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# OPTIMIZING TUNA FISHERIES: LESSONS FROM VIETNAM'S TRANSITION FOR SUSTAINABLE RESOURCE EXPLOITATION

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**Abstract**

**Objective:** This study explores Vietnam's tuna fishing practices, emphasizing community-focused marine exploitation policies. We analyze tuna species' productivity from 2010 to 2017, identifying the key components that drive Total Factor Productivity (TFP) and raising awareness about overexploitation risks. **Methods:** Leveraging the Färe-Primont (FP) index, we examine Vietnam's potential in ocean tuna fishing, assess efficiency, and propose strategies for improvement. Our research incorporates direct interactions with local fishermen, shedding light on the significance of seafaring knowledge and self-initiated equipment and technique acquisition. **Results:** The findings reveal that Vietnam possesses substantial untapped potential for ocean tuna fishing; however, from 2010 to 2017, inefficiencies resulted in Vietnam achieving only 25-35% of its potential. Enhancing efficiency by reducing small-scale vessels and transitioning to well-equipped larger vessels could yield a remarkable 60% improvement. Additionally, shifting specific fishing methods within different Vietnamese provinces/regions could enhance productivity by approximately 20%. **Conclusion:** Government support is pivotal in providing knowledge and related support services to equip local communities effectively. Removing barriers between the government and local fishermen is a primary task for Vietnam, paving the way for broader discussions on digital transformation and enforcing stricter local fishing regulations. This study underscores the importance of aligning the interests of local communities, government policies and law, and sustainability practices to harness Vietnam's vast potential in tuna fishing while safeguarding the marine ecosystem.

**Keywords:** Tuna Fishing, Marine Exploitation, Total Factor Productivity, Sustainability, Vietnam.

## 1. INTRODUCTION

The commercial significance of tuna has witnessed a notable upsurge, making a substantial contribution to the global economy and actively contributing to its growth. Tuna, arguably the ocean's most economically valuable fish, serves as a crucial source of both sustenance and employment worldwide; accordingly, for example, in 2018, the global tuna market was valued at approximately US$12 billion, with annual sales reaching as high as US$42 billion, comprising nearly 30% of the total international seafood trade (Dammannagoda, 2018). The most extensive fishing grounds for tuna are primarily concentrated in the Pacific Ocean, where the comprehensive economic worth of tuna fishing operations, encompassing the value of processed canned tuna products, reached a remarkable $40 billion annually for decades (Galland, 2023). Notably, **almost half** of the tuna catch was traded on the international market through complex global value chains. Accordingly, in the realm of international seafood

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commerce, tuna is the fourth most traded commodity, constituting 9% of the total export value, following closely behind shrimp (15%), salmon (14%), and whitefish (10%). It exhibits a discernible upward trajectory in contributing to this market sector (O'Neill, Asare, & Aheto, 2018).

Given the substantial benefits associated with tuna exploitation, there is a growing concern over the phenomenon of overfishing, particularly in nations undergoing a transition in their understanding of sustainable fishing practices (Bailey, Sumaila, & Martell, 2013). This transitional phase often comes with limited awareness and knowledge regarding sustainable harvesting, exacerbating the issue (Adams & Jeanrenaud, 2008). It should be noted that the irreversibility of overfishing tuna is evident in the profound and irreplaceable impacts it inflicts on marine ecosystems, encompassing the loss of biodiversity, altered food webs, habitat destruction, reduced ecological resilience, and long-term genetic consequences (Dunning, 2023). Therefore, it becomes imperative to prioritize extensive research into the dynamics of overfishing to safeguard global environmental sustainability. This research sheds light on mitigating the severe and irreversible ecological repercussions of excessive tuna exploitation.

Vietnam serves as a compelling case study model, where the intricate interplay between legal evolution, geographical advantages, and shifting policy dynamics holds the potential to inform and drive sustainable practices on a global scale for several vital reasons (Nguyen & Tran, 2023). *First*, it is a nation in transition, with evolving legal frameworks for the protection and management of marine resources. Notably, Vietnam has faced 'yellow card' warnings in the context of overfishing, highlighting its pressing need to address sustainability concerns. *Second*, Vietnam boasts extensive fishing grounds within the region, characterized by its strategic location along the western shores of the South China Sea (Pomeroy, Nguyen, & Thong, 2009). With a vast maritime expanse covering approximately 3,448,000 square kilometers and an extensive coastline spanning 3,260 kilometers, Vietnam's territorial waters, exclusive economic zones, and numerous islands and bays collectively offer exceptional potential for sustainable tuna fisheries. *Third*, recent governmental efforts in Vietnam signify a proactive shift towards sustainability, transcending mere economic interests. The government's declaration through Decision No. 1090/QD-TTg outlines a clear goal for 2025: to reduce fishing permits in offshore areas by 10% compared to 2020 and establish species-specific allowable catch limits for tuna fishing (DECISION, 2022). *Fourth*, therefore, this region presents a unique opportunity to transform tuna fishing policies, aligning them with broader sustainable development objectives for the maritime domain.

To effectively address the issue of overfishing among Vietnamese fishermen and promote sustainable practices in tuna fisheries, a combination of approaches rooted in legal evolution, policy dynamics, and appealing to the self-interest of local fishing communities can be considered (Walters, 1997). This approach must involve the implementation of catch limits and regulations on the number of fishing permits issued to individual households, aiming to restrict the total fishing effort within sustainable levels. However, the challenges of implementing such measures in Vietnam are compounded by existing legal limitations and enforcement issues (Nguyen & Tran, 2023). An alternative approach focuses on appealing to the self-interest of

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fishermen by providing warnings about the declining productivity of their catch over time, thereby fostering greater understanding and support for sustainable fishing practices (Crance & Draper, 1996; Haapasaari, Michielsens, Karjalainen, Reinikainen, & Kuikka, 2007). In this transitional phase, where sustainable fishing practices are still gaining acceptance, both regulatory and incentive-based approaches offer practical means to restrict overfishing and protect invaluable marine ecosystems, setting an example for sustainable tuna fisheries on a global scale.

