Yıldız Sos Bil Ens Der, Cilt. 8, Sayı. 2, pp. 90−100, 2024

Yıldız Sosyal Bilimler Enstitüsü Dergisi
Yıldız Social Sciences Institute Journal
Web sayfası bilgisi: https://ysbed.yildiz.edu.tr
DOI: 10.14744/ysbed.2024.00046

Original Article / Orijinal Makale

Harvest function and determinants of technical inefficiency in Turkish large-scale marine fisheries

Türkiye'deki büyük ölçekli deniz balıkçılığında hasat fonksiyonu ve teknik verimsizliğin belirleyicileri

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ARTICLE INFO

Article history
Received: 28 October 2024
Revised: 19 November 2024
Accepted: 12 December 2024

Keywords:
Stochastic frontier model, inefficiency effects, harvest function, fisheries management.

ABSTRACT

This study examines the harvest function and factors of technical inefficiency in Turkish large-scale marine fisheries, using data from the TURKSTAT Fisheries Statistics Micro Data Set. The main purpose is to incorporate bioeconomic modeling into technical efficiency analysis by estimating a stochastic frontier harvest function that considers both fishing effort and stock biomass. Through inefficiency effects model, the influences of vessel attributes, gear types, fishing areas, and technological instruments on the technical inefficiency of fishing units are investigated. The results indicate that fishing efficiency is influenced by gear type, regional practices, and the accessibility of specific technologies. Specifically, environmentally unfavorable methods like bottom trawling are demonstrated to be less efficient than other techniques. Additionally, Turkish fisheries are experiencing diminishing returns to both effort and stock, underlining the need for more rigorous effort reduction policies and adaptive quota regulations, particularly for economically essential species. Moreover, the results provide guidance for improving fisheries management policies in Türkiye and highlight the importance of balancing efficiency and sustainability through enhanced regulation of fishing practices, technological advancements, and regional management approaches.

Cite this article as: Güngör V, Taştan H. Harvest function and determinants of technical inefficiency in Turkish large-scale marine fisheries. Yıldız Sos Bil Ens Der 2024;8:2:90−100.

MAKALE BİLGİSİ

Makale Hakkında
Geliş tarihi: 28 Ekim 2024
Revizyon tarihi: 19 Kasım 2024
Kabul tarihi: 12 Aralık 2024

Anahtar kelimeler:
Stokastik sınır modeli, verimsizlik etkileri, hasat fonksiyonu, balıkçılık yönetimi.

ÖZ

Bu çalışma, TÜİK Su Ürünleri İstatistikleri Mikro Veri Seti'nden elde edilen verileri kullanarak Türkiye'deki büyük ölçekli deniz balıkçılığının hasat fonksiyonunu ve teknik verimsizlik faktörlerini incelemektedir. Temel amaç, hem balıkçılık çabasını hem de stok biyokütlesini dikkate alan stokastik bir sınır üretim fonksiyonu tahmin ederek biyoekonomik modellemeyi teknik verimlilik analizine dahil etmektir. Verimsizlik etkileri modeli aracılığıyla, tekne özelliklerinin, av aracı türlerinin, avlanma alanlarının ve teknolojik araçların balıkçılık birimlerinin teknik verimsizliği üzerindeki etkileri araştırılmıştır. Sonuçlar, balıkçılık verimliliğinin av aracı türü, bölgesel uygulamalar ve belirli teknolojilerin erişilebilirliğinden etkilendiğini

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Published by Yıldız Technical University, İstanbul, Türkiye

göstermektedir. Özellikle, dip trolü gibi çevresel açıdan elverişsiz yöntemlerin diğer tekniklere göre daha az verimli olduğu gösterilmiştir. Buna ek olarak, Türkiye'deki balıkçılıkta hem çabanın hem de stokun getirisi azalmakta, bu da özellikle ekonomik açıdan önemli türler için daha titiz çaba azaltma politikalarına ve uyarlanabilir kota düzenlemelerine duyulan ihtiyacın altı çizilmektedir. Ayrıca sonuçlar, Türkiye'deki balıkçılık yönetimi politikalarının iyileştirilmesi için yol göstermekte ve balıkçılık uygulamalarının daha iyi düzenlenmesi, teknolojik ilerlemeler ve bölgesel yönetim yaklaşımları yoluyla verimlilik ve sürdürülebilirliğin dengelenmesinin önemini vurgulamaktadır.

Atıf için yazım şekli: Güngör V, Taştan H. Türkiye'deki büyük ölçekli deniz balıkçılığında hasat fonksiyonu ve teknik verimsizliğin belirleyicileri. Yıldız Sos Bil Ens Der 2024;8:2:91–100.

INTRODUCTION

Resource conservation, food production, economic wealth generation, including equitable income and sustained employment for fishers, and the preservation of fishing community existence can be listed as the primary objectives of fisheries management. For these purposes, sustainability and efficiency of fisheries and equity among stakeholders are essential concepts that policymakers must follow (Mardle et al., 2002).

