countries between developed and emerging economies and evaluated their performances by DEA. Ding, Zheng and Kang (2017) developed a three-stage DEA to improve the efficiency assessment of the ocean economy. In this paper, we apply a non-parametric model proposed by Baležentis et al. (2020), which ensures a link between the production and the pollution-generating sub-technologies. There are also some studies concerning FDH. Huang and Wang (2002) compared the differences in economic efficiency and economies of scale in Taiwanese commercial banks, using both the FDH model and parametric method. Balaguer-Coll, Prior and Tortosa-Ausina (2007) found the outcomes of using DEA and FDH are both robust when researching the efficiency of local governments in Spain. Besir and Aldea (2019) built the FDH model to reveal the effect of extreme values on efficiency estimates.

There are three main contributions of this paper: the first contribution is that this paper will rich and expand the early studies, choosing the 34 regions as the sample. The research on the benefits of integration will be furthered greatly. Another contribution is that we use two different technologies to measure their efficiency: DEA and FDH, which increase the confidence of our outcomes. Lastly, as far as we know, this paper is the first study to analyze the economic and environmental potential

of reallocating resources, under the condition that Taiwan establishes closer relationships with the Mainland of China. Based on the assumption of economic cooperation and integration (Boussemart, Leleu and Shen, 2015; Shen et al., 2018), a novel model of measuring potential economic and environmental gains is proposed under both DEA (convex technology) and FDH (nonconvex technology) models.

3. METHODOLOGY

3.1 Production Technology and Distance Functions

This paper proposes a novel approach to evaluate production gains under the integration or disintegration of economies. Taking China as an example, each province or municipality can be regarded as a decision-making unit (DMU). There has been a total of 34 DMUs contained. One can estimate the production gains if all or a part of DMUs are participating in the economic integration.

Following Koopmans (1951), Debreu (1951), and Shephard (1953), the production technology of China can be modeled by the production set. As suggested by Murty et al. (2012), the national production set includes inputs and outputs within a by-production approach. Leleu (2009) proposed a framework, which mixed DEA and FDH models together. Valadkhani, Roshdi and Smyth (2016) have used DEA to measure the performance of CO_2 among different countries. This approach requires two types of inputs: clean and dirty inputs, namely, both can produce desirable outputs while undesirable outputs can be only generated by the latter one. Furthermore, this by-production technology can be separated into two sub-technologies: one is the traditional technology using all inputs to produce the desirable outputs (T_{Eco}); another is to represent the pollution-generating process, where the undesirable output is generated with the dirty inputs (T_{Env}). This production technology (T) can be defined as:

$$T = T_{Eco} \cap T_{Env} = \left\{ (K, L, E, GDP, CO_2) \in R_+^5 : (K, L, E) \text{ can produce } GDP; E \text{ can generate } CO_2 \right\}$$

$$T_{Eco} = \left\{ (K, L, E, GDP) \in R_+^4 \mid f(K, L, E, GDP) \leq 0 \right\}$$

$$T_{Env} = \left\{ (E, CO_2) \in R_+^2 \mid g(CO_2, E) \leq 0 \right\} \quad (1)$$

where T_{Eco} represents the first sub-technology to measure economic efficiency, using capital stock (K), labor force (L), and energy consumption (E) as inputs to produce the desirable output, GDP. T_{Env} denotes the second sub-technology to evaluate the environmental performance, the undesirable output, carbon emissions (CO_2) can be only generated by the dirty input, energy consumption (E). In addition, the free disposability is generally assumed in T_{Eco} for all inputs and good outputs, while the costly disposability is imposed on T_{Env} for the dirty input and bad output.

Besides, some general economic assumptions are introduced into the production technology, for instance, variable-return-to-scale (VRS), convexity, etc. We relax the convexity assumption. Both convex and nonconvex production technologies are applied in the empirical analysis.

The distance function is a representation of production technology, and it measures the efficiency gap between the convex or nonconvex frontier and evaluated DMUs. For instance, the output-oriented distance function allows measuring the possible expansion of good outputs and reduction of bad outputs simultaneously at a given level of inputs. Following Chambers et al. (1996), we apply an output-oriented directional distance function:

$$D\left(K, L, E, GDP, CO_2; g_K, g_L, g_E, g_{GDP}, g_{CO_2}\right) \\ = \sup_{\delta, \theta} \left\{ \delta, \theta \in \mathbb{R}_+ : \left(K, L, E, GDP + \delta \times g_{GDP}, CO_2 - \theta \times g_{CO_2} \right) \in T \right\} \quad (2)$$

where:

$$\left(g_K, g_L, g_E, g_{GDP}, g_{CO_2} \right) = \left(0, 0, 0, \sum_{n=1}^N GDP, \sum_{n=1}^N CO_2 \right)$$

are the direction vectors related to inputs and outputs. We adopt an output-oriented directional distance function and (g_K, g_L, g_E) is defined as 0. Instead of using the output level of the evaluated plan as the direction vector, g_{GDP} and g_{CO_2} are defined as the aggregate values of economic and environmental outputs among 34 DMUs including mainland provinces, Hong Kong, Macau, and Taiwan in China. Under such a setting, all scores are additive, and the efficiency scores can be compared and aggregated across DMUs. Meanwhile, δ and θ are inefficiency scores, suggesting the maximum potential for an increase in desirable outputs and decrease in undesirable outputs, respectively. Through the above setting, if δ is 1%, the DMU could increase its good outputs economically by 1% compared with the aggregate good output comprising all the DMUs. Similarly, if θ is 1%, the DMU could decrease its bad outputs environmentally by 1%, related to the aggregate bad output including all the DMUs.

3.2 Decomposition of the Aggregate Inefficiency

Suggested by Zhu et al.(2021), assume that 34 DMUs (31 mainland provinces, Hong Kong, Macau, and Taiwan) of China could be considered a whole economy, and a free resource reallocation is allowed across all DMUs. It should be noted that, unlike Shen et al. (2018), the constructed production technology and directional vectors of distance functions at the aggregate level are based on the 34 DMUS, not on the 31 provinces in the East Midwest of China. The main purpose of this setting is to assume that Taiwan is willing to participate in cooperation and integration with other provinces in China and assess the potential benefit of the above integration for Hongkong, Macao, and Taiwan in China. The production technology of China (T_{China}) is the summation of provincial technology (T_n):

$$T_{China} = \sum_{n=1}^N T_n = N * T_n \quad (3)$$

where n is the index of the province. According to Li et al. (1995) and Zhu et al. (2021), the production technology is equal to N multiplied by individual production technology under VRS.

