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The role of production factors on landings heterogeneity between EU countries

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A B S T R A C T

Distribution of natural resources is considered to be a key aspect in ensuring the success of conservation policies. The Common Fisheries Policy, implemented by the European Union (EU), is an example of long-term international cooperation for sustainability of the marine environment. Nonetheless, continued enforcement of the policy is threatened by its insufficient effectiveness in restoring fish stocks and the tensions that have arisen over unequal distribution of benefits. Recent adoption of the Blue Growth Strategy represents an additional challenge for EU fisheries, since it encourages new alternative economic activities. The present analysis aims to identify ways of enhancing the sustainability of EU fisheries while achieving greater equity in resource distribution and maintaining the activity of the fishing industry, an important staple of many coastal communities in the EU. To this end, the study decomposes heterogeneity amongst per capita landing rates of EU Member States. A number of findings from the decompositions used may be highlighted. Firstly, most of the heterogeneity in per-capita landing rates between Member States occurs within the main EU fishing areas, especially FAO Areas 27 and 37. Secondly, fishing production factors affect per-capita landing heterogeneity to a different extent in Areas 27 and 37. The only exception is the number of fishers, the factor contributing most to heterogeneity in both areas. Technological factors appear to diminish heterogeneity in Area 27 whilst positively contributing to heterogeneity in Area 37. More efficient fleet adjustments could be designed taking into account these contributions by production factors to heterogeneity within fisheries.

1. Introduction

Egalitarian international distribution of resources allows global growth to be fostered [1] by providing the poorest countries with incentives to invest in human capital and entrepreneurial activities [2,3]; it also foments well-being by reducing the level of poverty and food insecurity as established in the United Nations Sustainable Development Goals [4,5]. Furthermore, the distribution of scarce natural resources may be crucial to the success of the international agreements needed to ensure their conservation [6–8]. Ensuring more equitable distribution of resources through the establishment of property rights may threaten sustainability if exploitation of those resources is not properly regulated [9–11]. However, very dissimilar exploitation patterns may make it harder for countries to accept the same responsibility for preserving resources [12–15].

The development of appropriate ownership schemes has helped to prevent over-exploitation of common-pool resources [16]. In fisheries, distributional concerns and economic inefficiency are linked to inadequacy of property rights [17,18]. Consequently, developments in ownership arrangements have become a key ingredient in fisheries management. The 1982 declaration of the Exclusive Economic Zones (EEZs), which recognized the jurisdiction of coastal countries over the natural resources in their 200-nautical-miles adjacent waters [19], may be considered as a global system that grants property rights to countries. Creation of the EEZs helped to rebuild certain stocks, especially in countries with science-based fisheries management [20] and to protect fisheries from unauthorized fishing [21]. From this perspective, EEZs may be viewed as a form of community quota, since only domestic

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vessels are allowed to access coastal fisheries. However the area to be managed is so large that fisheries authorities have to implement more disaggregated rights-permit schemes, for instance, individual transfer quotas (ITQs) and territorial use rights for fishing (TURFs) programs, which in most cases take into consideration social and equity criteria, in addition to conservation and efficiency benchmarks [22,23].

In this context, management of the European Union's fisheries may be considered to be a quite relevant case study since it involves several countries committed to a cooperative approach embodied in the Common Fisheries Policy (CFP). The CFP applies to all EU Member States (MSs), but only 22 of the 27 countries in the Union are coastal. Each coastal state has the right to manage natural resources in its EEZ, but under the CFP, the fishing area of all MSs is considered as a single zone. The main purpose of the CFP is to preserve fishing operations, fish consumption and the marine ecosystems in which EU fleets operate. To this end, the policy has been adapted over time and since the lastest reform in 2013 [24], it now covers aspects such as maximizing sustainable yield exploitation for all stocks; reducing discards (the "Landing Obligation"); adapting capital-intensity to fishing opportunities; improving aquaculture to reduce reliance on wild fish and enhancing the role of scientific research in assessing sustainable fishery management. In addition to monitoring the inputs used by countries (such as maximum number of vessels or kilowatts), the CFP establishes fishing *quotas*, i.e. the quantity of fish of each species that can be extracted by each MS, in order to balance fishing operations and fishing opportunities. These quotas are allocated to each country as a fixed percentage of the total allowable catches (TACs). TACs are set by the Council of Fisheries Ministers, based on scientific advice provided by the International Council for the Exploration of the Sea (ICES) and the Scientific, Technical and Economic Committee of Fisheries (STECF). The fixed percentages used to divide the TACs up amongst MSs are determined by the principle of Relative Stability, which gives priority to countries' historical-fishing operations in each fishery [24–26]. In short, the CFP is aligned with the principles of conservation and efficiency of fisheries as well as being committed to the historical fishing rights of Member States.

One of the ways in which MSs circumvent the principle of relative stability is by bringing influence to bear at the annual closed-door negotiations at which TACs are set for stocks of interest to them. [27] found that between 2011 and 2015, the TACs set were on average 20% annually above those proposed in the scientific advice. The MSs benefiting most from this surplus were Denmark and United Kingdom (in absolute terms) and Spain and Portugal (in relative terms). The rigidity of quota regulation has led to the emergence of two instruments enabling different fishing actors (Member States, Production Organizations and fishers) to adapt their fishing operations to their specific needs or preferences. On the one hand, TACs may be landed by foreign operators using domestic vessels under domestic rights, a practice known as "quota hopping" [28]. On the other hand, fishing actors may transfer TACs between them ("quota swapping") [29]. According to [28], 20% of TACs in 2013 were reallocated through international quota swapping.