Thus, analyses of efficiency and productivity in fisheries are crucial for assessing the performance of a decision-making fishing unit and identifying opportunities for enhancement. Such analyses facilitate the monitoring of the economic welfare of participants in capture fisheries. Some knowledge regarding efficiency, productivity, and their determinants can assist fishers in enhancing economic performance and profits, while policymakers may utilize this information to formulate suitable and effective policies for sustainable fisheries management moving forward (Van Nguyen & See, 2023).

Although most economic models accept the premise that all firms operate efficiently, empirical observations typically indicate a significant presence of inefficiency in reality. Variations in inefficiencies among firms, regions, or countries may stem from diverse managerial practices. Technical efficiency is a metric normalized against a benchmark, such as the corresponding frontier outcome, which is optimal concerning the criteria of maximizing output for a given level of input and technology (Kumbhakar et al., 2018).

Most studies examining technical efficiency in fisheries have treated the technical and employment attributes of vessels as inputs, modeling the quantity of fish caught as a function of these factors. This methodology renders output a function solely of technical capital or fishing effort in bioeconomic models, while omitting fish stocks, resulting in omitted variable bias. Conversely, bioeconomic models posit that all fishers function optimally with efficient use of effort and exploitation of stocks.

The main purpose of this study is to form a bridge between these two approaches by incorporating bioeconomic harvest function into the technical efficiency analysis. The inefficiency effects model suggested by Battese & Coelli (1995) allows for simultaneously estimating both the stochastic frontier, in which harvest is a function of effort and stock, and the determinants of inefficiency.

Although there are some studies that incorporate stock levels in their analysis, this is the first study that employs TURKSTAT Fisheries Micro Data Set for this purpose. The monthly data set includes technical, geographical, and operative information on all large-scale fishing units responsible for more than half of the total catch in Turkish territorial waters. Moreover, the monthly stock data employed in this study were previously estimated utilizing the same dataset and grounded in a modification to the methodology suggested by Zhang & Smith (2011).

Hence, this is a comprehensive study that can guide fisheries management in Türkiye. It allows for inferences regarding the significance of effort reduction policies, the imperative to diminish environmentally detrimental fisheries, the regions that should be prioritized in policy formulation, and the application of quotas.

The following section provides background information on fisheries policy in Türkiye. A review of the pertinent literature is subsequently provided. The stochastic frontier model and its variables are elucidated in the methodology section. The fifth section provides information regarding the data set and descriptive statistics. Following the summary of results in the sixth section, a discussion ensues in the subsequent section. The final section concludes.

BACKGROUND

The capture fisheries and aquaculture sectors are essential for global food security, employment, and economic development, especially in coastal areas. This has been mainly driven by the recent growth of aquaculture, the most rapidly expanding food sector globally (Troell et al., 2014). At the same time, the harvest levels of capture fisheries have remained stagnant over the past decades (FAO, 2022). The decline in wildlife livestock and habitat loss attributed to climate change (Calvin et al., 2023), marine pollution (Jeftic et al., 2009), and overfishing (Srinivasan et al., 2010) are regarded as the primary reasons for this trend.

Among these impacts, overfishing is arguably the most significant factor contributing to the depletion of stocks. This issue is relevant to fishing effort, which entails the technical capabilities of vessels and the duration of fishing activities. Over the years, advancements in fisheries technologies and the profitable nature of industrial fishing, along with heightened consumer and input demand, have led to a consistent increase in global fishing capacity and effort (Anticamara et al., 2011; Bell et al., 2017). Consequently, there has been an estimated annual rise in global catch losses of around 0.25 million tonnes due to overfishing (Srinivasan et al., 2010).

As a peninsular country, Türkiye is surrounded by the Black Sea to the north, the Aegean Sea to the west, and the Levantine Sea to the south. The Marmara Sea, completely encircled by the country's coastlines, acts as a link between the Aegean Sea and the Black Sea via the Dardanelles and the Bosporus. Ulman et al. (2013) presented a summary of Türkiye's marine fishing history covering those four major marine regions. Between the early 1950s and late 1980s, Türkiye's fishing industry had depicted a rapid growth with the help of technological developments and improved industrial practices. The transition to a market-based economy in the 1980s and increased government investment in the fishing sector have resulted in major transformations in Turkish fishing activities. The expansion of the harvest levels in this period resulted in a historical peak in 1988, followed by sharp declines in consecutive years. This has raised the concerns about overfishing and environmental degradation and necessitated the implementation of new conservation and management strategies, especially for the Black Sea. As a result of the decline in demersal fisheries due to overfishing, some bottom trawl vessels began targeting small pelagic species in the 1990s. This was a period of significant increases in anchovy fishing, making it a vital part of the industry.

Today, fisheries management is centrally executed by the General Directorate of Fisheries and Aquaculture (BSGM) established under the Ministry of Agriculture and Forestry (TOB). The regulations on fisheries are outlined in circulars published every four years. The most recent document regarding commercial fishing activities, Circular No. 6/1 (Resmi Gazete, 2024), defines its aim as "to regulate obligations, restrictions and prohibitions pertaining to fisheries to safeguard fishery resources and guarantee their sustainable management, considering scientific, environmental, economic, and social factors". Overall, the Circular specifies regulations concerning both inputs and outputs.