Firstly, if all DMUs in China can participate in this economic integration and allow to reallocate resources across provinces, the overall production gain can be measured by overall inefficiency (OI). OI is defined by:

$$OI = D\left(\sum_{n=1}^N K, \sum_{n=1}^N L, \sum_{n=1}^N E, \sum_{n=1}^N GDP, \sum_{n=1}^N CO_2; 0, 0, 0, \sum_{n=1}^N GDP, \sum_{n=1}^N CO_2\right) \quad (4)$$

OI could be disaggregated with a positive or negative value. If OI is 1%, it suggests all DMUs can expand their overall output level by 1% possibly. And, if OI is negative, it means that all DMUs

present an efficiency beyond the constructed production frontier, accompanied by a lower probability. Then, OI can be further decomposed into technical inefficiency (TI) and structural inefficiency (SI).

To illustrate TI and SI clearly, we introduce two DMUs A and B under convex technology with input (x), good output (y), and undesirable output (z) shown in Figure 1. Based on the by-production approach, two sub-technologies are presented within producing good output (x - y space) or bad output (x - z space). TI is at the individual level and measures the distance between the individual frontier (T) and DMUs, which explains the possible efficiency improvement through using resources effectively. Then, we focus on SI, which is at the aggregate and individual levels. And, SI indicates the potential productivity gain through DMUs collaboration and reallocation of resources. Assume A and B are on the production frontier, which means their TI is 0, implying their TI is 0. One can observe in Figure 1, SI is assumed to be positive at the aggregate frontier. Even A and B serve as the benchmarks at the individual level (frontier T), there is still a possible improvement at the aggregate level (frontier 2T). This structural element indicates a potential desirable output expansion (or undesirable output reduction) through reallocating resources.

Similarly, under nonconvex production technology, SI appears at the aggregate production frontier (2T) when A and B are efficient at the individual frontier (T) in Figure 2. To put it another way, when TI is 0 but SI is not 0, it signifies that DMUs cannot enhance resource utilization efficiency via individual efforts, but can become a whole through collaboration among DMUs to accomplish resource redistribution and thus reach the aggregate production frontier and attain complete efficiency.

Figure 1. Illustration of structural inefficiency under convex technology

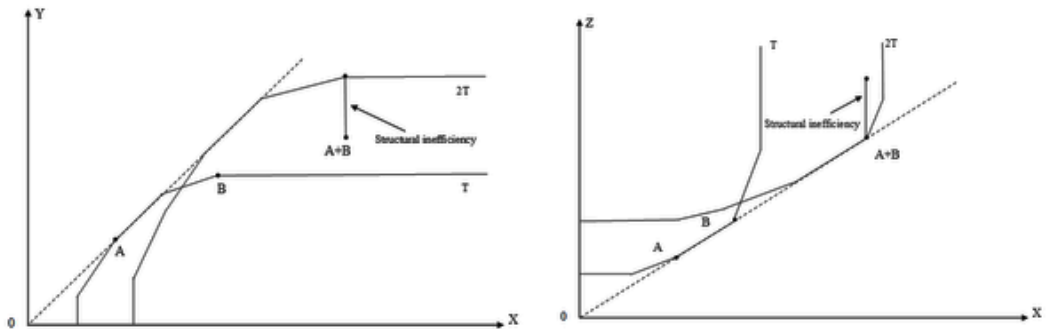


Figure 2. Illustration of structural inefficiency under nonconvex technology

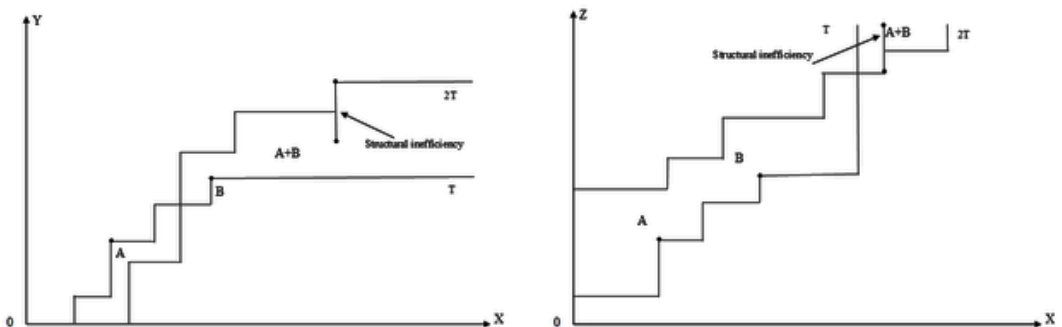


Table 1. Economic interpretation of indicators

Indicator	Economic interpretation	Example
OI	Overall production gain with economic growth and environmental protection	If OI is greater than 0, it suggests a possible gain can be achieved by reducing TI or SI.
TI	The production gain can be obtained by efficiently using resources	If TI is greater than 0, it suggests a potential gain can be achieved by well using resources.
SI	The production gain can be obtained by reasonably allocating resources	If SI is greater than 0, it implies the evaluated DMU can obtain a positive production gain within the integration of economies; If SI is less than 0, the evaluated DMU would contribute to the improvement for other DMUs.

SI and TI can be computed as:

$$\begin{aligned}
 TI &= D\left(K, L, E, GDP, CO_2; 0, 0, 0, \sum_{n=1}^N GDP, \sum_{n=1}^N CO_2\right) \\
 SI &= OI - \sum_{n=1}^N TI = D\left(\sum_{n=1}^N K, \sum_{n=1}^N L, \sum_{n=1}^N E, \sum_{n=1}^N GDP, \sum_{n=1}^N CO_2; 0, 0, 0, \sum_{n=1}^N GDP, \sum_{n=1}^N CO_2\right) \\
 &\quad - \sum_{n=1}^N D\left(K, L, E, GDP, CO_2; 0, 0, 0, \sum_{n=1}^N GDP, \sum_{n=1}^N CO_2\right) \quad (5)
 \end{aligned}$$

The OI is an aggregate indicator that can indicate the performance of the whole of China. TI presents the possible improvement of output if the evaluated DMU has not achieved optimal utilization of resources for itself. In this case, we can employ TI as the indicator measuring the inefficiency level, regardless of whether the DMU participates in the economic integration. SI could represent the additional production gain if the DMU engages in economic integration. If a positive SI is detected, the evaluated DMU would benefit from economic cooperation. Alternatively, the DMU would contribute to the improvement of other units if SI is negative. Thus, the value and sign of SI provide us with key information when exploring whether there are potential gains from DMUs collaboration. A more detailed explanation of the economic interpretation is shown in Table 1.

After decomposing the total OI into TI and SI, this paper attempts to distinguish between environmental inefficiency and economic inefficiency. Therefore, this paper further strips the sub-frontiers of environmental and economic dimensions and performs a second decomposition. OI is possibly decomposed as:

$$\begin{aligned}
 \sum_{n=1}^N OI &= \sum_{n=1}^N TI + \sum_{n=1}^N SI \\
 &= \sum_{n=1}^N TI_{Eco} + \sum_{n=1}^N TI_{Env} + \sum_{n=1}^N SI_{Eco} + \sum_{n=1}^N SI_{Env} \quad (6)
 \end{aligned}$$

3.3 Measuring Directional Distance Functions

In this paper, the output-oriented directional distance functions (DDF) are applied to estimate TI and OI. Notable interpretations are as follows. First, distance functions can be measured by either parametric or nonparametric ways, and we adopt the latter approach to avoid predefining the functional

form of production technology. Second, we make the assumption of variable returns to scale, by adding constraints on the sum of activity variables. Third, we change the convexity assumption by setting constraints on the activity variables. When setting the convexity assumption, we restrict the value of the active variable to be greater than or equal to 0. The evaluated DMU can refer to a dummy DMU composed of linear combinations. While relaxing the convexity assumption, we restrict the value of the active variables to 0 or 1. The evaluated DMUs refer only to the actual DMUs that exist in reality, rather than the virtual DMUs constituted.