Taking into account the distributional perspective of the CFP, this article seeks to analyze how landings in EU waters are distributed among MSs. Specifically, the analysis is based on data on the value of landings from 23 MSs between 2008 and 2016 (including the UK as one of the MSs during that period). Although some of the countries considered are characterized by having a set of data-poor indicators [30], there are two key advantages to considering this set of countries. Firstly, relevant defining variables for the countries' fleets, such as number of fishers, which are not available in global terms for recent periods, can be entered in the analysis. Secondly, an analysis of the distribution of landings within the EU measured by value shows the particularities of fishing management in the region. In this regard, the distributional analysis was performed by distinguishing the origin of landings between fishing areas, considering those from the Northeast Atlantic, Baltic and North Seas areas (FAO area 27, hereinafter ATW) and those from the Mediterranean and Black Seas (FAO area 37, hereinafter MBS) which represent 62% and 22% of the total value of EU landings, retrospectively, for the period studied. This distinction is relevant, not only because the decline in MBS fisheries contrasts with the improvement observed in trends in ATW fisheries [31], but also because the nature of these fisheries is conditioned by differences in the biological characteristics of their ecosystems, the implementation of CFP and their cultural heritage [32].

A large body of literature already exists on the international distribution of the use of natural resources and environmental capacity, much of it addressed using analyses of inequality metrics [33–37]. This literature has focused to a lesser extent on fishery resources. In particular, the distributional effects generated by specific right-based management systems in fisheries such as ITQs have been assessed by quantifying changes in the distribution of landings and fishing incomes among fishers and boat owners by using inequality metrics [38–43]. Another set of articles uses the same approach to analyze the distributional effects of the introduction of ITQs on the industry. In this context, the ownership of catch rights has been concentrated amongst a few large fishers and companies, increasing their market power in, for example, New Zealand commercial fishing [44] and the Icelandic fisheries [45,46]. From a global perspective, [47] show that high sea catches are very unevenly distributed among countries; most of the heterogeneity observed is due to dissimilarities in the technological capacity and number of fishers of countries, rather than any biological idiosyncrasies of the fishing areas harvested.

The analysis presented here also follows this international perspective and has a dual objective. On the one hand, it seeks to ascertain to what extent the heterogeneity observed in the distribution of landings (in value per capita) between MSs can be explained by differences between the fishing areas of origin (e.g., species diversity, climate, nutrients, implementation of the CFP and other productivity factors) and to what extent by differences between different fishing actors in these areas (e.g., technological features of the fleet such as gear length, power, and distance and fishers capacities). This issue is addressed by decomposing inequality in landings into its so-called *between-within* components. At the same time, the analysis seeks also to determine the technological reasons for the uneven distribution of landings (in value per capita) between the countries within each fishing area (ATW and MBS). To that end inequality in landings is decomposed into the sum of several components representing the fishing production factors of the countries. Traditionally, catches from fisheries are represented as the result of production factors such as labor and capital services which may also include energy [48]. This study focuses mainly on the role of the technological features characterizing fleets. Specifically, it considers the following factor drivers related to different aspects of fishing fleets: technological productivity (measured by landings per kWt of engine power), technical progress (measured by engine power in kWt per vessel), capital-intensity (measured by vessels per fisher) and fishing labor (measured as the percentage of fishers in the total labor force). The breakdown in the inequality indexes set out in [49] is used to account for the technological changes observed in the links between the production factors defined.

In view of the characteristics of the EU fleet, it is pertinent to study the role of production factors in determining the distribution of landings among MSs. In 2016, the EU fleet comprised more than 65,000 active vessels, of which 75% were classed as small-scale coastal vessels, 24.6% as large-scale vessels and the remaining remaining 0.4% as distant-water vessels [50]. Despite the prevalence of small-scale coastal fisheries (SSCF) in terms of vessels, this segment accounts for just 8% of total gross tonnage and about 30% of engine power [50,51]. From the perspective of labor input, based on a selection of case studies, [52] find that SSCFs in the EU are made up of vessels with smaller crews than larger-scale fleets, although global employment in SSCF amounts to a similar level to that of large-scale fleets. These findings are corroborated in [50], which quantifies the fishers of SSCF as 51% of the EU fleet and

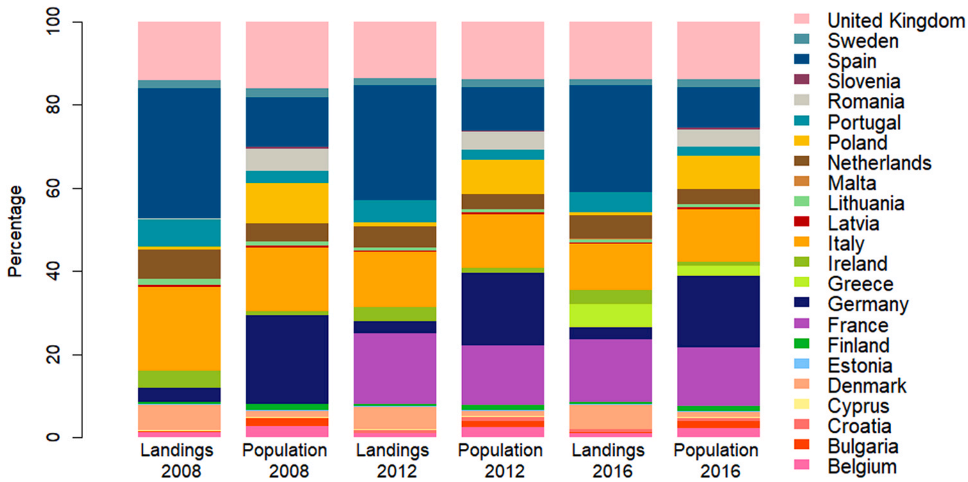


Fig. 1. Landings value and population of coastal MS (2008, 2012, 2016).

41% in terms of full-time equivalent units. The relevance of the SSCF also differs between the fishing areas considered; while 22% of the value of catches captured in MBS came from SSCFs, in ATW they represented only 12% of its total value [50]. Nevertheless, the effectiveness of the CFP in ensuring the sustainable activity amongst this type of fleet, as required by United Nations Sustainable Development Goal 14.b [4] has been questioned [52–56].