In assessing the efficiency of offshore fishing operations in Vietnam, this study adopts the Färe-Primont (FP) index introduced by O'Donnell (2012a, 2012b). Theoretical discussions on the advantages of this index have been widely deliberated in the literature O'Donnell (2016, 2018), while its application in various research fields globally is evident, spanning economics (Van, Van Dao, Hoang, & Van Hien, 2023; Vu & Tran, 2021), education (Tran, Thanh, Van Le, Phuong, & Lan, 2022; Trinh Thanh et al., 2022), and environmental studies (Njuki, Bravo-Ureta, & O'Donnell, 2018). Thus, this study makes several significant contributions. *First*, it provides fresh insights into evaluating offshore fishing efficiency in Vietnam, focusing on economically and commercially important tuna species. It should be noted that Vietnam presents an ideal case study due to its government's efforts to restore effective marine resource management, the vast expanse of its fishing grounds, and its status as a transitional country seeking optimal solutions. *Second*, leveraging the advantages of the FP index, this study decomposes productivity into several components, including technical efficiency (describing technical knowledge transfer among regions/fishermen), allocative efficiency (describing resource allocation across various fishing activities), and scale efficiency (depicting the organization of fishing activities at an optimal or suboptimal scale). *Third*, therefore, this research offers valuable insights for policymakers in shaping sustainable resource management strategies in Vietnam, which are crucial for the nation's continued development in marine resource exploitation.

## 2. THEORICAL FRAMEWORK

### *2.1 Evaluate Exploitation Efficiency and Management Approaches*

In fisheries management, numerous studies have explored the application of production analysis methodologies, such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA), in the context of offshore fishing. Notably, Wang, Maunder, Aires-da-Silva, and Bayliff (2009) employed DEA to assess the technical efficiency of tuna fishing vessels operating in the Eastern Pacific Ocean, providing insights into how DEA can be utilized to evaluate individual vessel performance and identify best practices that could enhance the overall productivity of the fishing fleet.

In a parallel vein, the work of Osawe, Adeqeye, and Omonona (2008) made a significant contribution by applying Stochastic Frontier Analysis (SFA) to model the production process in the fishing industry. SFA was employed to account for the stochastic and risk-laden nature of offshore fishing operations, offering a robust framework to evaluate vessel efficiency while considering the inherent uncertainties and environmental factors associated with the field.

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Similar research endeavors have been conducted in regions facing overfishing risks, including Taiwan (Chiang et al., 2004), Ghana (Onumah et al., 2018), Nepal (Sharma & Leung, 1998), and India (Sharma & Leung, 2000), significantly enriching the application of production analysis techniques in the pursuit of optimizing offshore fishing operations.

Furthermore, theories related to improving the welfare of fishermen have been approached from both bottom-up and top-down perspectives. While the efficient conservation approach through the assessment of community welfare from the bottom-up perspective has been suggested by Yapanto et al. (2023), involving the establishment of community-based fishing systems, the top-down approach, as exemplified in Vietnam by Huong, Viet, Tha, and Nhan (2023), focuses on sharing government management experiences. Similarly, Sastro and Fikri (2023) describe studies aimed at reducing gender inequality on the Coast of North Aceh, Indonesia, and investigating the sustainable exploitation of resources.

### *2.2 Overview of the Fishing Area*

Vietnam's offshore fishing activities are concentrated in four primary regions: (i) the Gulf of Tonkin, shared with China; (ii) the central region of Vietnam; (iii) the southeastern region of Vietnam; and (iv) The southwestern region of Vietnam, a part of the Gulf of Thailand shared with Cambodia and Thailand. Beyond these geographic areas, as stipulated by Government Decree No. 31/2010/ND-CP dated March 30, 2010, Government Decree No. 53/2012/ND-CP dated June 20, 2012, which amended and supplemented specific provisions of Government Decree No. 33/2010/ND-CP, and Government Decree No. 26/2019/ND-CP, which detailed the implementation of the 2017 Fisheries Law, fishing zones can be categorized into nearshore, coastal, and offshore areas. The inland region is considered to extend up to six nautical miles from the baseline (within territorial waters, as per United Nations Convention on the Law of the Sea [UNCLOS] 1982), the coastal region encompasses waters beyond the nearshore area, up to a limit of not more than 24 nautical miles, and the offshore area comprises waters beyond the coastal region.

Tuna fishing in Vietnam exhibits notable characteristics. Coastal provinces in the central region, such as Khanh Hoa, Binh Dinh, and Phu Yen, significantly contribute to the overall tuna exports. The primary tuna fishing methods in Vietnam include pole-and-line, purse seine, and longline fishing. Pole-and-line fishing predominantly targets yellowfin (Thunnus albacares) and bigeye (Thunnus obesus) tuna, while purse seine and longline methods focus primarily on skipjack (Katsuwonus pelamis) and other tuna species. Notably, pole-and-line fishing is mainly conducted in Khanh Hoa, Binh Dinh, and Phu Yen provinces. As of 2022, it is estimated that Vietnam had over 3,600 ocean tuna fishing vessels with an engine power of over 50 horsepower and about 35,000 workers. However, most vessels are small, wooden, and ill-suited for harsh weather conditions and climatic variability, while they also need advanced fishing equipment and proper fish preservation and storage technologies.

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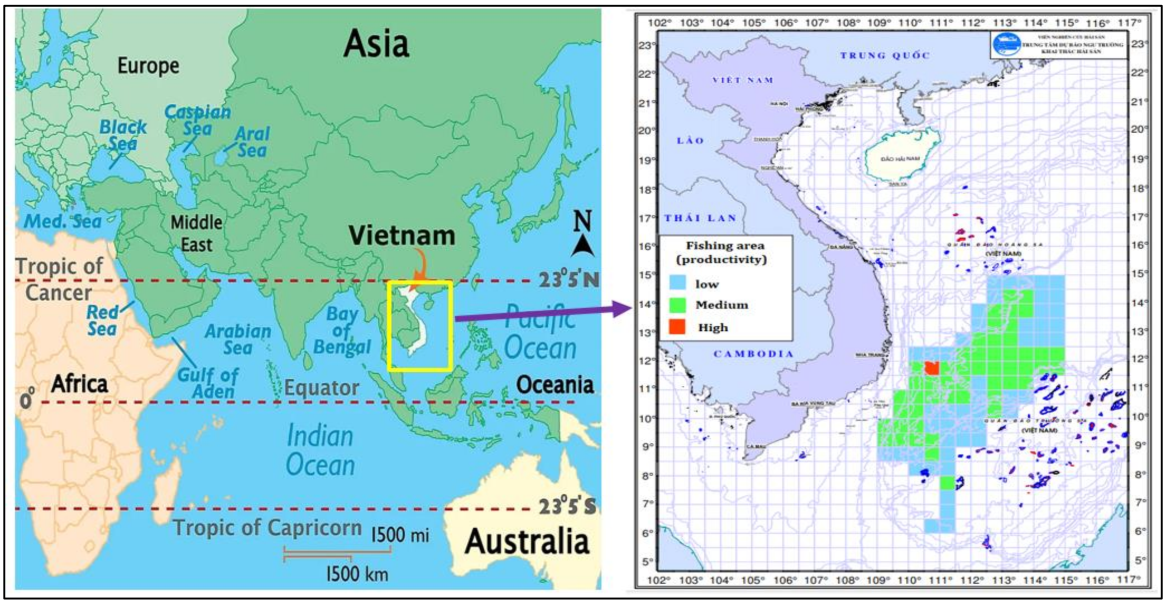