A non-parametric estimate model with linear program (LP) is used to assess an output-oriented directional distance function. Following Murty et al. (2012), equal weight is assigned to the economic inefficiency ($\frac{1}{2}\delta$) and the environmental inefficiency ($\frac{1}{2}\theta$) at the individual level. Considering convexity and non-convexity, TI is estimated by:

$$\begin{aligned}
 D(K, L, E, GDP, CO_2; g_{GDP}, g_{CO_2}) &= \max_{\delta, \theta, \lambda, \sigma} \frac{1}{2}(\delta + \theta) \text{ s.t. } \sum_{n=1}^N \lambda_n GDP_n \geq GDP_{n'} + \delta g_{GDP} \\
 \sum_{n=1}^N \lambda_n K_n &\leq K_{n'} \\
 \sum_{n=1}^N \lambda_n L_n &\leq L_{n'} \quad \sum_{n=1}^N \lambda_n E_n \leq E_{n'} \quad \sum_{n=1}^N \sigma_n CO_{2n} \leq CO_{2n'} - \theta g_{CO_2} \quad \sum_{n=1}^N \sigma_n E_n \geq E_{n'} \\
 \sum_{n=1}^N \lambda_n &= N, T_{Eco} \text{ under VRS } \lambda_n \geq 0, n = 1, \dots, N, T_{Eco} \text{ is convex} \\
 \lambda_n &= \{0, 1\}, n = 1, \dots, N, T_{Eco} \text{ is nonconvex} \quad \sum_{n=1}^N \sigma_n = N, T_{Env} \text{ under VRS} \\
 \sigma_n &\geq 0, n = 1, \dots, N, T_{Env} \text{ is convex} \quad \sigma_n = \{0, 1\}, n = 1, \dots, N, T_{Env} \text{ is nonconvex} \quad (LP1)
 \end{aligned}$$

where λ and σ are activity variables for T_1 and T_2 , respectively. The positive values mean the observed production plan serves as the benchmark for evaluated DMU.

According to Eq. 3, the summation of activity variables equals N, which indicates the assumption of VRS. The convex technology is illustrated by $\sigma_k \geq 0$, whereas the non-convex technology is represented by $\sigma_k = \{0, 1\}$. In addition, δ and θ are the economic sub-technology inefficiency for desirable output (GDP) and the environmental sub-technology inefficiency for undesirable output (CO_2), respectively.

Similarly, at the aggregate level, comparable weights are attributed to economic sub-technology and environmental sub-technology. Thus, a comprehensive OI is obtained by:

$$\begin{aligned}
 D\left(\sum_{n=1}^N K, \sum_{n=1}^N L, \sum_{n=1}^N E, \sum_{n=1}^N GDP, \sum_{n=1}^N CO_2; g_{GDP}, g_{CO_2}\right) &= \max_{\delta, \theta, \lambda, \sigma} \frac{1}{2}(\delta + \theta) \\
 \text{s.t. } \sum_{n=1}^N \lambda_n GDP_n &\geq \sum_{n=1}^N GDP_n + \delta g_{GDP} \quad \sum_{n=1}^N \lambda_n K_n \leq \sum_{n=1}^N K_n \quad \sum_{n=1}^N \lambda_n L_n \leq \sum_{n=1}^N L_n \\
 \sum_{n=1}^N \lambda_n E_n &\leq \sum_{n=1}^N E_n \quad \sum_{n=1}^N \sigma_n CO_{2n} \leq \sum_{n=1}^N \lambda_n CO_{2n} - \theta g_{CO_2} \quad \sum_{n=1}^N \sigma_n E_n \geq \sum_{n=1}^N \lambda_n E_n \\
 \sum_{n=1}^N \lambda_n &= N, T_{Eco} \text{ under VRS } \lambda_n \geq 0, n = 1, \dots, N, T_{Eco} \text{ is convex} \\
 \lambda_n &= \{0, 1\}, n = 1, \dots, N, T_{Eco} \text{ is nonconvex} \quad \sum_{n=1}^N \sigma_n = N, T_{Env} \text{ under VRS} \\
 \sigma_n &\geq 0, n = 1, \dots, N, T_{Env} \text{ is convex} \quad \sigma_n = \{0, 1\}, n = 1, \dots, N, T_{Env} \text{ is nonconvex} \quad (LP2)
 \end{aligned}$$

The core distinction between the TI and OI estimate processes is the construction of production technology. $\sum_{n=1}^N T_n$ is introduced to express the aggregate concept and evaluate the OI, while T_n is used to calculate the TI at the individual level. Then, SI is derived by the difference between OI and TI, which is presented in 3.2.

4. DATA AND RESULTS

4.1 Data

There are 34 DMUs contained in this paper, 31 mainland areas, Hong Kong, Macau, and Taiwan. It is noted that due to the relatively small economic aggregates in Hong Kong and Macau, the two special administrative regions are regarded as one unit. Our non-parametric framework includes three inputs, one desirable output and one undesirable. Following Shen et al. (2021), Zhao et al. (2022) and Guo & Liu (2022), specifically, we select capital, labor force, and energy consumption as input indicators, while GDP and CO₂ are chosen as desirable output and undesirable output, respectively. The capital stock is calculated using Goldsmith's (1951) perpetual inventory approach, with purchasing power parities in 2017 US dollars. The labor input indicator considering labor quality is a better measure than labor quantity because it can distinguish skilled labor from unskilled labor, but its data are difficult to obtain. Therefore, the total number of employees is chosen as the indicator of representing the labor force. The unit to estimate the energy consumption of each region is 10,000 tons of standard coal. The real GDP is measured in purchasing power parities in 2017 US dollars. And CO₂ is measured in million tons. The data were resourced from the Penn World Table provided by the University of Groningen (Freenstra, Inklaar and Timmer, 2015), International Energy Agency (CO₂ Emissions from Fuel Combustion, 2020), China Statistical Yearbook (National Bureau of Statistics of China, 1998-2020), Hong Kong Statistical Yearbook (Electrical and Mechanical Services Department, 1998-2020), Macau Statistical Yearbook (The Statistics and Census Service, 1998-2020), Taiwan Energy Statistics Annual Report (Bureau of Energy, Ministry of Economic Affairs, 1998-2020).