Since 2012 Blue Growth has been part of the European Commission Strategy. This plan aims to foster growth in maritime sectors with innovative potential, such as ocean energy, aquaculture, tourism, biotechnology and marine mineral resources, while keeping traditional and new exploitation of the environment within sustainable limits; and both public and private institutions of the MSs are expected to cooperate in the interests of efficient management of marine resources [57,58]. From the perspective of the economic literature, the theoretical and empirical evidences on the relationship between growth and inequality (generally measured in terms of income) are mixed. In general terms, it is accepted that inequality has positive short-term effects on economic performance whereas long-term effects are negative [3,59]. Likewise, heterogeneity in the use of marine resources may, at least in the long term, be expected to affect the blue growth strategy. In this regard, although heterogeneity in landings between countries is not a prominent issue in the blue growth strategy, it is relevant to study its connection with the underlying productivity factors in order to understand and assess the programs in terms of the jobs generated within the EU marine sectors.

Although the per-capita value of landings became more uniform across MSs between 2008 and 2016 [60], heterogeneity still causes tension between them. Indeed, it appears to have played a significant role in the UK's decision to leave the European Union [61–64]. At the same time, major divergences may be found in the fleets and fishing operations of different MSs [60]. The present analysis focuses on two main aspects. The first objective is to detect whether heterogeneity in the per-capita value of landings between MSs is caused by differences in the harvesting area (*between* heterogeneity) or by the dissimilar characteristics of the fishing actors operating in each area (*within* heterogeneity). The second objective is to identify the main production factors leading to heterogeneity in the per-capita value of landings between countries fishing in the same area. The main results show that most of the heterogeneity arises within fishing areas. The number of fishers appears to have been the greatest contributor to per-capita heterogeneity in landings amongst MSs between 2008 and 2016 in the ATW and MBS areas. The effect of technological factors varies within the areas. In the ATW area, technological factors contribute to a decrease in per-capita landing heterogeneity. By contrast, in the MBS area, technological factors augment per-capita landing heterogeneity. Changes in the contribution of technological factors to heterogeneity within each area reflect technological advances in fishing and a reduction in fleet size in Europe in recent years [65,66].

The remainder of this analysis is structured as follows. Section 2 briefly describes the distribution of landings per capita and fishing production factors between MSs and fishing areas. Section 3 sets out the *Theil-0* index used to measure heterogeneity and two decomposition used for the analysis: the *between-within* areas decomposition and the multiplicative factor decomposition. The results of the analysis are detailed in Section 4. Section 5 concludes and discusses the main findings.

2. Description of data

Data on landings and the production factors of countries are drawn from the Scientific, Technical and Economic Committee for Fisheries [60]. Population data is taken from the World Bank [67]. The data available on fishing activity makes it possible to cover 23 coastal MSs out of a total of 28 EU MSs for the period 2008–2016. The United Kingdom has been included as it was still a MS during that period.

For the purpose of this study, landings are measured in terms of the value of landings, and thus, unless otherwise indicated, any use of the term "landings" henceforth will refer to the value of landings. Since distributional concerns are the main focus, all recorded landings are considered, regardless of their future use (consumption or trade).

2.1. Distribution of landings between EU countries

Complete homogenization in the distribution of the value of landings occurs when countries have the same percentages of landings as population. As shown in Fig. 1, countries' shares in overall landings differ considerably from their respective population shares. These asymmetries appear to have persisted throughout the period analyzed.

In particular, countries such as Denmark, Greece, Ireland, Portugal and Spain have overall landings that exceed their share of the total population, and some have benefited greatly from negotiation of the TACs by the Council of Fisheries Ministers [27]. By contrast, the overall landing shares of Germany, Poland and Romania are lower than their relative population shares. In these countries, the role of commercial fisheries is small, in economic terms, although inland and recreational fishing and SSCF are increasing in significance [68–70].

2.2. Distribution of landings between fishing areas

The majority of EU fishing activity is concentrated in FAO Areas 27 and 37 [50], which accounted for around 62% and 22% of the value of

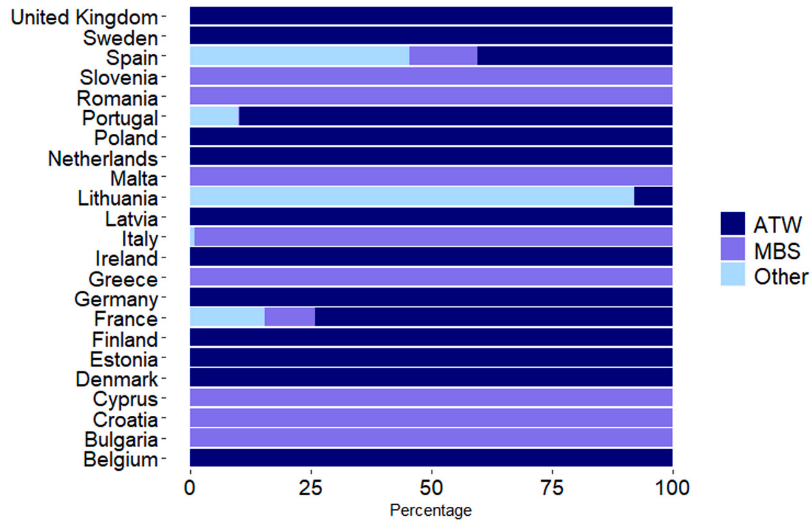


Fig. 2. Share of the landings value from each area.

EU landings between 2008 and 2016, respectively. Nevertheless, their contributions to the value of the landings of MSs differ considerably. In this regard, Fig. 2 shows a clear distinction between those countries that border Atlantic waters (Northern EU countries, whose income from fishing activity comes from FAO Area 27) and those bordering the Mediterranean and Black Seas (Southern EU countries, whose income from fishing comes from FAO Area 37). Only a few countries bordering both the Atlantic Ocean and the Mediterranean Sea (i.e. France, Portugal and Spain) benefit from harvesting in both of these FAO areas.

Only a limited number of countries within the EU (i.e. Spain, France, Lithuania, Poland, Latvia, Portugal, the Netherlands and Germany) appear to have enjoyed any significant income from fishing activity in other FAO areas (Other Fishing Regions or OFRs) during the period under analysis. Within this group there are two clearly differentiated types of catch: on the one hand, catches from the outermost regions, i.e. the EEZs of the Canary Islands (Spain), Azores and Madeira (Portugal) and the French overseas regions (Guyana, Martinique, Guadalupe, Reunion and Mayotte); and on the other hand, catches from long-distance fisheries in regions outside EU waters [50]. The dataset for the present analysis provides complete information for more than 80% of 2016 EU landings from OFR [50]. In particular, landings from these areas are considered for Spain, France, Lithuania, Portugal and Italy. See A for more detailed information on the origin of OFR landings for these countries.