**Figure 1: Research area**

Source: Authors compiled from Vietnam Directorate of Fisheries and World Alas

Tuna fishing in Vietnam is concentrated in three primary regions: (i) The yellowfin and bigeye tuna are primarily found in the offshore waters of Binh Dinh and Phu Yen provinces, bounded by longitudes 110°30'E - 112°00'E and latitudes 12°00'N - 13°03'N. In addition, the waters off Khanh Hoa province (110°00'E - 112°00'E, 12°00'N - 13°00'N) and the western area of the Truong Sa (Spratly) Islands (110°00'E - 112°00'E, 8°00'N - 10°00'N) are significant tuna fishing regions. Skipjack tuna is concentrated in regions covering Phu Yen (109°30'E - 111°03'E, 12°00'N - 14°00'N), the area extending from Khanh Hoa to Binh Thuan waters (110°30'E - 112°03'E, 11°00'N - 12°00'N), and the offshore waters of Vung Tau (109°00'E - 111°00'E, 8°00'N - 10°00'N). These tuna fishing grounds are distinct and correspond to different fishing seasons. During the Northeast monsoon season from November to April, the tuna fishing grounds are primarily in the northern region of the South China Sea, near the Hoang Sa (Paracel) Islands, characterized by average water depths ranging from 400 to 4,000 meters. This period typically witnesses higher fishing yields compared to other months, with the peak often observed between December and February.

*During the Southwest monsoon season*, tuna fishing vessels move southwards to the waters of the South China Sea and the Truong Sa Islands, where the average water depths range from 200 to 3,000 meters. Some tuna fishing vessels still operate from Quy Nhon to Nha Trang, with trip durations typically lasting 7-15 days. However, the fishing yields during the Southwest monsoon season are lower than those during the Northeast monsoon, and the quality of the catch is lower. *During the Northeast monsoon*, tuna is usually distributed at higher water levels compared to the Southwest monsoon. Notably, tuna is caught from April to August in the

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southern waters of the South China Sea, the Truong Sa Islands, and near the coastal regions. Drift net fishing areas also exhibit seasonal characteristics.

Many purse seine vessels from the central region move to the Gulf of Tonkin, with depths of 20 to 60 meters for catching tuna from November to March in the lunar calendar, while other vessels, typically targeting skipjack tuna and dolphins, operate in the central waters of Vietnam from April to August, with fleets mainly active along the stretch from Da Nang to Vung Tau. In other months, these fleets operate primarily in the coastal waters of Binh Dinh and Phu Yen or cease fishing to perform vessel maintenance and prepare fishing equipment for adverse weather conditions. The highest catch levels are typically achieved during two main periods: from December to January and from July to August each year.

## 3. METHODOLOGY

### *3.1. Measures Total Factor Productivity (TFP) and Färe-Primont (FP) index*

To measure the efficiency of fishing operations (i.e., Total Factor Productivity [TFP]) and its components using a benchmarking approach, this study relies on an index proposed by O'Donnell (2012a, b). This method allows for assessing multi-input and multi-output efficiency; accordingly, TFP is the ratio of aggregate outputs to aggregate inputs in the production process given a time and specific space. In the case of n firms in period $t$, TFP is defined mathematically as:

$$TFP_{nt} = \frac{Y_{nt}}{X_{nt}} \quad (1)$$

where $Y_{nt} = Y_{(y_{nt})}$ and $X_{nt} = X_{(x_{nt})}$ denote the aggregate output and aggregate input, respectively. $y_{nt}$ and $x_{nt}$ represent each output and input within the production process. Aggregating inputs and outputs is not merely accomplished through straightforward mechanical addition but involves relatively complex methods (aggregation functions), as exemplified commonly by the distance function by Shephard (1970). The distinction between aggregation functions and reference point selection leads to differences in TFP indices. The list of commonly used aggregation functions and benchmarking methods is synthesized by O'Donnell (2012a). In this study, the aggregation function and reference point are calculated using the Färe-Primont index, as defined by O'Donnell (2014). The aggregation function is defined as follows:

$$Y_{(y)} = D_O(x_0, y, t_0) \text{ and } X_{(x)} = D_I(x, y_0, t_0) \quad (2)$$

where

$$D_O(x, y, t) = min\left\{p > 0 : x \text{ can produce } \frac{y}{p} \text{ in period } t\right\}$$

and

$$D_I(x, y, t) = max\left\{p > 0 : \frac{x}{p} \text{ can produce } y \text{ in period } t\right\}$$

Notably, the Färe-Primont index can evaluate TFP with multiple variables comprehensively,

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while it can satisfy the economic assumptions that other commonly used indices, such as the Malmquist index, may not be able to meet. Another notable aspect of this index is that it does not require price data, as in the case of the Paasche and Laspeyres indices.