Table 2 shows the descriptive statistics of input and output during the 1997-2019 period. There are significant differences among different regions of these variables. For example, the minimum capital stock is -15529.6 mil.2017US\$, while the maximum one is 8499614.0 mil.2017US\$. Moreover, the most energy consumption (41390.0) is approximately 6800 times than the least (6.2). It is apparent that these similar patterns can be found in labor force, GDP, and CO₂.

4.2. Empirical Results and Discussions

All inefficiency scores throughout 1997-2019 are presented in Table 3. First, average economic OI, TI, and SI in China are 43.2%, 30.1%, and 13.2% under convex technology, respectively. Second, average environmental OI, TI, and SI are more minor: 28.4%, 24.4%, and 4%, respectively. Thus,

Table 2. Descriptive statistics for inputs and outputs, 1997-2019

Indicator	Unit	Mean	Std	Min	Max
Capital stock	mil. 2017US\$	1530920.0	1486511.0	-15529.6	8499614.0
Labor force	million persons	23.7	17.2	1.3	65.2
Energy consumption	10 ⁴ tons/standard coal	10247.1	7976.7	6.2	41390.0
GDP	mil. 2017US\$	405875.7	384460.6	4833.6	2211589.0
CO ₂	million tons	205.1	168.3	0.2	834.7

Table 3. Annual average inefficiency scores of China (%,1997-2019)

Model	Convex technology						Nonconvex technology					
Type	Economic			Environment			Economic			Environment		
Province	OI	TI	SI	OI	TI	SI	OI	TI	SI	OI	TI	SI
Beijing	1.2	0.6	0.6	-0.8	0.1	-0.9	0.2	0.0	0.2	-1.5	0.0	-1.5
Tianjin	2.9	0.9	2.0	-0.6	0.5	-1.1	1.9	0.0	1.9	-1.3	0.1	-1.5
Hebei	0.5	2.3	-1.8	5.3	1.9	3.3	-0.5	0.3	-0.8	4.6	1.0	3.5
Shanxi	2.6	1.1	1.5	2.7	1.6	1.1	1.6	0.2	1.4	2.0	0.8	1.2
Inner Mongolia	2.7	1.4	1.4	2.7	2.3	0.4	1.7	0.8	0.9	2.0	1.8	0.2
Liaoning	1.1	1.8	-0.7	3.0	1.2	1.8	0.1	0.5	-0.4	2.3	0.2	2.1
Jilin	3.0	1.3	1.6	0.2	1.0	-0.8	2.0	0.6	1.4	-0.5	0.5	-1.0
Heilongjiang	2.4	1.3	1.0	0.7	0.8	0.0	1.4	0.4	1.0	0.0	0.2	-0.2
Shanghai	0.4	0.0	0.4	0.4	0.5	-0.2	-0.6	0.0	-0.6	-0.3	0.1	-0.4
Jiangsu	-4.2	0.7	-4.9	4.4	1.7	2.6	-5.2	0.1	-5.2	3.6	0.9	2.8
Zhejiang	-1.4	1.1	-2.6	1.8	1.0	0.9	-2.4	0.0	-2.4	1.1	0.4	0.7
Anhui	1.4	0.7	0.7	1.1	1.5	-0.3	0.4	0.2	0.2	0.4	0.7	-0.3
Fujian	1.0	0.5	0.5	-0.1	0.5	-0.6	0.0	0.0	0.0	-0.8	0.1	-0.9
Jiangxi	2.4	0.3	2.0	-0.4	0.8	-1.1	1.3	0.0	1.3	-1.1	0.4	-1.5
Shandong	-2.9	2.1	-5.0	5.8	0.4	5.4	-3.9	1.8	-5.7	5.1	0.2	4.9
Henan	-0.4	2.1	-2.5	3.1	1.4	1.6	-1.4	0.3	-1.7	2.4	0.2	2.1
Hubei	0.9	1.5	-0.6	1.4	0.9	0.5	-0.1	0.1	-0.2	0.7	0.5	0.2
Hunan	1.0	1.3	-0.3	0.7	0.5	0.1	0.0	0.1	-0.1	-0.1	0.1	-0.2
Guangdong	-5.5	0.0	-5.5	3.4	0.4	2.9	-6.5	0.0	-6.5	2.6	0.0	2.6
Guangxi	2.5	1.0	1.5	-0.3	0.6	-0.9	1.5	0.5	1.0	-1.0	0.2	-1.2
Hainan	3.9	0.3	3.6	-1.8	0.1	-2.0	2.9	0.0	2.9	-2.5	0.0	-2.5
Chongqing	2.5	0.8	1.7	-0.5	0.4	-1.0	1.5	0.1	1.5	-1.2	0.1	-1.4
Sichuan	0.6	1.4	-0.8	1.1	0.1	1.0	-0.4	0.0	-0.4	0.4	0.0	0.4
Guizhou	3.3	0.6	2.6	0.2	0.8	-0.6	2.2	0.0	2.2	-0.5	0.3	-0.7
Yunnan	2.5	1.4	1.1	-0.2	0.5	-0.7	1.5	0.7	0.8	-0.9	0.1	-1.0
Tibet	4.2	0.0	4.2	-2.2	0.0	-2.2	3.2	0.0	3.2	-2.9	0.0	-2.9
Shaanxi	2.3	1.5	0.8	0.1	0.8	-0.7	1.3	0.6	0.8	-0.6	0.3	-0.9
Gansu	3.5	0.5	2.9	-0.7	0.5	-1.1	2.5	0.0	2.5	-1.4	0.1	-1.5
Qinghai	4.1	0.2	3.9	-1.7	0.0	-1.8	3.1	0.0	3.1	-2.4	0.0	-2.5
Ningxia	4.0	0.2	3.9	-1.0	0.6	-1.6	3.0	0.0	3.0	-1.7	0.4	-2.1
Xinjiang	3.1	1.0	2.2	0.3	0.7	-0.4	2.1	0.0	2.1	-0.5	0.3	-0.8
Hong Kong&Macau	1.0	0.0	1.0	-1.4	0.0	-1.4	0.0	0.0	0.0	-2.1	0.0	-2.1
Taiwan	-3.5	0.0	-3.5	1.8	0.1	1.7	-4.5	0.0	-4.5	1.1	0.0	1.1
China	43.2	30.1	13.2	28.4	24.4	4.0	10.1	7.4	2.7	5.1	10.0	-4.9

economic inefficiency is higher than the environmental score. Moreover, the inefficiency scores under nonconvex technology are less than that of the convex cases.

Under convex technology, China has great potential to improve its economic and environmental development, with TI exceeding SI. Thus, TI contributes the most to OI. In regions, some of the China-developed provinces, such as mainland regions like Shanghai and Guangdong, and other areas like Hong Kong, Macau, and Taiwan all have 0% of economic TI, which means they serve as the benchmarks for all DMUs in economic dimension. Hebei, Shandong, and Henan have the highest economic TI implying these regions have the most considerable possible economic improvement. Environmental TI in Tibet, Hong Kong, and Macau are at a null level indicating these regions have the best environmental performance. However, Inner Mongolia, Hebei, and Jiangsu contributed most of the environmental inefficiency scores in China which show these provinces are the most polluted and have the most enormous possible environmental improvement.