2.3. Multiplicative factor decomposition of landings per capita

The IPAT identity describes the multiplicative contribution of population (P), affluence (A) and technology (T) on environmental impact (I) [71,72]. Environmental impact may be expressed in terms of resource depletion or accumulation of emissions; population refers to the size of the human population; affluence refers to the level of consumption by that population; and technology refers to the processes used to obtain resources and transform them into useful goods and wastes.

Likewise, the per-capita value of landings for any country is expressed as the result of the interaction of various input factors. In particular, the value of countries' per-capita landings (Impact) can be expressed as the product of the technological productivity and progress of their fleets (Technology), their capital-intensity (Affluence) and the percentage of their population engaged in fishing operations (Population). Mathematically, the value of landings per capita of country i is decomposed as:

$$\frac{Landings_i}{Population_i} = \frac{Landings_i}{Engine\ power_i} \times \frac{Engine\ power_i}{Vessels_i} \times \frac{Vessels_i}{Fishers_i} \times \frac{Fishers_i}{Population_i},$$

where *Engine power* refers to total kilowatts (kWt), *Vessels* to the number of units used in commercial fishing and *Fishers* to the number of fishing workers; all in reference to the fleet of country i.

The $Landings_i$ / $Engine\ power_i$ ratio denotes the productivity of the aggregated fleet in country i. In fisheries, this is usually referred to as LPUE (landings per unit of effort) [50]. Fishing effort can be measured either by the natural characteristics of fishing vessels (such as engine power) or by fishing operations (for example, number of days fishing) [73]. This ratio represents the productivity of fleets considering the first of these criteria.

The $Engine\ power_i$ / $Vessels_i$ ratio reflects the average engine power of vessels in country i. A positive change in this indicator means that on average, vessels become more powerful; this ratio is therefore associated with the technological level of the fleet of country i.

The $Vessels_i$ / $Fishers_i$ ratio measures the relationship between physical capital and labor for the aggregated fleet of country i. Higher values for this ratio indicate that fleets are more capital-intensive, a factor that is associated with smaller scale fleets as more vessels are employed per fisher. This is a characteristic of less industrial fleets. By contrast, lower values of this ratio are associated with larger scale fleets since fewer vessels are used per fisher.

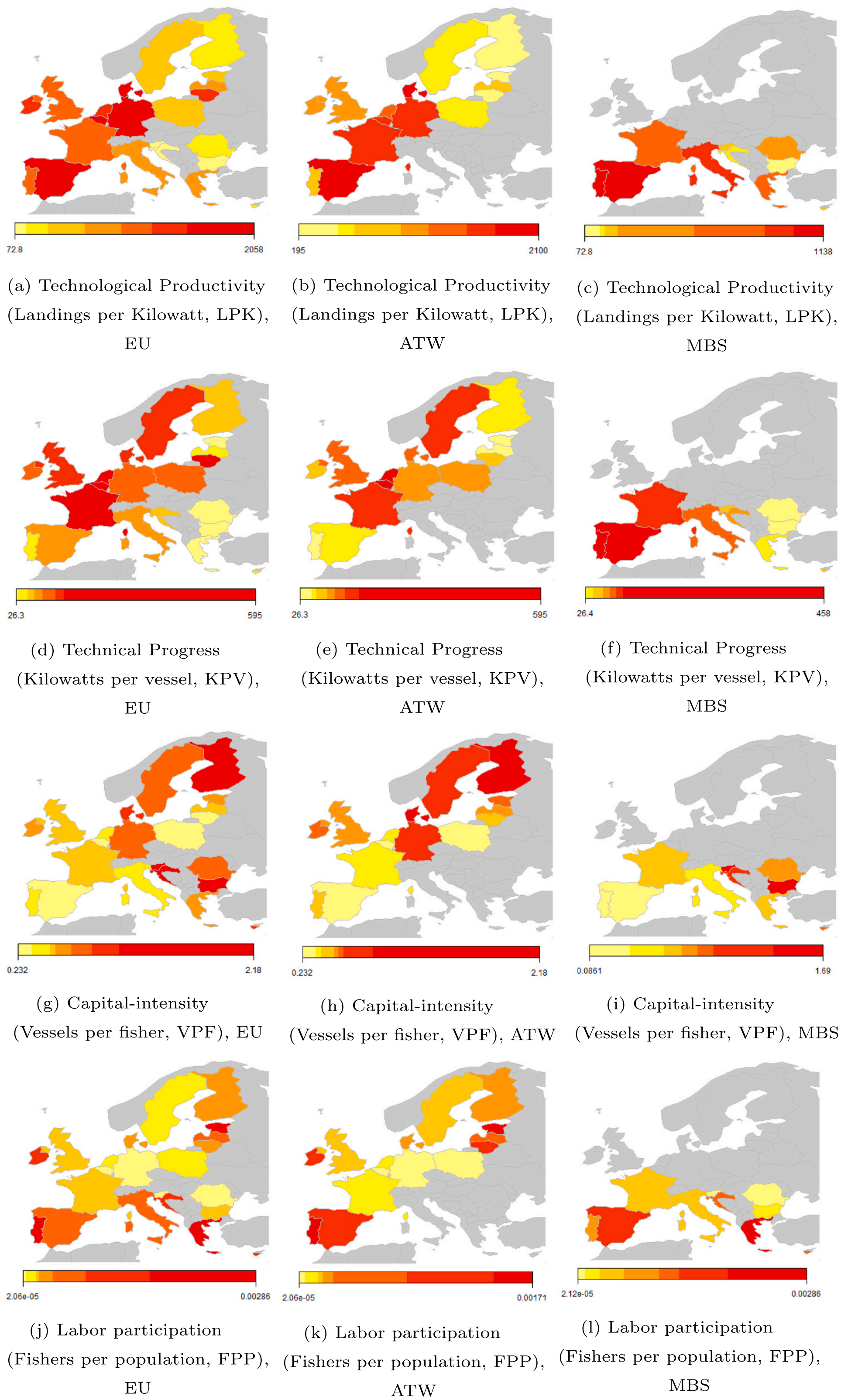
The last ratio, $Fishers_i$ / $Population_i$, shows the scale of the fishing sector in the labor force of economy i.