### *3.2. Decomposite Components in TFP*

O'Donnell (2012a, b) decomposed the TFP index into technical change and efficiency change, encompassing both technical efficiency and scale efficiency. Initially, the overall efficiency of each decision-making unit [DMU] (i.e., firm/household/province) relative to the optimal level is expressed through total factor productivity efficiency (TFPE) (O'Donnell, 2012a, 2012b). Accordingly, TFPE is measured as the ratio of actual TFP to TFP under optimal conditions (TFP*) given at time $t$ and specific area. The total production efficiency of DMU $n$ in period $t$ is thus presented.

$$TFPE_{n,t} = \frac{TFP_{nt}}{TFP_t^*} = \frac{Y_{nt}}{X_{nt}} \Big/ \frac{Y_t^*}{X_t^*} \qquad (3)$$

where $TFP_t^*$ represents the maximum TFP that can be achieved in period t with existing technology, $X_t^*$ and $Y_t^*$ denote the aggregate input and output, respectively, under optimal TFP conditions. In economic terms, this signifies whether the firm exhibits flexibility in using inputs and outputs to optimize resources and whether it operates under optimal conditions. Considering Figure 2, a DMU needs to evaluate its TFP efficiency, represented by point A; accordingly, TFP is measured by the slope of line OA (where point O is the origin, and aggregate input and aggregate are both equal to 0), and the slope of line OE denotes the maximum achievable TFP* in the same period.

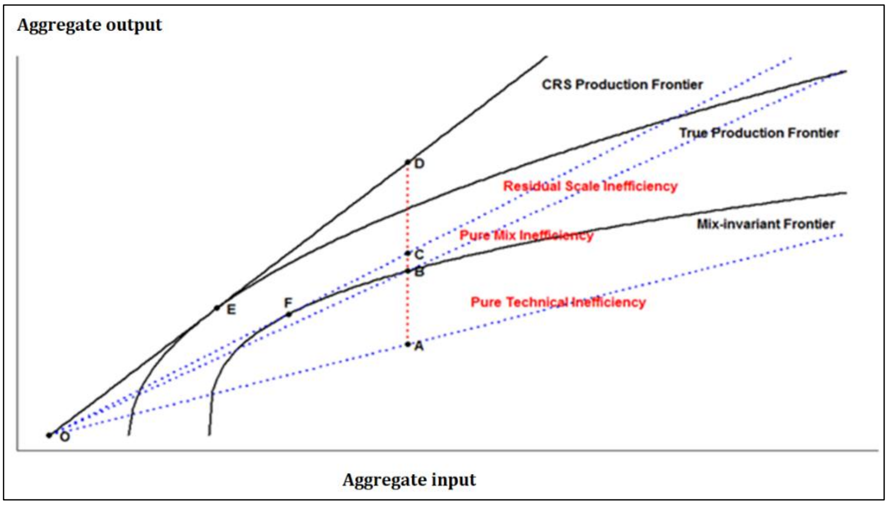


**Figure 2: Definition of TFP and decomposition of indicators through economies of scale**

Source: Redrawn by the authors using R software (see more O'Donnell, 2012a,b)**O'Donnell (2012a, b) decomposes TFPE in a number of different ways. For example, expressed through the formula:**

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$$TFPE_{n,t} = OTE_{n,t} \times OSE_{n,t} \times RME_{n,t} = OTE_{n,t} \times OME_{n,t} \times ROSE_{n,t} \quad (4)$$

where $OTE_{nt}$ (output – oriented pure technical efficiency), $OSE_{nt}$ (scale efficiency) and $RME_{nt}$ (residual mixed efficiency), $OME_{nt}$ (mix efficiency) and $ROSE_{nt}$ (residual output-oriented scale efficiency) represent different aspects of efficiency. OTE measurement is also known as technical efficiency, which focuses on output orientation and was proposed initially by Farrell (1957). OTE can be understood as comparing DMUs using the best possible inputs and outputs in the current real-world situation. In mathematical terms, it involves comparing the aggregate output of a DMU with the optimal aggregate output that can be achieved by using the same aggregate input while holding the components of each output constant. This difference is illustrated in the main figure, showing the slope contrast between OB and OA, where OTE equals the slope of OA divided by the slope of OB. The curve passing through point B represents the mix-invariant frontier.

OSE denotes, in economic terms, the operation of DMUs at an optimal scale in the current real-world scenario; accordingly, it signifies the transition from a mix-invariant production path to another mix-invariant production frontier with the assumption of constant returns to scale. From a mathematical perspective, OSE is measured as the ratio of the slope of OB to OC. The key distinction between points C and D (as shown in Figure 2) primarily measures the excess factors due to inefficient resource allocation for output selection. This alteration involves comparing the aggregate input between the two enveloping frontiers with a constant scale but different assumed output combinations. This efficiency is quantified by RME, which is the ratio of the slope of OC to the slope of OD or OE. Therefore, we have:

$$TFPE_{n,t} = \frac{TFP_{nt}}{TFP_t^*} = \frac{Slope\ of\ OA}{Slope\ of\ OE} = \frac{Slope\ of\ OA}{Slope\ of\ OB} \times \frac{Slope\ of\ OB}{Slope\ of\ OC} \times \frac{Slope\ of\ OC}{Slope\ of\ OE} \quad (5)$$

In economic terms, to put it differently, OTE reflects the efficiency of provinces/ firms/ households in adopting the latest fishing techniques within their community. OSE or ROSE, on the other hand, captures the scale efficiency (compared to the optimal level for provinces/firms/households within their community), while RME or OME mirrors the efficiency in allocating input resources (among different fishing methods and the type of tuna caught) given the available resources at a particular point in time with constant technology. Thus, The change of firm n between two periods $t_1$ and $t_2$ can be defined as follows:

$$TFP_{n,t_1,t_2} = \left(\frac{TFP_{n,t_2}}{TFP_{n,t_1}}\right) \quad (6)$$

$$TFP_{n,t_1,t_2} = \left(\frac{TFP_{t_2}^*}{TFP_{t_1}^*}\right) \times \left(\frac{OTE_{n,t_2}}{OTE_{n,t_1}}\right) \times \left(\frac{OSE_{n,t_2}}{OSE_{n,t_1}}\right) \times \left(\frac{RME_{n,t_2}}{RME_{n,t_1}}\right) \quad (7)$$

The first and second components in equation (7) represent dTECH and dOTE, respectively, reflecting changes in technology and technical efficiency between the two stages. The last two ratios in equation (7), denoted as dOSE and dRME, correspondingly indicate changes in scale efficiency and the way input and output products are combined.