The input controls can be associated with the regulations on seasons, locations and fishing techniques. Specifically, the majority of the large-scale fishing activities are prohibited in the country's territorial waters from April 15 to August 31. Moreover, many well-defined locations where fishing is completely forbidden are listed. Additionally, many restrictions on net length, mesh size, distance to coast, water depth, and light use are listed for various gear types and fishing methods.

On the other hand, the output controls that require landing inspections are related to the quality and quantity of the fishing activities. To begin with, many species that are completely forbidden to catch are listed. Besides, minimum size and weight requirements for others are tabulated. Still, in case of bycatch, at most 5% of the total catch is permitted by the Circular.

Finally, species that are subject to annually determined quota levels are specified. Among those, turbot (scophthalmus maximus), Atlantic bluefin tuna (Thunnus thynnus), baby clam (chamelea gallina), sea cucumber (holothuroidea), and eel (anguilla anguilla) have already been subject to quota in Circular No. 5/1 (Resmi Gazete, 2020). In contrast, European anchovy (engraulis encrasicolus) has been added to the new document for the first time, and its quota level is determined as 400000 tons for 2024-2025 fishing season. However, this quota for anchovies exceeds the 273914 tons caught in 2023, becoming the peak level in the past decade.

Moreover, despite the strict regulations on environmentally infamous fishing methods, bottom trawling is the most frequently used method among the large-scale fishing units that are responsible for the 68% of the total catch between 2015 and 2021. Coupled with unspecified trawling, beam trawling and dredging, they constitute almost half of the monthly observations.

Furthermore, despite the detailed structure of the regulations, there are no regulations addressing the potential impacts of fishing technologies, except the frequency output limitation on sonar use in the Marmara Sea. Technological devices are essential in providing navigational and communicational safety for the workers, reducing bycatch of irrelevant species, and increasing fishing efficiency. However, some of them might be cancelling out the benefits of the regulations that limit fishing capacity and effort. Nævdal (2022) illustrated that the technological developments necessitate an increase in the minimum size of stock required for sustainable fisheries and more conservative harvest rules. In other words, technological devices like sonar and echo sounder yield many economic and environmental benefits only if the regulations are more protective than adequately. As two of the most important goals of environmental policy are efficiency and sustainability, regulatory bodies must seek a balance between these goals in their approach to technology.

LITERATURE REVIEW

The literature on the technical efficiency analysis in fisheries mostly overlooks the possible effect of the stock levels on the production and efficiency possibly due to the lack of data on the stock levels. However, if there are large variations in the stock levels in a given fishery, both parametric and non-parametric analyses may produce biased results. The most popular approaches employed by efficiency and productivity studies in capture fisheries are data envelopment analysis (DEA) and stochastic frontier analysis (SFA) (Van Nguyen et al., 2021; Van Nguyen & See, 2023).

Both methods have benefits and pitfalls. The most significant advantages of DEA as a non-parametric method are that it allows for analyzing multiple outputs and does not require a functional form. However, these analyses cannot capture random errors essential in capture fisheries by their nature. If the associated stock levels are missing in these analyses, the ignored error term will be even larger. On the other hand, by adding a random error term next to the inefficiency component, SFA seems more appropriate in the efficiency analysis of fisheries. In addition, as a parametric approach, it is more relevant for panel data analysis, providing insights into not only the efficiency of fishing activities but also the underlying production functions.

The main problem in employing SFA in fisheries is that it is highly complex, as it requires an appropriate functional form for the frontier, a distributional assumption of the inefficiency component, and a choice of various replaceable inputs that can be included in the analysis. To be more precise, while Esmaeili (2006) and Alvarez et al. (2020) used a Cobb-Douglas production function in the frontier, Coglan & Pascoe (2007) and Quijano et al. (2018) used it in a translog form. In addition, SFA allows for different distributional assumptions on the inefficiency part of the composite error term, including half-normal, truncated-normal, exponential, and gamma distributions. For example, Kirkley et al. (1995) assumed a half-normal distribution compared to others, mostly assuming a truncated normal. More related to data availability, most studies' choices of fixed and variable inputs involve the vessels' technical aspects and fishing durations rather than biomass and composite effort variables standard in the production functions of bioeconomic models. These include but not limited to gross tonnage (Viswanathan et al., 2002), engine power, deck area, and gear length (Fousekis & Klonaris, 2003) as fixed inputs, along with the number of crew members (Susilowati et al., 2005), fishing days or hours he most efficient gears including beam trawl, and fuel consumption (Dağtekin et al., 2021) as variable inputs. Despite these issues creating complexity in its applications, SFA remains a valuable tool for simultaneously estimating the units' production function and inefficiency level.