To simplify the comments on analyses and their results, the above terms are referred as technological productivity (Landings per Kilowatts, LPK), technical progress (Kilowatts per Vessel, KPV), capital-intensity (Vessels per fisher, VPF) and labor participation (Fishers per population, FPP). Applying this notation, the decomposition can be rewritten as:

$$LPC_i = LPK_i \cdot KPV_i \cdot VPF_i \cdot FPP_i.$$

The countries in the sample show great diversity in the production factors defined above (LPK, KPV, VPF and FPP). Fig. 3 shows the average use of these production factors by MSs. In particular, the distribution of the factors is shown in three scenarios: the ATW scenario, with the distribution of factors engaged exclusively with fishing in FAO area 27; the MBS scenario, with the distribution of factors engaged exclusively with fishing in FAO area 37; and the EU scenario with the overall distribution of factors.

The distribution of technological productivity shows that average returns from fishing differed significantly between countries in the



(a) Technological Productivity (Landings per Kilowatt, LPK), EU

(b) Technological Productivity (Landings per Kilowatt, LPK), ATW

(c) Technological Productivity (Landings per Kilowatt, LPK), MBS

(d) Technical Progress (Kilowatts per vessel, KPV), EU

(e) Technical Progress (Kilowatts per vessel, KPV), ATW

(f) Technical Progress (Kilowatts per vessel, KPV), MBS

(g) Capital-intensity (Vessels per fisher, VPF), EU

(h) Capital-intensity (Vessels per fisher, VPF), ATW

(i) Capital-intensity (Vessels per fisher, VPF), MBS

(j) Labor participation (Fishers per population, FPP), EU

(k) Labor participation (Fishers per population, FPP), ATW

(l) Labor participation (Fishers per population, FPP), MBS

Fig. 3. Distribution of fishing production factors across EU coastal countries. Average during 2008 and 2016. EU: factors used in all areas; ATW: factors used in FAO area 27; MBS: factors used in FAO area 37. Color bar indicates with yellow low numbers and red high values of each production factor.

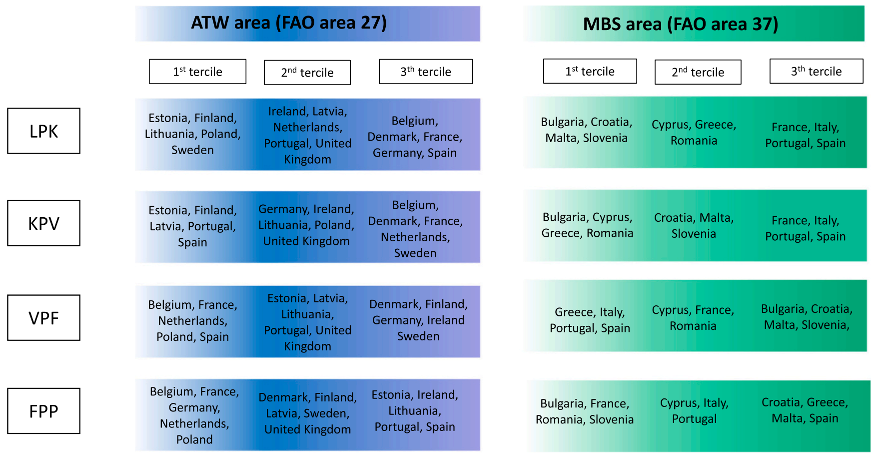


Fig. 4. Relevance of production factors by fishing areas and countries. LPK (Landings per Kilowatt), KPV (Kilowatts per vessel), VPF (Vessels per fisher), FPP (Fishers per population).

period analyzed, ranging from almost 73 to around 2060 Euros per kilowatt (Fig. 3a). The subtle division between Western and Eastern EU countries in the general framework becomes noticeable when we examine the ATW and MBS areas separately (Fig. 3b and c). Here, Western EU countries can clearly be seen to enjoy a much higher average return than Eastern EU countries.

Central EU countries appear to have employed more high-powered vessels in fishing than other EU countries during the period under analysis (Fig. 3d), especially in the ATW area (Fig. 3e). In the MBS area (Fig. 3f), average use of technical progress is a differentiating characteristic of Western EU countries, which use more high-powered vessels.

The distribution of capital-intensity shows that Western EU countries use more industrial fleets than most of Eastern EU countries (Fig. 3g, h, and i). As for the respective areas, the use of industrial fleets is greater in MBS area than in ATW area. In particular, the average number of fishers by vessel in MBS ranges between 1 and 12 whereas in ATW area ranges between 1 and 5.

Compared to other regions, Europe has one of the lowest percentages of overall population working in fishing [74]. Within the EU, the percentage of the population employed in the sector varies markedly from country to country (Fig. 3j, k, and l). In general, the largest ratios of fishers-per-capita are found in the Southern countries.

Fig. 4 shows the use of resources by each country in the ATW and MBS areas. Countries are classed into three groups depending on the average use of the corresponding production factor in each area between 2008 and 2016. If its average use of a certain factor is in the lowest third of the distribution, the country is assigned to the First tercile (1^{st} tercile) category. A country is placed in the Second tercile (2^{nd} tercile) category when it is in the middle third of the distribution. Finally, the country is placed in the Third tercile (3^{rd} tercile) category if it is in the highest third of the distribution.