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### *3.3. Data*

The research data was collected from the Vietnam Directorate of Fisheries. The data is organized in the form of panel data, covering three key tuna fishing provinces in Vietnam: Phu Yen, Binh Dinh, and Khanh Hoa, during the period from 2010 to 2017. Specifically, the research data was collected for the three main tuna fishing occupations in this region, which include purse seine fishing, pole-and-line fishing, and gillnet fishing. The choice of the year 2017 has two main reasons that drive the endpoint: first, to ensure data consistency, notably after Vietnam received the yellow card from the European Commission due to IUU fishing in Ecuador, which led to significant policy changes, notably the 2017 Fishing Law. Thus, we focused on a stable and consistent policy period to minimize potential inaccuracies. Second, the availability of data is a crucial consideration. In practice, data on marine capture are private and are not collected regularly. Therefore, the period from 2010 to 2017 was selected to ensure data consistency and availability. To assess the efficiency of ocean tuna fishing occupations, this research treats the fishing activities of each province/region as a production function with five inputs aimed at producing an optimal level of output. The inputs of this fishing process (production) include five types of vessels, specifically: (a) vessels with a capacity of 50-89 GT, (b) vessels with a capacity of 90-149 GT, (c) vessels with a capacity of 150-249 GT, (d) vessels with a capacity of 250-399 GT, and (e) vessels with a capacity greater than 400 GT. The output consists of the total catch of three main types of oceanic tuna: bigeye tuna, yellowfin tuna, and skipjack tuna. It should be noted that these three fishing occupations catch different species of tuna, even though there are some common species, such as bigeye tuna, yellowfin tuna, and skipjack tuna. Thus, caution is required when considering the output based on the total production of the three main tuna species.

In general, each fishing occupation tends to focus on catching certain species that are most suitable for their specific fishing techniques. In Vietnam, pole-and-line fishing efficiently catches bigeye and yellowfin tuna and is prominent in Khanh Hoa and Binh Dinh provinces. Gillnet fishing primarily targets skipjack tuna and is prominent in Phu Yen and Binh Dinh provinces. Purse seine fishing mainly captures skipjack tuna and is prominent in Phu Yen and Khanh Hoa provinces. Furthermore, the combined total of the three main tuna species, bigeye tuna, yellowfin tuna, and skipjack tuna, accounts for a significant portion of the catch composition, precisely over 68% for pole-and-line fishing, over 75% for gillnet fishing, and over 88% for purse seine fishing, during the 2010-2017 period. Given the relatively minor price differences among these three species and the research's focus on maximizing output while minimizing inputs, the selection of the output as the total production of these three tuna species is deemed appropriate. Second, to ensure a more accurate assessment of the operational efficiency of tuna fishing, the data arrangement and selection must consider external environmental factors (or control for differences). Within the scope of this study, environmental variables can be divided into two main groups: (a) the working environment on the vessels is determined by the equipment and gear used on the fishing boats and the characteristics of the fishing vessels (e.g., length, capacity, engine power of different vessel types, radar systems, new equipment/fishing gear, and fishing efforts). (b) The environmental conditions beyond control include government fishing policy systems, natural climate variations, and changes in

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fish stocks due to water conditions or currents, among others. Indeed, there are other environmental conditions (shock events) that may include phenomena like the Formusa sea pollution incident in 2016 or European Union warnings/yellow cards regarding this issue. These aspects have been discussed in various sources (Antonius Gagern & Jeroenvan den Bergh, 2013; Liam Campling, 2016; Nguyen Ngoc Duy, Ola Flaaten, & Le Kim Long, 2015; Rahmadi Sunoko & Hsiang-Wen Huang, 2015). However, the data arrangement method, which includes five inputs represented by five types of vessels and the output as the total production of three main tuna species, as previously described, can help address certain issues related to the working environment on vessels. In practice, the classification of the five vessel types, based on their engine power, allows for the direct or indirect control of the input characteristics, particularly engine power, length, capacity, and other relevant features of each vessel type. Moreover, each vessel type typically corresponds to specific fishing gear and equipment. Thus, the data organization method presented earlier is well-suited for effectively controlling the operational conditions on the vessels. Concerning the group of uncontrollable environmental variables, it is assumed in this study that these conditions remain relatively stable over the short research period of 2010-2017 for the three provinces: Phu Yen, Binh Dinh, and Khanh Hoa. Additionally, the Vietnamese government's policy conditions and sudden shocks that could affect the evaluation of the operational efficiency of ocean tuna fishing during the 2010-2017 period are the same. The table below describes usage data.

**Table 1: Descriptive Statistics**

| Provinces | Inputs/outputs | Min | Mean | Max | SD |
|---|---|---|---|---|---|
| Phu Yen | **Inputs:** | | | | |
| | (1) Ships with capacity of 50-89. | 1 | 52.90 | 135.00 | 9.73 |
| | (2) Ships with capacity 90-149. | 1 | 40.10 | 185.00 | 11.43 |
| | (3) Ships with capacity 150-249. | 1 | 65.14 | 295.00 | 21.38 |
| | (4) Ships with capacity 250-399 | 1 | 53.29 | 328.00 | 19.89 |
| | (5) Ships with capacity > 400. | 1 | 34.05 | 252.00 | 16.69 |
| | **Output:** | | | | |
| | Total output | 41 | 725.81 | 2728.00 | 178.96 |
| Binh Dinh | **Inputs:** | | | | |
| | (1) Ships with capacity of 50-89. | 1 | 30.33 | 125.00 | 9.06 |
| | (2) Ships with capacity 90-149. | 1 | 24.38 | 328.00 | 15.36 |
| | (3) Ships with capacity 150-249. | 1 | 68.71 | 463.00 | 24.86 |
| | (4) Ships with capacity 250-399 | 1 | 123.14 | 438.00 | 28.07 |
| | (5) Ships with capacity > 400. | 1 | 225.52 | 971.00 | 65.07 |
| | **Output:** | | | | |
| | Total output | 16 | 1618.66 | 6175.00 | 400.38 |
| Khanh Hoa | **Inputs:** | | | | |
| | (1) Ships with capacity of 50-89. | 1 | 1.00 | 1.00 | 0.00 |
| | (2) Ships with capacity 90-149. | 1 | 13.38 | 55.00 | 3.84 |
| | (3) Ships with capacity 150-249. | 1 | 14.76 | 35.00 | 2.88 |
| | (4) Ships with capacity 250-399 | 1 | 51.33 | 121.00 | 9.87 |
| | (5) Ships with capacity > 400. | 1 | 45.38 | 218.00 | 12.47 |
| | **Output:** | | | | |
| | Total output | 12 | 2370.58 | 11427.00 | 754.68 |

Source: Authors collected from the Vietnam Directorate of Fisheries

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## 4. RESULTS AND DISCUSSION

### *4.1. Basic Results*

Table [2] evaluates the efficiency of ocean tuna fishing across different fishing methods. Overall, the efficiency of ocean tuna fishing in Vietnam is relatively limited but possesses high development potential; accordingly, the efficiency levels within the provinces vary between 25% and 35% compared to the potential level (as indicated by TFPE). In other words, if the maximum potential is attained, the tuna fishing industry in Vietnam could experience an additional growth of 65%-75%.