Despite the extensive tendency to use variables that can only be interpreted as components of the fishing effort, few studies recognize the importance of stock levels' impact on harvest and efficiency. As the biomass data is unavailable for most waters worldwide, actual biomass values based on stock assessment reports are rare. Still (Yang et al., 2017) evaluated the technical efficiencies (TE) of fishing units by using actual stock data as an additional explanatory variable in the frontier. On the other hand, the remaining studies had to use different proxies for the stock biomass. To illustrate, Kirkley et al. (1995) developed one by calculating the average catch level per hour in the last towing. This calculation was based on the geometric mean of the catch by vessels in the same area, during the same period, and with the same dredge size. In their study, Dresdner et al. (2010) developed an abundance indicator by calculating the total amount of fish caught and dividing it by the number of days the fleet was active in a month. Then, they adjusted that value by considering the fleet's average capacity over a year. Nevertheless, none of these studies proposed a link between bioeconomic parameters and efficiency analysis. By using them in SFA, only Duy & Flaaten (2016) compared three stock proxy indexes, including one based on changes in the average level of catch per unit effort (CPUE) to be directly incorporated into the frontier, a CPUE-adjusted output measure, and a composite stock effect index referring to the technical change component of the Malmquist productivity index (MPI). The last one was found to be more robust, although efficiency scores showed no differences.

In addition to different approaches to applying SFA, the purposes of the mentioned studies and their evaluations of TE vary. Nevertheless, it is worth noting that the ones considering biomass as a variable in their analyses provide more specific results than others that interpret their findings to relate to fisheries policy. Some studies have considered the need or effects of individual transferable quotas (ITQs), property rights that allocate specific quotas to individual fishers, aiming to improve efficiency and sustainability. Kirkley et al. (1995) aimed to evaluate the policies to enhance TE and reduce mortality rates. They found that efficient harvest in commercial fisheries is associated with resource abundance and the captain's ability to adapt to changing conditions. In addition, the regulatory policies, including crew size, dredge width, days-at-sea, vessel tracking systems, and minimum fish size restrictions, were found to be ineffective, and the intention to implement ITQs was affirmative as it could increase efficiency and reduce mortality as well as the externalities arising from advanced technology. Susilowati et al. (2005) aimed to highlight the significance of property rights and the contradiction between private technical efficiency and social-technical efficiency in an open-access fishery. To them, private incentives increase fishers' exploitation rates, leading to overfishing and resource depletion; hence, implementing well-defined property rights, such as ITQs or effectively managed common property, could help achieve sustainable resource use and economic efficiency. Similarly, Jeon et al. (2006) also focused on the property rights. For them, increasing TE without addressing property rights and fishing capacity can lead to resource depletion. Policies should balance the need to improve TE with measures to control fishing efforts and protect resource stocks. This may involve better management of property rights and regulation of input use. Dresdner et al. (2010) aimed to estimate the effect of ITQs on fishery efficiency. They found that introducing ITQs had improved fleet efficiency.

Moreover, there are studies that focus on input controls in their analyses. Kompas et al. (2004) aimed to evaluate the impacts of input controls on the TE of fisheries. They found a shift from regulated inputs to unregulated ones that reduced efficiency. They suggest that alternative regulatory measures, such as individual output controls or a mix of input and output controls, might be more effective in promoting economic efficiency while ensuring sustainable fish stocks. Esmaeili (2006) also examined the impact of input controls on TE, suggesting that while these controls are intended to prevent overfishing and ensure sustainable practices, they can also inadvertently constrain technical efficiency by limiting the ability of fishers to optimize their input mix.

Furthermore, some studies focus on the implications of vessel reduction programs. Coglan & Pascoe (2007) aimed to highlight the contradiction between the sustainability gains from decommissioning programs and the enhancements in human capital in fisheries and associated technological developments. They found that while training programs can enhance individual productivity, they may also increase overall fishing efforts, potentially counteracting conservation efforts. Thus, policies must balance these competing objectives. Yang et al. (2017) also focused on the buyback programs in overexploited fisheries. They suggest that vessels with larger sizes and enthusiastic owners should be considered when applying these programs as they are more efficient than others. Quijano et al. (2018) emphasized the inadequacy of buyback programs in a mixed fishery, suggesting considering specific attributes of fleet segments and supporting these programs with regulations including limited seasons and quota regimes.

Finally, remaining studies explore the alternative determinants of TE in fisheries. Viswanathan et al. (2002) evaluated TE as a measure of skipper skill. They found that it varies significantly by season, vessel size, and skipper ethnicity. Fousekis & Klonaris (2003) evaluated TE as an existing potential to increase short-run output without additional fishing effort. TE is influenced by vessel and skipper characteristics, with newer vessels and engines, higher propulsion power, and the skipper's family background and education level positively affecting TE. The study identifies that the fleet operates under increasing returns to scale, suggesting potential productivity gains with increased effort. However, these gains may be negated by adverse effects on resource stocks in the long term. Alvarez & Schmidt (2006) evaluated the variance of the inefficiency component (σ_u^2) as skill and the variance of the error term (σ_v^2) as luck and made a comparison between them. They found that luck is more important in determining the catch levels; thus, the evaluations based on skipper skills are misleading. Van Nguyen et al. (2019) evaluated the effect of regional economic differences in technical efficiencies of open-access fisheries. More developed regions were found to be more efficient than others. Alvarez et al. (2020) found that specialization in target species leads to less efficient harvest. Finally, Dağtekin et al. (2021) studied the determinants of efficiency, including the credit use and subsidy provisions to fishing units. They found that the subsidy rates positively affected efficiency, while credit rates had no significant effect. Hence, subsidies must be carefully regulated to prevent overfishing and ensure sustainable practices.