Given that no common pattern can be drawn, rather than focusing on each country, details are given of those with the highest and lowest landings per capita. Denmark, which is one of the countries with the highest rate of landings per capita, harvests only in the ATW area. Within this area, Denmark stands in the highest third of the distribution for technological productivity, technical progress and capital-intensity. The only exception is the ratio of fishers per capita, where it stands in the medium range. This may be explained by the major role of industrial vessels in Denmark, which is characterized by being one of the largest producers of fishmeal and fish oil in Europe. In 2016, 97% of landings were caught by semi-industrial or industrial vessels, representing around 25% of active vessels in the Danish fishing fleet [75]. Ireland is another example of a country fishing only in the ATW area with a large ratio of landings per capita. Ireland's technological productivity and technical progress lie in the middle third, but in terms of capital-intensity and fishing labor per capita it is in the top third of distribution. Greece is also among the countries with the highest ratio of landings per capita. However, the country's fishing activity is limited to the MBS area. Within this area, Greece is in the lowest third of technical progress and capital-intensity, in the middle third for technological productivity and in the highest third for fishing labor per capita. Portugal, one of the countries with the highest landings-per-capita ratios, has fishing activity in both the ATW and MBS areas. However, its profile varies from one area to another. In the ATW area, Portugal is in the highest third of fishing labor per capita, in the middle third of technological productivity and capital-intensity and in the lowest third in technical progress. In the MBS area, Portugal is in the highest third of capital productivity and technical progress, the middle third of capital-intensity and the lowest third of fishing labor per capita. Like Portugal, Spain is among the countries with the highest levels of landings per capita in the ATW and MBS areas. However, there is less disparity in its profile in the two areas. Spain is in the highest third of technological productivity and fishing labor per capita and in the lowest third of capital-intensity. In technical progress, the country is in the highest third in the MBS area, but in the lowest third in the ATW area. Germany has one of the lowest landings-per-capita levels of all countries. It fishes in the ATW area and its fleet is characterized by high levels of technological productivity and capital-intensity, medium levels of technical progress and low levels of fishing labor per capita. Poland, which is similar to Germany in terms of low landings per capita and fishing activity location, belongs to the lowest third of technological productivity, capital-intensity and fishing labor per capita. Romania is also among the countries with low landings per capita. In contrast to Germany and Poland, Romania's fishing activity is confined to the MBS area. Within this area, Romania is in the medium third of technological productivity and capital-intensity and in the lowest third in technical progress and fishing labor per capita.

3. Methodology for measuring heterogeneity

3.1. Measuring heterogeneity

The inequality metrics approach has been used to quantify heterogeneity in the distribution of the variables of interest. In particular, this study measures heterogeneity using the second measure of Theil proposed by [76], also called the Mean Logarithmic Deviation index. This index can be derived from the Generalized Entropy family [77,78] for a parameter value equal to zero ($\alpha = 0$).

For the purpose of this study, this inequality measure is referred to as the *Theil-0* index, denoted by T, and its application to the distribution of landings per capita (LPC) can be expressed as

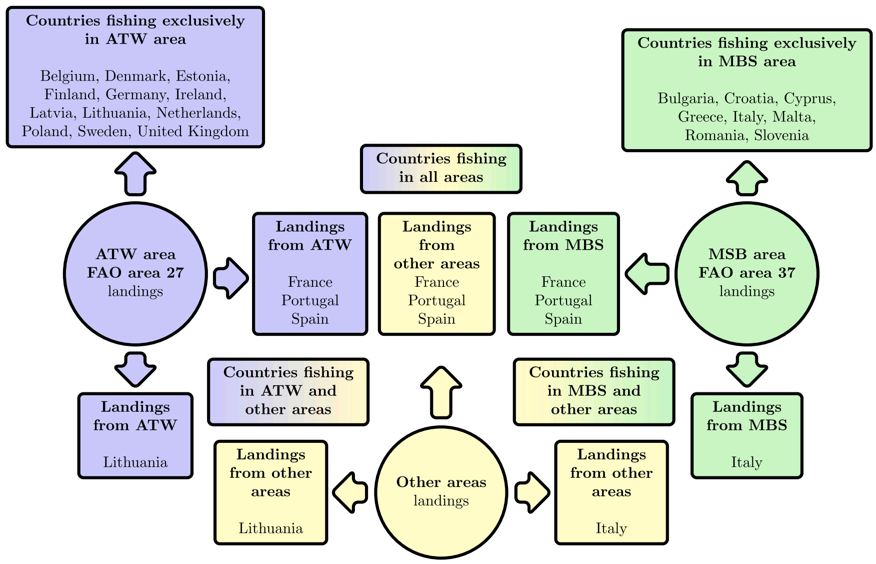


Fig. 5. The logic behind the *between-within* heterogeneity decomposition. Landings of every country can be assigned to one of the fishing areas. The between component represents the heterogeneity of landings between the fishing areas (between countries of different colors) and the within component represents the heterogeneity of landings within the areas (within countries with the same color).

Table 1
Pearson correlation between production factors.

	Area 27				Area 37			
	LPK	KPV	VPF	FPP	LPK	KPV	VPF	FPP
LPK	1.00	0.32	-0.38	-0.23	1.00	0.58	-0.73	-0.05
KPV	0.32	1.00	-0.31	-0.46	0.58	1.00	-0.54	0.06
VPF	-0.38	-0.31	1.00	-0.16	-0.73	-0.54	1.00	-0.25
FPP	-0.23	-0.46	-0.16	1.00	-0.05	0.06	-0.25	1.00

LPK (Landings per kilowatt), KPV (Kilowatts per vessel), VPF (Vessels per fisher), FPP (Fishers per population).

$$T(LPC) = \sum_{i}^{n} p_i \cdot \ln\left(\frac{\overline{LPC}}{LPC_i}\right), \quad (1)$$

where the subindex i refers to each of the n countries, p_i weights the observations of countries according to their share of the total population and $\overline{LPC}$ refers to the overall average for landings per capita. The greater the value of the index, the greater the disparities between the fishing areas considered. In the extreme case where landings per capita of countries are exactly the same, this index takes a value of $T = 0$. Thus, values closer to zero reflect more even distributions of landings per capita.

The *Theil-0* index satisfies the basic properties of anonymity, population and scale invariance and the Pigou–Dalton transfer principle. Moreover, apart from the absolute Gini index, this index is the only measure that respects both the principle of transfer and the principle of monotonicity in distance, for which reason Shorrocks [77] argued that this index is the *"most satisfactory of the decomposable measures"* because it unequivocally decomposes overall inequality into the contribution from the inequality within subgroups and that from the inequality between subgroups, for any partition of the population.