The contribution to the current TFPE efficiency mainly depends on output-oriented technical efficiency (OTE), with efficiencies ranging from 0.6234 to 0.9539, averaging around 0.8207. These findings align with previous research on the evaluation of technical efficiency (TE), particularly in the study by Thi Duy Thanh Pham, Hsiang-WenHuang, and Ching-Ta Chuang (2014). Significantly, scale efficiency, as indicated by OSE and ROSE scores, is low, typically below 0.4. In simple terms, on average, the tuna units are operating at only 40% efficiency compared to their peers within their fishing community. This can be attributed to two main factors. First, overfishing occurs, where the exploitation rate surpasses the environmental carrying capacity, as recently highlighted in a study by Nguyen and Tran (2023). Secondly, small-scale operations prevent fishermen from achieving economies of scale. Also, the fishing vessels are equipped with rudimentary tools and equipment. Therefore, improvements in Vietnam's tuna fishing industry could reach up to 60% through measures such as (i) reducing the number of small-scale tuna fishing vessels, including those catching underdeveloped species and violating international laws, as highlighted in studies by Nguyen and Tran (2023) and Thi Duy Thanh Pham et al. (2014); and (ii) enhancing the scale, knowledge, and equipment of fishing vessels that engage in the industry.

**Table 2: Evaluating the efficiency of ocean tuna fishing by occupation (longline, gillnet, purse seine)**

| Indicators | longline fishing | Gillnet fishing | Purse seine |
|---|---|---|---|
| Total factor productivity efficiency (TFPE) | 0.3311 | 0.2466 | 0.3496 |
| Output-oriented technical efficiency (OTE) | 0.9539 | 0.6234 | 0.8849 |
| Output-oriented scale mixed efficiency (OSME) | 0.3471 | 0.3957 | 0.3951 |
| Output-oriented scale efficiency (OSE) | 0.9695 | 0.6260 | 0.5498 |
| Residual mixed efficiency (RME) | 0.3581 | 0.6321 | 0.7187 |
| Output-oriented mixed efficiency (OME) | 1.0000 | 1.0000 | 1.0000 |
| Residual output-oriented scale efficiency (ROSE) | 0.3471 | 0.3957 | 0.3951 |

Source: Authors (based on method of O'Donnell, 2012a, b)

### *4.2. Evaluate the effectiveness between provinces according to each fishing method*

Table [3] considers the efficiency of ocean tuna fishing between provinces and across different fishing methods, namely gillnet fishing, purse seine, and longline. The efficiency levels vary among the provinces and fishing methods for catching ocean tuna. For example, Khanh Hoa

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reveals efficiency in longline fishing (62.84%) and purse seine (36.19%). Phu Yen, on the other hand, exhibits efficiency in gillnet fishing (59.46%) and purse seine (63.04%). Binh Dinh showcases its efficiency in longline fishing (32.76%) and gillnet fishing (56.42%). These variations emphasize the importance of having targeted exploitation strategies for different fishing areas. For instance, with fixed input resources, shifting from purse seine to longline fishing in Khanh Hoa can improve efficiency by over 26%.

Similarly, transitioning from longline fishing to gillnet fishing in the Binh Dinh region may enhance efficiency by nearly 24%. It is worth noting that Binh Dinh, Khanh Hoa, and Phu Yen are adjacent provinces that collectively exploit the tuna fishing area depicted in Figure [1]. In other words, this transition presents minimal geographical barriers. Contributions to the efficiency of tuna fishing are also reflected through OTE and OSME indices. Remarkably, technical efficiency in Khanh Hoa is lower than the overall average, indicating room for significant improvement by enhancing knowledge exchange and technology transfer among fishermen.

**Table 3: Evaluate the effectiveness between provinces according to each fishing method**

| **Longline fishing** | **TFPE** | **OTE** | **OSME** | **OSE** | **RME** | **OME** | **ROSE** |
|---|---|---|---|---|---|---|---|
| Phu Yen | 0.1763 | 1.0000 | 0.1763 | 0.9505 | 0.1855 | 1.0000 | 0.1763 |
| Binh Dinh | 0.3276 | 1.0000 | 0.3276 | 0.9609 | 0.3410 | 1.0000 | 0.3276 |
| Khanh Hoa | 0.6284 | 0.8679 | 0.7240 | 0.9977 | 0.7257 | 1.0000 | 0.7240 |
| **Gillnet fishing** | **TFPE** | **OTE** | **OSME** | **OSE** | **RME** | **OME** | **ROSE** |
| Phu Yen | 0.5946 | 1.0000 | 0.5946 | 1.0000 | 0.5946 | 1.0000 | 0.5946 |
| Binh Dinh | 0.5642 | 1.0000 | 0.5642 | 0.8543 | 0.6604 | 1.0000 | 0.5642 |
| Khanh Hoa | 0.1274 | 0.6929 | 0.1839 | 0.1946 | 0.9453 | 1.0000 | 0.1839 |
| **Purse seine** | **TFPE** | **OTE** | **OSME** | **OSE** | **RME** | **OME** | **ROSE** |
| Phu Yen | 0.6304 | 1.0000 | 0.6304 | 0.7437 | 0.8477 | 1.0000 | 0.6304 |
| Binh Dinh | 0.0657 | 0.3293 | 0.1998 | 0.3299 | 0.6057 | 1.0000 | 0.1998 |
| Khanh Hoa | 0.3619 | 0.7358 | 0.4918 | 1.0000 | 0.4918 | 1.0000 | 0.4918 |

Source: Authors (based on method of O'Donnell, 2012a, b)

### *4.3. Evaluate the effectiveness over time according to each fishing method*

One of the crucial tasks in exploring overfishing areas is to examine the temporal trends among them. In this regard, Table [4] evaluates the efficiency of ocean tuna fishing by year, categorized by fishing methods. Evaluating the efficiency of ocean tuna fishing over time and by fishing methods reveals some noteworthy points. *First*, the potential for ocean tuna fishing (TFP*) experiences significant growth each year, with longline and purse seine fishing showing more substantial increases. This explains why some forecasts tend to be overconfident in the development of tuna fishing activities in certain Southeast Asian countries, as these forecasts consider their potential rather than the actual exploitation status (Batty & Fernandes, 2018; Dammannagoda, 2018).