One can notice both negative and positive OI among regions, and negative OI is mainly due to negative SI in decomposition. As discussed in the methodology part, a positive value of SI implies the evaluated DMU would benefit from the economic integration. In contrast, a negative value of SI suggests this province has sufficient resources with a possible contribution to the improvement of other units. For instance, Guangdong, Shandong, and Jiangsu are with negative economic SI among regions, indicating that the DMUs may have over-provisioning resources.

Figure 3 shows the economic and environmental inefficiencies under both convex and nonconvex technologies over time in a whole with Mainland provinces, Hong Kong and Macau, and Taiwan. Overall, it is apparent that all of the OI, TI, and SI have increased during 1997-2019. For economic improvement, OI and TI generally have the same trend compared to SI, and they both had a breakpoint in 2004, then increased, reaching the highest point in 2016. The SI is basically between 10% and 20%. Those imply the whole of China still has the considerable potential to improve its technology and structural efficiency in the economy. It is similar to the environmental development; TI dominates SI; however, the improvement space for China's environment of both TI and SI is less than that of the economic aspect relatively. The nonconvex technology also indicates similar information but with negative SI and OI, which is not found in convex technology.

Figure 3. Average inefficiency scores in China (%;1997-2019)

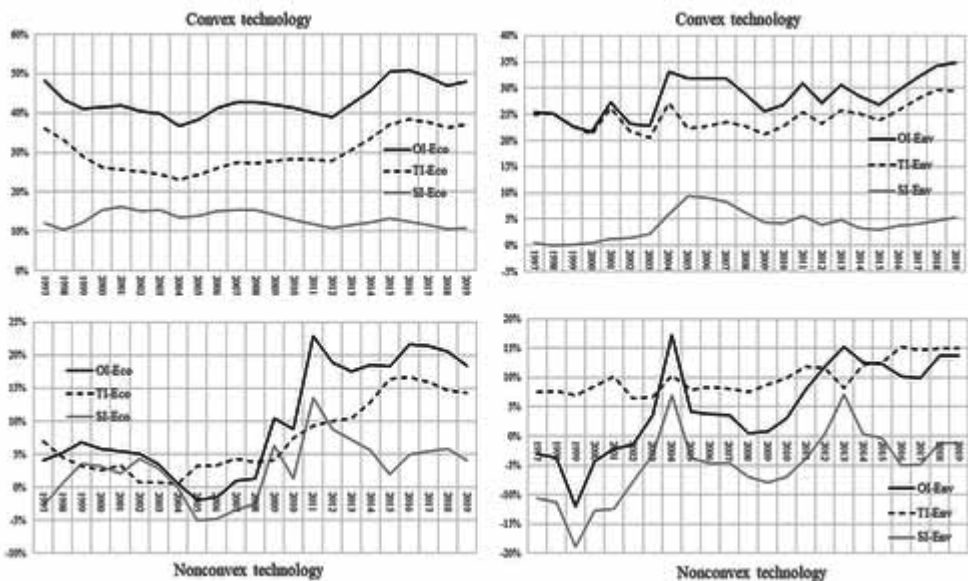


Figure 4 depicts the economic and environmental inefficiencies under the convex and nonconvex technologies in Hong Kong and Macau during 1997-2019. For economic inefficiency, though TI is always 0%, the SI and OI have an increasing trend no matter using convex or nonconvex technology. This implies that Hong Kong and Macau have utilized their resources ideally to gain economic productivity. However, the SI is no more at a null level after 2004 (2008 for nonconvex technology), which suggests that Hong Kong and Macau would benefit from resource reallocation and economic integration from that period. For environmental performance, OI and SI show a decreasing trend in Hong Kong and Macau, suggesting that Hong Kong and Macau are super-efficient in terms of the environment, and this tendency becomes more prominent over time.

In Figure 5, economic SI is negative while environmental SI is positive in Taiwan. This indicates that resource reallocation would improve environmental evaluation instead of economic structural performance if Taiwan is willing to participate in economic integration and cooperation with other provinces in China. One should notice that economic SI in both convex and nonconvex technologies exhibit a similar trend: approaching zero. This suggests the advantages of the overallocation of resources are gradually diminishing in Taiwan. In other words, Taiwan would benefit from integrating with other provinces in China in the coming future. For environmental performance, OI is decreasing mainly due to the reduction of SI in Taiwan.

5. CONCLUSION AND POLICY IMPLICATIONS

With the deepening of reform and opening-up policy, China's comprehensive national strength and international influence are consistently increasing. Moreover, there also has been great potential to improve its economy and environment. To calculate the economic and environmental benefits from economic integration and cooperation, we proposed a novel model to measure the potential gains between the mainland provinces, Hong Kong, Macau, and Taiwan in China, using the data of 34 regions from 1997 to 2019.

Figure 4. Average inefficiency scores in Hong Kong and Macau (%;1997-2019)