This is the first study that employs the TURKSTAT Fisheries Statistics Micro Data Set for an estimation of a harvest function in the presence of inefficiency. Thus, an analysis that covers the entire Turkish territorial waters can be conducted. Another unique aspect of this study is that this study uses monthly estimates for aggregated biomass in Turkish territorial waters.

METHODOLOGY

Since the theoretical harvest function is based on the microeconomic theory, it assumes efficient utilization of fishing effort and stock biomass. Nevertheless, although the fishing units can install technological devices unless they initially have them or switch from less efficient gears and regions to more efficient ones, it is not the case in the data sets. Thus, although they can help create a stock index, choice of gear, region, or technology cannot guarantee either efficient exploitation of the estimated stock or the efficient use of the fishing effort.

For these reasons, the model applied in this study offers to estimate both harvest function that is associated with efficient utilization of effort and stock and the parameters of the inefficiency effects that result in deviations from the production possibilities frontier. Following the random effects and time-varying inefficiency effects model suggested by Battese & Coelli (1995), the frontier model is defined as:

$$lnH_{it} = \beta_0 + \beta_1 lnE_{it} + \beta_2 lnX_t + \varepsilon_{it} \tag{1}$$

where H_{it} is the harvest level of fishing unit i at month t, E_{it} is the effort level defined as the product of gross tonnage of the vessel used, monthly fishing days and daily average fishing hours in the month, X_t is the aggregate stock level, and $\varepsilon_{it} = -u_{it} + v_{it}$ is the composite error term. The term, $u_{it} \geq 0$, is the one reflecting technical inefficiency, which is assumed to be an independently distributed random variable with a truncated normal distribution with mean $\boldsymbol{z_{it}\vartheta}$ and constant variance σ_u^2. The term, v_{itj}, is assumed to be an identically and independently distributed stochastic error term with standard normal distribution with mean zero and constant variance σ_v^2. Moreover, u_{itj} and v_{itj} are independent random variables of each other.

At the same time, the inefficiency effects model is defined as:

$$u_{it} = f(\boldsymbol{z_{it}};\boldsymbol{\vartheta}) + \eta_{it} \tag{2}$$

where $\boldsymbol{z_{it}}$ is the vector of inefficiency effects for each observation, including the natural logarithm of the engine power, dummies for seven different gear types, four regions, and the presence of four technologies. In addition, since the fishing units use at least one of the gear types and harvest one of the regions, the value of the intercept reflects the inefficiency level of the base dummy, which uses first gear in the first region and do not use any of the four technologies. Thus, $\boldsymbol{\vartheta}$ is the vector of 17 parameters. Moreover, η_{it} is assumed to be a random variable with truncated normal distribution with zero-mean and constant variance, satisfying $\eta_{it} \geq -\boldsymbol{z_{it}\vartheta}$.

Finally, it is assumed that heteroskedasticity is present in the model and the variance of the stochastic error term is defined as a function of the effort levels. Hence, the following equation is also simultaneously estimated

$$\sigma_v^2 = \gamma_0 + \gamma_1 lnE_{it} + \omega_{it} \qquad (3)$$

DATA AND DESCRIPTIVE STATISTICS

This study is based on the information on large-scale fishing units spanning from January 2015 to December 2021. TURKSTAT Fisheries Statistics Micro Data Set contains monthly information on harvest of each species, components of effort, gear type, and fishing location, and annual information on the technical properties of vessels, including tonnage, engine power, sonar, echo sounder, generator, and cold storage room.

Since each vessel is separated into multiple fishing units in the case that it has changed its gear choice or fishing region, there are 4904 different fishing units observed in 56 months, constituting a total of 69107 observations. Based on the monthly aggregated catch and total effort levels obtained from the data set and monthly estimated stock levels, their fluctuations are depicted in Figure 1.

It can be clearly observed that these three variables generally move together except the fishing ban periods, during which the effort and associated harvest levels are zero and stock levels are expanding.

Moreover, the descriptive statistics illustrate that monthly average stock level in Turkish territorial waters is 479327 Tons with high volatility in the research period. Following the similar trends, excluding the periods of fishing bans,