*Second*, the efficiency of ocean tuna fishing, as represented by TFPE, demonstrates substantial variations. For instance, while longline and purse seine fishing exhibit growth similar to an inverted U-shape, gillnet fishing experienced growth after 2014. It is worth noting that, by

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2017, the average efficiency of tuna fishing across these methods reached approximately 40% compared to the potential level. The U-shaped productivity pattern, as depicted in Figure [3], strongly implies overfishing by Vietnamese fishermen in these two fishing methods.

*Third*, the efficiency of ocean tuna fishing primarily derives from the component of technical efficiency, which remains stable over time (maintaining an efficiency level of 82%-90%). In practice, Vietnamese fishermen have formed self-organized communities to share knowledge about seafaring, shipbuilding techniques, or various forms of sea-related collaboration. Nevertheless, cooperation between fishermen and local government authorities has several limitations, especially regarding adherence to common fishing regulations (Nguyen & Tran, 2023).

*Fourth*, the combined scale efficiency (OSME) is still low and has considerable potential for future development. Combined scale efficiency reflects the flexibility of the local population in sea-related matters, including the ability to shift fishing methods and vessel types and adapt to changes in fishing scale. In Vietnam, low efficiency in ocean tuna fishing is significantly affected by small-scale fishing. Also, the influence of techniques, fishing equipment, and other support technologies impacts the realization of the potential of tuna fishing.

**Table 4: Evaluating the efficiency of tuna fishing over time by methods (longline, seine, gillnet)**

| **Longline fishing** | **TFP*** | **TFPE** | **OTE** | **OSME** | **OSE** | **RME** | **OME** | **ROSE** |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.5225 | 0.1909 | 1.0000 | 0.1909 | 0.8093 | 0.2359 | 1.0000 | 0.1909 |
| 2011 | 0.5225 | 0.3750 | 0.7185 | 0.5220 | 0.9947 | 0.5248 | 1.0000 | 0.5220 |
| 2012 | 0.5225 | 0.5853 | 1.0000 | 0.5853 | 1.0000 | 0.5853 | 1.0000 | 0.5853 |
| 2013 | 0.5225 | 0.3091 | 1.0000 | 0.3091 | 1.0000 | 0.3091 | 1.0000 | 0.3091 |
| 2014 | 0.5264 | 0.2155 | 1.0000 | 0.2155 | 1.0000 | 0.2155 | 1.0000 | 0.2155 |
| 2016 | 0.5264 | 0.3758 | 1.0000 | 0.3758 | 1.0000 | 0.3758 | 1.0000 | 0.3758 |
| 2017 | 0.5264 | 0.4163 | 1.0000 | 0.4163 | 1.0000 | 0.4163 | 1.0000 | 0.4163 |
| **Gillnet fishing** | **TFP*** | **TFPE** | **OTE** | **OSME** | **OSE** | **RME** | **OME** | **ROSE** |
| 2010 | 0.1715 | 0.0849 | 0.2754 | 0.3085 | 0.7700 | 0.4006 | 1.0000 | 0.3085 |
| 2011 | 0.1715 | 0.2413 | 0.6562 | 0.3676 | 0.5533 | 0.6644 | 1.0000 | 0.3676 |
| 2012 | 0.1715 | 0.1570 | 0.2772 | 0.5672 | 1.0000 | 0.5672 | 1.0000 | 0.5672 |
| 2013 | 0.3377 | 0.1145 | 1.0000 | 0.1145 | 0.2772 | 0.4129 | 1.0000 | 0.1145 |
| 2014 | 0.3450 | 0.5075 | 0.9131 | 0.5558 | 0.6500 | 0.8552 | 1.0000 | 0.5558 |
| 2016 | 0.3450 | 0.5526 | 0.9204 | 0.6003 | 0.7005 | 0.8569 | 1.0000 | 0.6003 |
| 2017 | 0.4981 | 0.5374 | 0.8692 | 0.6183 | 0.7005 | 0.8825 | 1.0000 | 0.6183 |
| **Purse seine** | **TFP*** | **TFPE** | **OTE** | **OSME** | **OSE** | **RME** | **OME** | **ROSE** |
| 2010 | 0.1960 | 0.5780 | 1.0000 | 0.5780 | 0.5829 | 0.9915 | 1.0000 | 0.5780 |
| 2011 | 0.1960 | 0.4435 | 1.0000 | 0.4435 | 0.4804 | 0.9232 | 1.0000 | 0.4435 |
| 2012 | 0.1960 | 0.4825 | 1.0000 | 0.4825 | 0.5829 | 0.8278 | 1.0000 | 0.4825 |
| 2013 | 0.5471 | 0.1547 | 1.0000 | 0.1547 | 0.5829 | 0.2653 | 1.0000 | 0.1547 |
| 2014 | 0.5471 | 0.2772 | 1.0000 | 0.2772 | 0.4445 | 0.6236 | 1.0000 | 0.2772 |
| 2016 | 0.5509 | 0.3560 | 1.0000 | 0.3560 | 0.3919 | 0.9084 | 1.0000 | 0.3560 |
| 2017 | 0.5509 | 0.3383 | 0.4249 | 0.7964 | 0.9161 | 0.8693 | 1.0000 | 0.7964 |

Source: Authors (based on method of O'Donnell, 2012a, b)