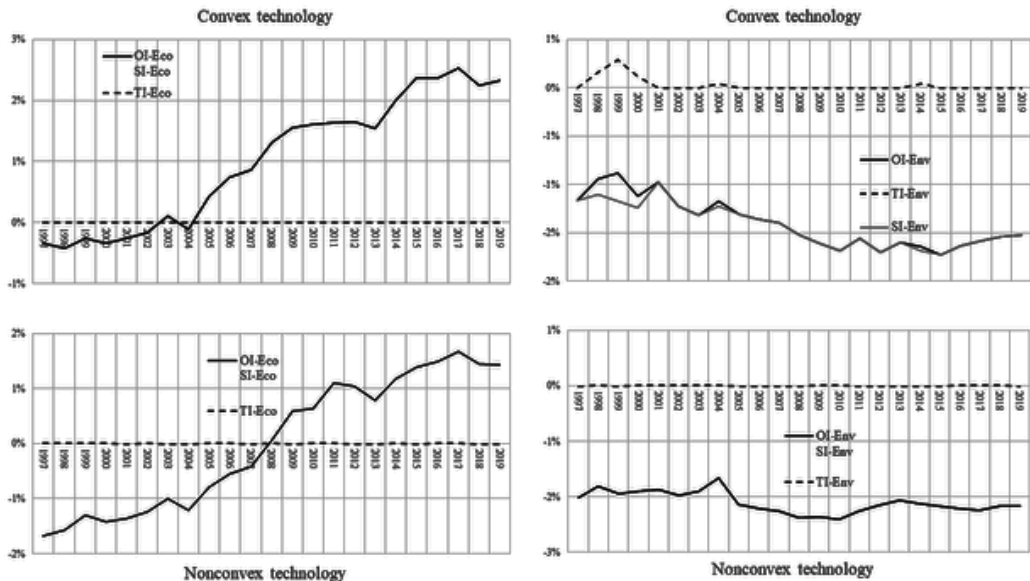
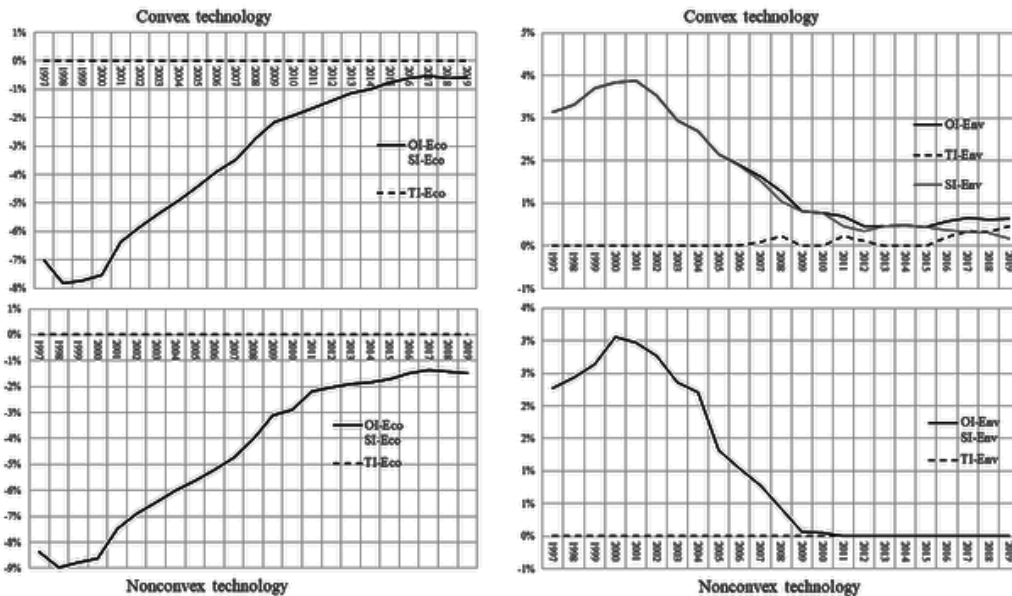


Figure 5. Average inefficiency scores in Taiwan (%,1997-2019)



The results show 34 DMUs in total. OI indicates overall production gain with economic growth and environmental improvement, TI means the production benefit can be obtained by efficiently using resources, and SI implies the production gain can be obtained by reasonably allocating resources.

Under the assumption that Taiwan is willing to participate in cooperation and integration with other provinces in China, the economic SI of Taiwan presented in this paper shows a trend close to zero, suggesting that Taiwan would realize economic benefits after reallocation of resources with the mainland of China in the coming future. The environmental SI of Taiwan is positive, meaning that Taiwan could gain green benefits through resource reallocation. Meanwhile, the economic OI and SI of Hong Kong and Macao are positive. Thus, Hong Kong and Macao could increase their economic efficiency by reallocating resources. For the mainland, there is still large potential to for provinces use and reallocate resources reasonably.

With the rapid development of economic globalization, there have been more urgent appeals for better cooperation and integration of the two sides of the Strait. If Taiwan desires to establish a closer relationship with other provinces in China, better green gain through reallocation and misallocation from the mainland of China will be achieved. Therefore, we should adhere to the one-China principle and promote the deeper cooperation and integration of the two sides of the Strait, which can benefit both Taiwan and the mainland of China. Policy implications can be derived through these findings.

First of all, it is suggested that Taiwan has obtained green gains from the cooperation and integration of the mainland of China. The two sides of the Strait should continue to maintain high-quality economic development, and strengthen their cooperation. Taiwan and the mainland of China should integrate the green concept into cross-strait construction together, focusing on the development of clean energy. To better improve the environment of the two sides of the Strait, the mainland of China can share the experience of environmental governance with Taiwan. The Chinese government can allow Taiwan-funded enterprises to learn from the recycling economy projects of the mainland's harmless disposal and recycling of urban sludge, thereby promoting Taiwan's efficiency of environmental governance. Moreover, under the circumstance that environmental problems are

prominent, the two sides of the Strait should concentrate more on the demand side, adjust factor input structure, and optimize their reallocation.

It can also be inferred that Taiwan will get economic benefits from the collaboration in the future. Therefore, the two sides of the Strait should cooperate to promote technological innovation, develop and utilize new energy. They need to accelerate technological progress, improve the renewable energy priority power generation system, use cross-regional transmission channels to expand the scope of renewable energy allocation, and carry out special renewable energy power transactions. It is of great significance for both of them to increase investment in clean energy research, which can not only advance their economies but also their protection of the environment. It is also recommended that Taiwan could share its advanced technology with the mainland of China. There are many high-tech industries in Taiwan, and its semiconductor industry has attracted worldwide attention, such as Taiwan Semiconductor Manufacturing Company, MediaTek, Advanced Semiconductor Engineering, United Microelectronics Corporation, and other semiconductor giants. With the circumstance of increasingly fierce competition in the whole world, the two sides of the Strait should increase engagement between each other, research and develop new technology, and improve the quality of the economy.

More importantly, from the perspective of political economy, it is necessary to strengthen political mutual trust between Taiwan and the mainland of China. The two sides of the Strait have maintained various mutual interactions for a long time, and the mainland of China is an important business partner for Taiwan. Thus, it is necessary to deepen the cooperation and integration between the two sides based on the original scale. The mainland of China should continue to strengthen trade exchanges with Taiwan, and explore the establishment of a cross-strait economic cooperation mechanism, thereby weakening political differences. The Chinese government also needs to effectively implement the plan of the cross-strait economic cooperation framework agreement. Meanwhile, the government should promote follow-up negotiations of the framework agreement, and strive to make the framework agreement more beneficial to small and medium-sized firms and people, especially in Taiwan. Simultaneously, the mainland of China can also increase trade investment in Taiwan, and organize various cross-strait economic cooperation forms through non-governmental economic organizations on both sides of the Strait. The government should create more information and opportunities for cross-strait business cooperation, implement the same treatment for Taiwan-funded enterprises as those on the mainland, and respect market mechanisms. Correspondingly, Taiwanese businesspeople also need to play their role as an important bridge to promote cross-strait economic cooperation. Taiwanese businessmen have rich knowledge of cross-strait economic development, policies, and business opportunities compared to the other people in Taiwan. Because Taiwanese businessmen have great connections, and close business relationships across the Straits with their organizational solid, they can coordinate and facilitate cross-strait relations.

The key limitations that may give insights for future study should be emphasized. First, we are still unable to distinguish the workforce by proficiency or education for appropriate measurement of labor inputs due to the difficulty in collecting accurate data on labor quality. The labor quality can be considered as the labor indicator in the future paper. In addition, we used the nonparametric model to evaluate the OI and TI to measure the potential benefits between the mainland provinces, Hong Kong, Macau, and Taiwan in China. Future research can examine the possible gain after cooperation with parametric models, such as stochastic frontier analysis.