3.2. Decomposition of heterogeneity by fishing areas

One of the advantages of using the *Theil-0* index is that it can be usefully decomposed, in order to evaluate the impact of the *between-within* components whenever the population can be partitioned into exclusive subgroups. This is the case of this study where the population (landings) are available at country level and can be sorted by fishing area of origin. Given this property, it is possible to quantify how much of the observed heterogeneity in the distribution of the landings can be explained by differences between the fishing areas of origin and how much by differences between the fishing actors operating within these areas. Fig. 5 represents the logic behind this decomposition.

Formally, for the application of this study, the *Theil-0* index can be decomposed as.

$$T(LPC) = T_B + T_W,$$

being.

$$T_B = \sum_g p_g \cdot \ln\left(\frac{\overline{LPC}}{\overline{LPC}_g}\right),$$

$$T_W = \sum_g p_g \cdot T(LPC_g),$$

where p_g is the proportion of population attributed to the area g, $\overline{LPC}_g$ is the average for landings per capita in area g, and $T(LPC_g)$ is the *Theil-0* index calculated considering exclusively the landings in area g, being $g = \{ATW, MSB, Others\}$ (more details in B). For the purposes of allocating the population of each country to fishing areas an equal distribution principle is assumed (see more details in [47]).

Note that the weights in the within-subgroup add up to one and do not depend on the mean of per capita landings for the area. This characteristic has been referred to as path-independent decomposability [79] and means that the additive decomposition of the index is independent of the path followed to define the two components. The above characterization shows that the overall heterogeneity is the sum of the weighted sum of heterogeneity within areas and the heterogeneity between areas.

The terms T_W and T_B are the within and between components, respectively. The within component accounts for heterogeneity inside each area and the between component accounts for heterogeneity between areas. In this study, landings are available at country level and can be classified by fishing area of origin. Given that the fishing areas considered (ATW, MBS and the remainder) are so dissimilar, it is of interest to ascertain what proportion of the heterogeneity observed is due to differences within and between fishing areas.

Table 2
Distribution of landings per capita among countries and fishing areas. Heterogeneity decomposition in *between-within* components.

Year	Theil	Decomposition				Contribution to the within heterogeneity					
		Between		Within		ATW area		MBS area		Other areas	
	Abs.	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
2008	0.86	0.04	4.31	0.82	95.69	0.49	59.11	0.34	40.78	0.00	0.11
2009	0.89	0.05	5.68	0.84	94.32	0.49	58.27	0.35	41.66	0.00	0.08
2010	0.75	0.03	3.73	0.72	96.27	0.41	57.36	0.30	41.91	0.01	0.74
2011	0.69	0.03	4.17	0.66	95.83	0.41	61.37	0.25	37.97	0.00	0.66
2012	0.68	0.04	5.40	0.64	94.60	0.37	58.05	0.26	40.88	0.01	1.08
2013	0.66	0.05	6.96	0.62	93.04	0.37	60.07	0.24	39.05	0.01	0.88
2014	0.65	0.05	7.08	0.61	92.92	0.38	62.97	0.22	36.13	0.01	0.90
2015	0.59	0.03	5.45	0.56	94.55	0.37	66.44	0.18	32.89	0.00	0.66
2016	0.63	0.03	5.08	0.60	94.92	0.38	63.10	0.21	36.01	0.01	0.89

3.3. Factor decomposition in fishing areas

When the value of per-capita landings is decomposed by input factors, as proposed in Section 2.3, it is of interest to study to what extent each factor contributes to heterogeneity in the distribution of landings between countries.

If the production factors in the decomposition were independent of one other, the heterogeneity of landings per capita estimated by the *Theil-0* index (T(LPC)) would be equal to the sum of the *Theil-0* index applied to the four production factors (see C), i.e.

$$T(LPC) = T(LPK) + T(KPV) + T(VPF) + T(FPP).$$

However, the factors are dependent by construction. Table 1 shows the empirical Pearson correlations between the factors for the two main fishing areas considered. Almost all have a negative relationship. The only common exception between areas is the link between technological productivity and technical progress, which may indicate that more technologically advanced vessels have greater capacities and can seek more productive areas further away [65,66]. The large magnitude of the negative relationship between technical progress and capital-intensity and between technical progress and fishing labor between areas reinforces the idea that two kinds of fleet coexists [66]: one more artisanal (using more capital and labor, but with less technical progress) and the other more technologically oriented (less numerous, but with more technical progress). In the MBS area, the correlation between technological productivity and capital-intensity is also notable, suggesting that increases (decreases) in technological productivity are associated with decreases (increases) in capital-intensity. Consistently with [50,65], this shows that industrial vessels (with larger crews per vessel) are associated with larger fishing returns. The relationship between capital-intensity and fishing labor per capita reflects the substitutability of these two factors.

Thus, in order to analyze the importance of each production factor in the heterogeneity of landings distribution it is necessary to take into account the interrelationships between the factors. Moreover, given the differences between correlations in the two areas the factor decomposition for the areas is expected to be different. To that end, the Theil decomposition proposed by [49] was applied to the data set for the ATW and MBS areas. Broadly speaking, this procedure decomposes the *Theil-0* index as the sum of the index for each factor considered plus an additional element reflecting the interrelations between the factors. Formally, the *Theil-0* index associated with the heterogeneity of landings per capita can be calculated as,

$$T(LPC)=T(LPK)+T(KPV)+T(VPF)+T(FPP)+\ln\left(\frac{\overline{LPC}}{\overline{LPK}\cdot\overline{KPV}\cdot\overline{VPF}\cdot\overline{FPP}}\right),$$

where the overline symbol on a variable reflects the weighted average of the corresponding variable for all countries. Each of the first four summands reflects the direct impact of each factor on landings heterogeneity and the fifth summand represents the indirect impact of all factors together due to their interrelationship. [49] show that this element can be expressed in terms of covariances between factors. See C for a full characterization.