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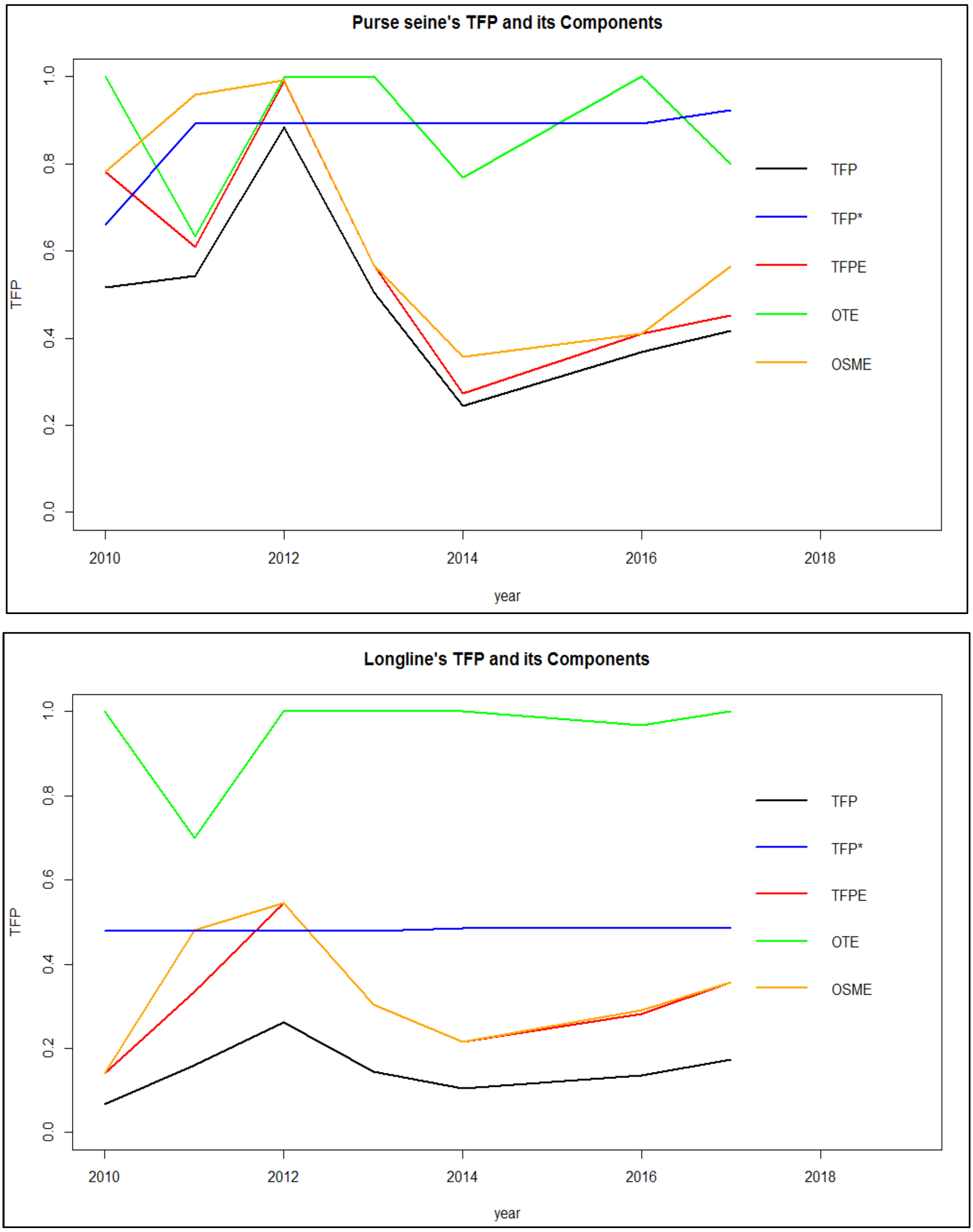


**Figure 3: Evolution of TFP and its components**

Source: Authors (based on method of O'Donnell, 2012a, b)

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## 5. CONCLUSION

Ensuring optimal marine resource exploitation is considered a paramount global task, especially in light of the numerous endangered aquatic species. Tuna, having been exploited for decades, has exhibited a trend of uncontrolled resource extraction, particularly in disputed marine territories among nations.

Determining the optimal fisheries yield and devising enforceable exploitation policies have encountered several hurdles in recent decades, particularly in countries undergoing transitions characterized by inconsistent policy approaches.

This study aims to provide insights into the tuna fishing practices in Vietnam, a transitioning nation, in an effort to formulate effective marine exploitation policies based on an approach that prioritizes the welfare of local communities over government-imposed policies and law. To achieve this, our primary approach involves an extensive examination of the evolution of tuna species' productivity under various fishing methods from 2010 to 2017.

Moreover, we focus on identifying the specific components that most significantly influence Total Factor Productivity (TFP) during this period. A decline in productivity, subsequently reducing income and welfare, serves as a crucial warning to fishing communities about the consequences of overexploiting marine resources. This decline is the most effective means to alert households to the issue of overfishing.

This research leverages the advantages of the Fa ̈re-Prinoment index and yields noteworthy results. *First*, it forecasts that Vietnam, situated in the Pacific Ocean region, holds substantial potential for the future development of ocean tuna fishing. However, during the 2010-2017 period, the efficiency of ocean tuna fishing in Vietnam reached only 25-35% of its potential.

This limitation is primarily attributed to the lack of scale efficiency (overexploitation involving small-scale vessels without adequate fishing equipment), which has been maintained at a 40% level relative to its potential. In other words, enhancing the efficiency of tuna fishing can result in nearly a 60% improvement by reducing the number of small-scale vessels involved in fishing and adopting strategies to transition to larger vessels equipped with proper fishing gear and specialized knowledge for various fishing methods.

*Second*, under unchanged conditions, shifting specific fishing methods in various provinces/regions within Vietnam can also improve productivity by approximately 20%, contingent on the advantages and skills of fishermen. Lastly, based on our direct interaction with fishermen in the research area, the acquisition of seafaring knowledge and the self-initiated acquisition of fishing equipment and techniques are pivotal.

Government support is crucial for equipping local communities with knowledge and offering related support services. Thus, removing the barriers between the government and local fishermen might become one of Vietnam's primary tasks before considering broader discussions on digital transformation or imposing stricter regulations on the local population.

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