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REFERENCES

- Ahn, C., & Cheong, I. (2007). A search for closer economic relations in East Asia, 58(2). *The Japanese Economic Review*, 173–190.
- Alborzi, S., Aminian, A., Mojtahedi, S., & Mousavi, S. (2008). An analysis of project risks using the non-parametric bootstrap technique. *2008 IEEE International Conference on Industrial Engineering and Engineering Management*, 1295–1299. DOI: doi:10.1109/IEEM.2008.4738079
- Balaguer-Coll, M., Prior, D., & Tortosa-Ausina, E. (2007). On the determinants of local government performance: A two-stage nonparametric approach. *European Economic Review*, 51(2), 425–451.
- Baležentis, T., Blancard, S., Shen, Z., & Streimikiene, D. (2020). Analysis of environmental total factor productivity evolution in European agricultural sector. *Decision Sciences*, 52(2), 483–511.
- Besir, L., & Aldea, A. (2019). Assessing eco-efficiency of countries in the context of renewable and non-renewable energy consumption: A non-parametric partial frontier perspective. *Economic Computation and Economic Cybernetics Studies and Research*, 53(2), 131–148.
- Bobocka, J. (1994). Central-European free-trade agreement. *Ekonomicky Casopis*, 42, 518–527.
- Boussemart, J., Leleu, H., & Shen, Z. (2015). Environmental growth convergence among Chinese regions. *China Economic Review*, 34, 1–18.
- Campos, N. F., Coricelli, F., & Moretti, L. (2019). Institutional integration and economic growth in Europe. *Journal of Monetary Economics*, 103, 88–104.
- Cheng, J., Dai, S., & Ye, X. (2016). Spatiotemporal heterogeneity of industrial pollution in China. *China Economic Review*, 40, 179–191.
- Cressati, C., Pascolini, M., & Spizzo, D. (2010). The alpine—adriatic—danubian euroregion: Geo-political and institutional issues. *The Planning Review*, 46(183), 41–48. doi:10.1080/02513625.2010.10557110
- Cui, L., & Song, M. (2019). Economic evaluation of the Belt and Road Initiative from an unimpeded trade perspective. *International Journal of Logistics-research and Applications*, 22(1), 25–46.
- Debreu, G. (1951). The coefficient of resource utilization. *Econometrica*, 19(3), 273–292.
- Dent, C. (2007). Full circle? ideas and ordeals of creating a free trade area of the Asia-Pacific. *The Pacific Review*, 20(4), 447–474. doi:10.1080/09512740701671961
- Ding, L., Zheng, H., & Kang, W. (2017). Measuring the green efficiency of ocean economy in China: An improved three-stage DEA model. *Romanian Journal of Economic Forecasting*, 20(1), 5–22.
- Feenstra, C., Inklaar, R., & Timmer, P. (2015). The next generation of the Penn World Table. *The American Economic Review*, 105(10), 3150–3182.
- Fernandes, C. I., Veiga, P. M., Ferreira, J. J., & Hughes, M. (2021). Green growth versus economic growth: Do sustainable technology transfer and innovations lead to an imperfect choice? *Business Strategy and the Environment*, 30, 2021–2037.
- Formanek, T., & Husek, R. (2018). Getis' non-parametric approach to spatial data analysis, with application to regional unemployment dynamics. *Mathematical Methods in Economics*, 36, 92–97.
- Goldsmith, R. W. (1951). A perpetual inventory of national wealth. *Studies in Income and Wealth*, 14, 5–73.
- Greaney, T., Li, Y., & Tu, D. (2017). Pollution control and foreign firms' exit behavior in China. *Journal of Asian Economics*, 48, 148–159.
- Gu, J., Renwick, N., & Xue, L. (2018). The BRICS and Africa's search for green growth, clean energy and sustainable development. *Energy Policy*, 120, 675–683.
- Guo, W., & Liu, X. (2022). Market fragmentation of energy resource prices and green total factor energy efficiency in China. *Resources Policy*, 76.

Guo, Y., Kim, S., Timothy, D., & Wang, K. (2006). Tourism and reconciliation between mainland China and Taiwan. *Tourism Management*, 27(5), 997–1005.

Hjaltadóttir, R., Makkonen, T., & Mitze, T. (2020). Inter-regional innovation cooperation and structural heterogeneity: Does being a rural, or border region, or both, make a difference? *Journal of Rural Studies*, 74, 257–270.

Hong, T., & Yang, C. (2011). The economic cooperation framework agreement between China and Taiwan: Understanding its economics and politics. *Asian Economic Papers*, 10(3), 79–96.

Huang, T., & Wang, M. (2002). Comparison of economic efficiency estimation methods: Parametric and non-parametric techniques. *Social Science Electronic Publishing*, 70(5), 682–709.

Iredale, R. (1999). The need to import skilled personnel: Factors favouring and hindering its international mobility. *International Migration (Geneva, Switzerland)*, 37(89), 123. PMID:12322078

Ivanova, A., & Angeles, M. (2006). Trade and environment issues in APEC. *The Social Science Journal*, 43(4), 629–642. doi:10.1016/j.soscij.2006.08.007

Kalantaripor, M., & Najafi, H. (2021). Spatial effects of energy consumption and green GDP in regional agreements. *Sustainability*, 13(18).

Kao, C. (1993). Economic interdependence between Taiwan and mainland China. *Issues & Studies*, 29(4), 51–71.

Khan, S. A. R., Yu, Z., Sharif, A., & Golpira, H. (2020). Determinants of economic growth and environmental sustainability in South Asian association for regional cooperation: Evidence from panel ARDL. *Environmental Science and Pollution Research International*, 27(36). PMID:32803598

Kim, H. W. (2002). Regional integration and inter-Korean economic cooperation: A perspective of international political economy. *Korean Journal of Defense Analysis*, 14(1), 277–304.

Koopmans, T. (1951). Analysis of production as an efficient combination of activities. *Activity Analysis of Production and Allocation*, 13(33), 7.

Lai, W., Song, H., Wang, C., & Wang, H. (2021). Air pollution and brain drain: Evidence from college graduates in China. *China Economic Review*, 68.

Laporte, B. (1998). Regional, national, political and structural constraints - Determinants of intraregional trade in West Africa? *Canadian Journal of Development Studies*, 19(1), 97–116.

Leleu, H. (2009). Mixing DEA and FDH models together. *The Journal of the Operational Research Society*, 60(12), 1730–1737.

Li, K., Gong, W., & Choi, B. (2021). The influence of trade and foreign direct investment on green total factor productivity: Evidence from China and Korea. *Journal of Korea Trade*, 25(2), 95–110.

Liberatore, A. (1991). Problems of transnational policymaking: Environmental policy in the European community. *European Journal of Political Research*, 19, 281–305.

Lubell, M., Hillis, V., & Hoffman, M. (2011). Innovation, cooperation, and the perceived benefits and costs of sustainable agriculture practices. *Ecology and Society*, 16(4), 23.