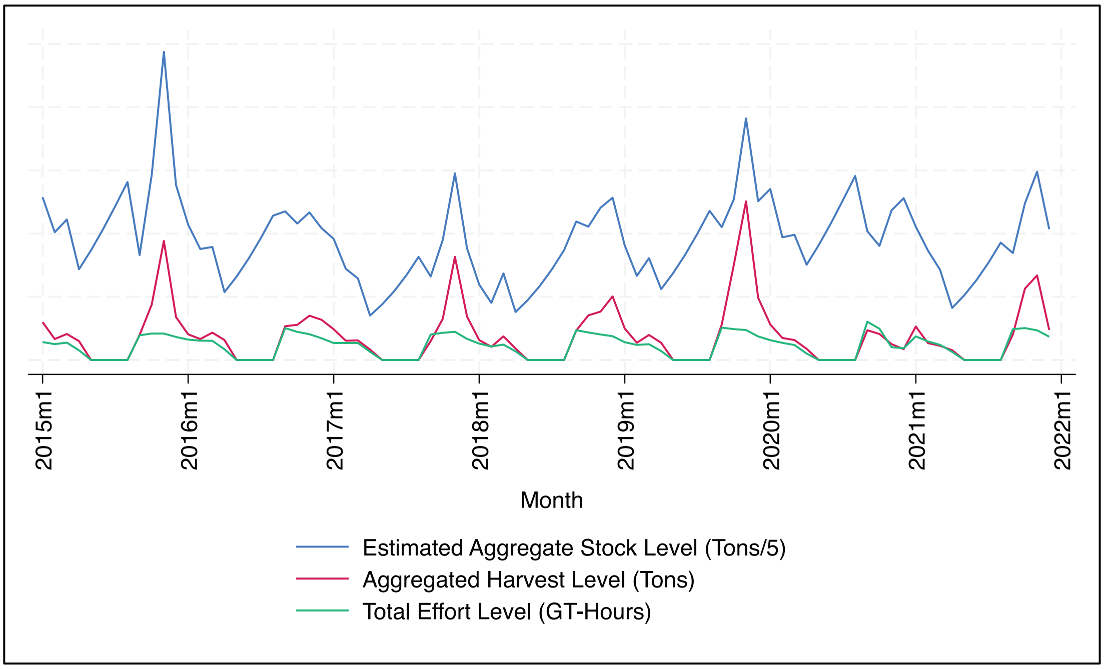

Figure 1. Harvest, effort, and stock.

Sources: TURKSTAT Fisheries Statistics Micro Data Set

Table 1. Descriptive statistics for harvest, effort, and stock

Variable	Mean	Standard Deviation	Min.	Max.
Harvest (Tons)	28757	22667.66	7762.91	125545
Effort (GT-Hours)	16524	5991.645	5090.9	30312.1
Stock (Tons)	479327	171547.2	175879	1219095

Sources: TURKSTAT Fisheries Statistics Micro Data Set

Table 2. Frequencies of gear types

Gear Type	Frequency	Percentage
Trawls (Unspecified)	4277	6.19
Bottom Trawls	23597	34.15
Midwater Trawls	4476	6.48
Purse Seines	11932	17.27
Beam Trawls or Dredges	7169	10.37
Entangling Nets	11876	17.18
Surrounding or Cast Nets	3765	5.45
Other Gears	2015	2.92

Source: TURKSTAT Fisheries Statistics Micro Data Set

average catch and effort levels constitute a catch per unit effort (CPUE) of 1.74 Tons/GT-Hours (Table 1).

Among the eight gear types that are aggregated, bottom trawl constitutes 34.15% of the monthly observations in the sample, followed by purse seine with a share of 17.27% and entangling nets with 17.18%. Combining environmentally infamous bottom trawl, beam trawl, and dredges, they are chosen 44.52% of the time in large-scale fishing operations (Table 2). Moreover, the numbers of the large-scale vessels through time seem stagnant based on the current data published by TURKSTAT MEDAS (n.d.) (Table 3).

TURKSTAT classifies Türkiye's coastal zones into five principal fishing regions, covering four seas. The coasts of the Black Sea are categorized into two regions. The eastern portion of the region is located between Artvin and Sinop, whereas the western portion is positioned between Kastamonu and Kırklareli. The fishing activities in the Bosporus and Dardanelles Straits are situated within the borders of the Marmara Sea. The two remaining fishing zones are the Aegean Sea, terminating at its southernmost point in Muğla, and the Levantine Sea, extending to its westernmost point in Antalya. The number of observations in the Eastern Black Sea is unexpectedly lower than in other regions, whereas the largest number of observations is in the Aegean Sea (Table 4).

Table 4. Frequencies of fishing regions

Region	Frequency	Percentage
Eastern Black Sea	10574	15.30
Western Black Sea	16531	23.92
Marmara Sea	11512	16.66
Aegean Sea	17078	24.71
Levantine Sea	13412	19.41

Source: TURKSTAT Fisheries Statistics Micro Data Set

Table 5. Shares of used technologies

Technology	Percentage
Sonar	33.97
Echo Sounder	87.56
Generator	39.17
Cold Conservation Room	88.67

Source: TURKSTAT Fisheries Statistics Micro Data Set

Additional technologies can be incorporated into the vessels alongside various gears. The primary devices are fish-finding sonars and echo sounders. While sonar utilization is infrequent, most observations employed echo sounders and maintain a cold conservation room. Finally, roughly 39.17% of observations derive advantages from an additional generator power to the existing engines (Table 5).