Mahmood, M., & Mostafa, G. (2018). Kazakhstan–BRICS economic cooperation: Exploring the possibilities. *Journal of Balkan & Near Eastern Studies*, 20(2), 148–164.

Medrano, J. (2012). The limits of European integration. *Journal of European Integration*, 34(2), 191–204. doi:10.1080/07036337.2012.641091

Narine, S. (1999). ASEAN into the twenty-first century: Problems and prospects. *The Pacific Review*, 12(3), 357–380. doi:10.1080/09512749908719296

Pan, Z., & Huang, W. (2020). The influencing factors of Cross-Taiwan-Straits direct shipping. *Journal of Coastal Research*, 109(sp1), 105–109.

Paroussos, L., Mandel, A., Fragkiadakis, K., Fragkos, P., Hinkel, J., & Vrontisi, Z. (2019). climate clubs and the macro-economic benefits of international cooperation on climate policy. *Post-Print*, 9(7), 542–546.

- Parreñas, J. (1998). ASEAN and Asia-Pacific economic cooperation. *The Pacific Review*, 11(2), 233–248. doi:10.1080/09512749808719255
- Peritz, L. (2018). Obstructing integration: Domestic politics and the European court of justice. *European Union Politics*, 19(3), 427–457.
- Pjerotić, J. (2008). Trade liberalization in the South East Europe: Effects and controversial issues. *Panoeconomicus*, 55(4), 497–522.
- Quang, V., & Koderá, J. (2013) Non-parametric estimation of a GARCH-M model with heuristic, *Mathematical Methods in Economics*, 962-967.
- Ruggiero, F., Vlad, L. B., Vlasceanu, G., Gavris, A., & Vasile, D. (2015). Energy cooperation, The strength of the EU's economic development. *Amfiteatru Economic Journal*, 17(40), 1080–1094.
- Shen, Z., Bai, K., Hong, T., & Baležentis, T. (2021). Evaluation of carbon shadow price within a non-parametric meta-frontier framework: The case of OECD, ASEAN and BRICS. *Applied Energy*, 299, 117275.
- Shen, Z., Baležentis, T., Chen, X., & Valdmanis, V. (2018). Green growth and structural change in Chinese agricultural sector during 1997–2014. *China Economic Review*, 51, 83–96.
- Shephard, R. W. (1953). *Cost and production functions*. Springer Berlin Heidelberg.
- Sun, Z., & Cheng, L. (2021). Air pollution and procyclical mortality: Evidence from China. *China Economic Review*, 68.
- Tan, H., & Hooy, C. (2007). The development of East Asian countries towards a knowledge-based economy: A DEA analysis. *Journal of the Asia Pacific Economy*, 12(1), 17–33.
- Ulachovic, U. (2004). David without Goliath: Belarus and European egocentrism. *Osteuropa*, 54(2), 206.
- Urban, F., Zhou, Y., Nordensvard, J., & Narain, A. (2015). Firm-level technology transfer and technology cooperation for wind energy between Europe, China and India: From North–South to South–North cooperation? *Energy for Sustainable Development*, 28, 29–40.
- Valadkhani, A., Roshdi, I., & Smyth, R. (2016). A multiplicative environmental DEA approach to measure efficiency changes in the world's major polluters. *Energy Economics*, 54, 363–375.
- Wang, M., Li, Y., Li, J., & Wang, Z. (2021). Green process innovation, green product innovation and its economic performance improvement paths: A survey and structural model. *Journal of Environmental Management*, 297. PMID:34314965
- Wang, W., & Zhang, B. (2017). Research on China regional level of the cooperation efficiency and evolution path of fiscal support and financial support for agriculture based on four stage window-DEA, *DEStech Transactions on Economics, Business and Management*, 3, 177–183.
- Xiang, S., Zhong, P., Zhan, D., Ke, C., Xiao, Z. B., Larry, L., Xing, T., Bo, Z., Xin, L., Chang, Z., Sheng, F., & Wei, X. (2021). Resources and environmental costs of China's rapid economic growth: From the latest theoretic SEEA framework to modeling practice. *Journal of Cleaner Production*, 315.
- Yoo, I. T., & Kim, I. (2016). Free trade agreements for the environment? Regional economic integration and environmental cooperation in East Asia. *International Environmental Agreements-politics Law and Economics*, 16, 721–738.
- Yunos, J. M., & Hawdon, D. (1997). The efficiency of the national electricity board in Malaysia: An intercountry comparison using DEA. *Energy Economics*, 19, 255–269.
- Zhai, F. (2018). China's Belt and Road Initiative: A preliminary quantitative assessment. *Journal of Asian Economics*, 55, 84–92.
- Zhang, Z. (2008). Asian energy and environmental policy: Promoting growth while preserving the environment. *Energy Policy*, 36(10), 3905–3924.
- Zhao, P., Zeng, L., Li, P., Lu, H., Hu, H., Li, C., Zheng, M., Li, H., & Qi, Y. (2022). China's transportation sector carbon dioxide emissions efficiency and its influencing factors based on the EBM DEA Model with undesirable outputs and spatial durbin model. *Energy*, 238, 121934.

Zhu, N., Dai, X., Baležentis, T., Streimikiene, D., & Shen, Z. (2021). Estimating production gains from international cooperation: Evidence from countries along the Belt and Road. *Economic Change and Restructuring*.

Ziolo, M., Jednak, S., Savić, G., & Kragulj, D. (2020). Link between energy efficiency and sustainable economic and financial development in OECD countries. *Energies*, 13(22), 5898.

ENDNOTE

- ¹ China has 34 provincial-level administrative units: 23 provinces (including Taiwan), 4 municipalities (Beijing, Tianjin, Shanghai, Chongqing), 5 autonomous regions (Guangxi, Inner Mongolia, Tibet, Ningxia, Xinjiang) and 2 special administrative regions (Hong Kong, Macau).

APPENDIX

Table 4. Abbreviation table

Abbreviation	Full Name
APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of South Asian Nations
BRI	the Belt and Road Initiatives
BRICS	Brazil, Russia, India, China, and South Africa.
DEA	Data Envelopment Analysis
DMU	Decision-making Unit
E	Energy Consumption
EU	The European Union
FDH	Free Disposal Hull
FTAAP	Free Trade Area of the Asia-Pacific
K	Capital Stock
L	Labor Force
LP	Linear Program
NAFTA	North American Free Trade Agreement
OECD	Organization for Economic Co-operation and Development
OI	Overall Inefficiency
OI-Eco	Economic Overall Inefficiency
OI-Env	Environmental Overall Inefficiency
SAARC	Secretariat, South Asian Association for Regional Cooperation
SEE	Southeast Europe
SI	Structural Inefficiency
SI-Eco	Economic Structural Inefficiency
SI-Env	Environmental Structural Inefficiency
TI	Technical Inefficiency
TI-Eco	Economic Technical Inefficiency
TI-Env	Environmental Technical Inefficiency
VRS	Variable-return-to-scale