RESULTS

In accordance with the bioeconomic theory, harvest is regarded as determined by stock and effort within the frontier function (Equation (1)). The intercept of the inefficiency effects (ϑ_0) indicates the inefficiency level of unspecified trawlers in the Eastern Black Sea that lack sonar, echo sounders, cold storage facilities, and generators, as the

Table 3. Annual number of vessels with most frequent gears

Year	Beam Trawls or Dredges	Purse Seines	Trawls	Others
2015	418	411	650	12861
2016	409	426	728	12938
2017	525	391	798	12765
2018	444	373	782	12569
2019	634	370	790	12298
2020	456	413	786	12588
2021	597	386	820	12417
2022	522	396	759	12387
2023	766	392	780	12050

Source: TURKSTAT MEDAS

Table 6. Estimation results

Frontier Function			**Inefficiency Effects Function**		
β_0	Intercept	-6.703*** (0.075)	ϑ_0	Intercept	1.425*** (0.066)
β_1	$ln(E_{it})$	0.718*** (0.004)	ϑ_1	$ln(ENGP_{it})$	-0.046*** (0.011)
β_2	$ln(S_t)$	0.692*** (0.007)	ϑ_2	$D_{bottomtrawl,it}$	0.130*** (0.018)
Error Variance Function			ϑ_3	$D_{midwatertrawl,it}$	-1.061*** (0.024)
γ_0	Intercept	0.281*** (0.008)	ϑ_4	$D_{purseseine,it}$	-1.109*** (0.021)
γ_1	$ln(E_{it})$	-0.076*** (0.003)	ϑ_5	$D_{beamtrawl/dredge,it}$	-1.923*** (0.03)
$E(\sigma_v)$		1.086	ϑ_6	$D_{entangling,it}$	0.318*** (0.022)
σ_u		0.003** (0.001)	ϑ_7	$D_{surrounding/cast,it}$	0.467*** (0.028)
			ϑ_8	$D_{othergear,it}$	0.451*** (0.033)
			ϑ_9	$D_{westernblack,it}$	0.793*** (0.017)
			ϑ_{10}	$D_{marmara,it}$	-0.195*** (0.028)
			ϑ_{11}	$D_{aegean,it}$	0.084*** (0.02)
			ϑ_{12}	$D_{mediterranean,it}$	-0.045** (0.022)
			ϑ_{13}	$D_{sonar,it}$	-0.066*** (0.012)
			ϑ_{14}	D_{echosounder,it}	-0.089*** (0.015)
			ϑ_{15}	$D_{coldstorageroom,it}$	0.020* (0.012)
			ϑ_{16}	$D_{generator,it}$	0.010 (0.007)

inefficiency effects encompass numerous dummy variables (Equation (2)). The variance of the stochastic error term, σ_v, is regarded as the error variance function of the effort (Equation (3)). The parameter estimates of these functions are summarized in Table 6.

All the parameters in the error variance function are significant, implying that there is heteroskedasticity in the error term. The intercept in the frontier function is the natural logarithm of the catchability, defined as $q_{SFA} = e^{\beta_0}$. The estimated parameter $\widehat{\beta_0} = -6.703$ is statistically significant at the 95% level, allowing for the calculation of the catchability as $\widehat{q_{SFA}} = e^{\widehat{\beta_0}} = 0.0012272$. Moreover, effort elasticity, $\widehat{\beta_1} = 0.718$, and stock elasticity, $\widehat{\beta_2} = 0.692$, of harvest are both statistically significant.

The inefficiency effects model offers insights into the units' distances from the frontier, as defined by the harvest or frontier function, contingent upon certain characteristics. Positive and larger $\hat{\vartheta}$ estimates indicate a greater distance from the frontier, whereas negative and smaller parameters are associated with higher efficiency levels. Thus, a fishing unit with base characteristics suffers from some inefficiencies with statistically significant intercept estimate, $\widehat{\vartheta_0} = 1.425$. Moreover, the vessels with larger engine powers significantly have lower inefficiency levels with the estimate $\widehat{\vartheta_1} = -0.046$.

Since the parameter estimates of $\widehat{\vartheta_{15}}$ and $\widehat{\vartheta_{16}}$ are not statistically significant at the 95% level, the presence of cold storage room or generator on the vessels do not influence on the inefficiency levels. On the other hand, the parameters on all other characteristics are significant. As there are 160 gear-region-technology combinations of vessel characteristics, each parameter combination is computed and parameter averages for eight gears, five regions and technology use are presented in Table 7.

Table 7. Average parameters for unit characteristics

Gear	Beam Trawls or Dredges	-0.448
	Purse Seines	0.366
	Midwater Trawls	0.414
	Trawls (Unspecified)	1.475
	Bottom Trawl	1.605
	Entangling Nets	1.793
	Other Gear	1.926
	Surrounding or Cast Nets	1.942
Region	Marmara Sea	0.812
	Mediterranean Sea	0.962
	Eastern Black Sea	1.007
	Aegean Sea	1.091
	Western Black Sea	1.800
Technology	Sonar	1.101
	No Sonar	1.167
	Echo Sounder	1.090
	No Echo Sounder	1.179

Results show that technically most efficient gear group is beam trawls or dredges. Surprisingly, the most preferred gear type, bottom trawl, is less efficient than purse seine and other trawl types. Another result is that units fishing in the Marmara Sea are significantly more efficient than others. Finally, both sonar and echo sounder provide efficiency gains in the fishing operations, as expected.

DISCUSSION

The frontier model results indicate that effort reduction is indispensable, as returns to effort is estimated to be less than unity. During the last decade, Turkish policymakers have attempted to reduce the number of large vessels in the fleet by starting a series of buyback programs. Nevertheless, those programs were empirically demonstrated to be ineffective (Göktay et al., 2018; Ekmekci & Ünal, 2019; Ünal & Göncüoglu-Bodur, 2020a; Ünal & Göncüoglu-Bodur, 2020b). In fact, the total number of trawlers and dredgers have increased since 2015 (Table 3).

In addition, the stock elasticity of harvest is slightly lower than the effort elasticity, indicating decreasing returns to stock. This condition is associated with the lower fluctuations in the harvest compared to biomass. In other words, when there is a stock expansion, the harvest expands with a lower rate. This seems positive in terms of stock recovery. However, when there is a sharp decline in stock levels due to many possible factors, catch levels do not follow as sharp as stock levels. This can be associated with overexploitation when stock levels are low. In this case, an implementation of catch quota to anchovy, which has the largest share in the catch levels, is necessary. However, the quota levels should be adjusted down if the season experiences low harvest.

An effective fisheries policy should increase technical efficiency of the fishing units. Hence, the gears, regions, and missing technologies associated with inefficiencies should be examined more carefully. In this case, among the large-scale fishing units, the most efficient gears, including beam trawls, dredges, purse seines, and midwater trawls should be encouraged. In contrast, the use of entangling, surrounding, and cast nets should be left to small-scale operations. Moreover, stricter regulations on bottom trawling, which is characterized by large-scale fisheries, are essential since they are environmentally undesirable and less efficient.

When the regions are compared in terms of technical inefficiency, the existing regulations imposed for the Marmara and the Mediterranean seems more fruitful compared to other seas. Especially, the fisheries in the Western Mediterranean Sea necessitate a closer glance in terms of policymaking activities. Finally, the measures that facilitate the use of technologies like sonar and echo sounder can yield substantial benefits for Turkish fisheries. However, as the use of technology becomes more intense, and stocks levels become more alarming, fisheries policy requires stricter catch limitations.

CONCLUSION

Given that efficiency and sustainability are principal objectives of environmental policy, the findings of this study may shed light on the current state of fisheries in Türkiye and provide progressive insights for fisheries management. Aiming to estimate the harvest function for Turkish fisheries by making use of the micro data set and previously estimated stock level data, this study has employed stochastic frontier model with inefficiency effects. For these purposes, the production relationship in the frontier is constructed in the form of bioeconomic harvest function which models catch level as a function of catchability, effort, and stock. On the other hand, several vessel characteristics and geographic locations are considered to be the sources of inefficiency.

The frontier model results have demonstrated that effort and stock elasticities are less than unity. Since stakeholders' control over stock levels is limited, stronger effort reduction policies are essential for fisheries management in Türkiye. Moreover, low stock elasticity necessitates lower catch quota levels for important species during the low harvest periods.

This study also demonstrates that bottom trawling, the most favored method among fishermen yet one of the most ecologically detrimental techniques, is also comparatively poor regarding fishing efficiency. Moreover, the policies previously enacted for the Marmara and Mediterranean Seas have demonstrated greater effectiveness compared to those in the Eastern Black Sea and the Aegean. Nonetheless, the Western Black Sea distinctly contrasts with other regions due to its inefficiency. Hence, Türkiye's fisheries management must prioritize addressing bottom trawling practices and the condition of the Western Black Sea fisheries.

It is unsurprising that the extensive utilization of fishing technologies will result in enhanced productivity. These devices are anticipated to mitigate issues such as bycatch and ghost fishing. Nonetheless, the utilization of such devices, particularly during times of diminished production, will inevitably result in overfishing issues. Consequently, expanding the quantity and complexity of output controls should be strategies that fisheries management implements in the future.

Etik: Bu makalenin yayınlanmasıyla ilgili herhangi bir etik sorun bulunmamaktadır.

Hakem Değerlendirmesi: Dış bağımsız.

Yazarlık Katkıları: Fikir: V.G., H.T.; Tasarım: V.G., H.T.; Denetleme: V.G., H.T.; Kaynaklar: V.G., H.T.; Veri Toplanması ve/ veya İşlemesi: V.G., H.T.; Analiz ve/veya yorumlama: V.G., H.T.; Literatür Taraması: V.G., H.T.; Yazıyı Yazan: V.G., H.T.; Eleştirel İnceleme: V.G., H.T.

Çıkar Çatışması: Yazarlar, bu makalenin araştırılması, yazarlığı ve/veya yayınlanması ile ilgili olarak herhangi bir potansiyel çıkar çatışması beyan etmemişlerdir.

Finansal Destek: Yazarlar bu çalışma için finansal destek almadıklarını beyan etmişlerdir.

Yazım Süreci Yapay Zeka Kullanımı: Beyan edilmemiştir.

Ethics: There are no ethical issues with the publication of this manuscript.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept: V.G., H.T.; Design: V.G., H.T.; Supervision: V.G., H.T.; Resources: V.G., H.T.; Data Collection and/or Processing: V.G., H.T.; Analysis and/or Interpretation: V.G., H.T.; Literature Search: V.G., H.T.; Writing Manuscript: V.G., H.T.; Critical Review: V.G., H.T.

Conflict of Interest: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Financial Disclosure: The authors declared that this study received no financial support.

Use of AI for Writing Assistance: None declared.

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