4. Results

4.1. Heterogeneity in fishing areas

Table 2 shows the *between-within* decomposition of heterogeneity in landings-per-capita among coastal MSs grouped by fishing areas (ATW, MBS and Others) and evolution of these figures from 2008 to 2016. The results show that landings per capita are more heterogeneously distributed within fishing areas than between them. This implies that ecological idiosyncrasies of fishing areas such as species composition of fish stocks, biodiversity, nutrients availability, temperature, climate conditions, etc. (underlying the between component) play a minor role in landings per capita heterogeneity amongst MSs when compared to the effects of using dissimilar fleets by countries harvesting in the same area (producing the within component).

Heterogeneity in the landings per capita appears to have decreased by around 27% from 2008 to 2016, mainly due to the observed decrease in heterogeneity within fishing areas. This suggests that landings per capita between MSs have become more alike due to the homogenization of their fleets, which may be driven by the reduction in fleet capacity projected in the CFP [24] as well as improvements in fishing technologies [66]. Despite the decrease over time, heterogeneity within fishing areas represents more than 90% of the total heterogeneity in landings per capita from 2008 to 2016.

The contribution of each area to the within heterogeneity can also be observed to be significantly different (second block in Table 2). In particular, the ATW area accounts for more than 60% of total within heterogeneity. The MBS area represents around 40% of total within heterogeneity while the contribution of Other areas remains below 1% throughout most of the period analyzed. Between 2008 and 2016, heterogeneity within ATW and MBS areas decreased. Nevertheless, the previous pattern was maintained during the period under analysis.

The major role played by fleet dissimilarities in explaining landings-per-capita heterogeneity between MSs justifies further exploration of the production factors leading to such heterogeneity.

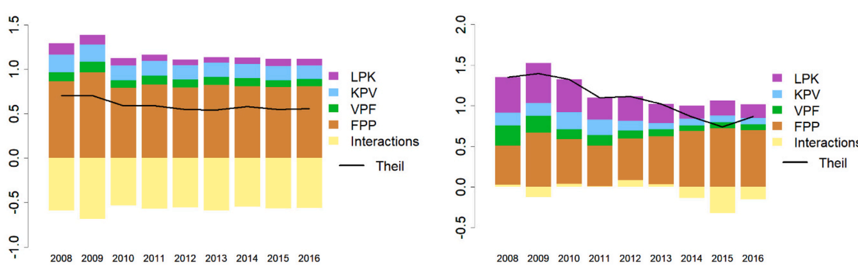
4.2. Factor decomposition in fishing areas

Given that ATW and MBS fishing areas represent most of the landings-per-capita heterogeneity, this Section focuses on the factor decomposition of the heterogeneity found in these areas.

Fig. 6 illustrates the decomposition of the landings-per-capita heterogeneity for each fishing area. The factor decompositions reveal that the reasons for the landings-per-capita heterogeneity vary between areas. The only similarity found in the decomposition of heterogeneity in the two areas is the major role played by fishing labor per capita. Indeed, the dissimilarities in the number of fishers per capita between MSs is the reason for most of the heterogeneity found in their landings per capita, regardless of the area harvested. Heterogeneity in the technical progress of fleets is the second major reason for landings-per-capita heterogeneity in the ATW area. However, technological productivity makes the second largest contribution to landings-per-capita heterogeneity in MBS area. Similarly, the interactions between production factors affect the heterogeneity in each area differently. Thus, interactions significantly reduce landings-per-capita heterogeneity in the ATW area, while having scarcely any effect on landings-per-capita heterogeneity in the MBS area. The overall heterogeneity in landings per capita of each area can be obtained by adding the contributions of production factors and their interactions. A comparison of total heterogeneity shows that landings per capita are more unevenly distributed between countries in the MBS area.

The direct and indirect effect of each factor on overall heterogeneity of landings per capita cannot be quantified in any straightforward way given the dependency between the production factors. Since there is no single way of distributing the indirect impact between factors [80], it is frequently distributed equally amongst them [81]. Following this procedure, Table 3 shows the percentage contribution of each production factor to the heterogeneity in landings per capita in the ATW and MBS areas over the period analyzed.

The heterogeneity in the number of fishers per capita generates most of the heterogeneity in the per-capita landings between MSs. The impact of this factor on heterogeneity of landings rose considerably from 2008 to 2016. In particular, the contribution of fishing labor per capita to landing heterogeneity increased by 18% and 40% respectively in ATW and MBS. Technical progress also positively affects landings heterogeneity in both areas. However, its contribution decreased over the period analyzed. The contribution of technological productivity and capital-intensity to landings heterogeneity is entirely different in each area. In ATW, these factors contributed negatively to landings-per-capita heterogeneity during the period analyzed. By contrast, these factors increased landing heterogeneity in the MBS area, especially technological productivity. The evolution of technological productivity, technical progress and capital-intensity led to the decrease observed in landings-per-capita heterogeneity in both areas from 2008 to 2016. This homogenization in technological factors reflects both the advances in fishing technology of MSs [66] and the limitation of the fleet capacity by the CFP [24].



(a) ATW area (b) MBS area

Fig. 6. Decomposition of landings heterogeneity per capita by input factors: Technological productivity (Landings per Kilowatt, LPK), technical progress (Kilowatts per Vessel, KPV), capital-intensity (Vessels per fisher, VPF) and labor participation (Fishers per population, FPP).

Table 3
Percentage contribution of input factors to heterogeneity in landings per capita.

	ATW area				MBS area			
Year	LPK	KPV	VPF	FPP	LPK	KPV	VPF	FPP
2008	-2.41	7.24	-6.77	101.93	32.67	12.24	18.67	36.42
2009	-8.91	3.42	-7.40	112.89	32.70	9.30	12.38	45.62
2010	-8.17	5.24	-7.73	110.65	31.20	16.77	10.05	41.98
2011	-12.47	3.79	-7.81	116.48	24.89	17.65	11.96	45.50
2012	-14.92	3.93	-9.10	120.09	28.89	12.86	10.36	47.89
2013	-16.15	2.88	-10.87	124.14	23.51	8.59	9.13	58.77
2014	-11.88	4.54	-8.88	116.22	14.67	5.49	3.88	75.96
2015	-11.92	3.65	-11.75	120.02	14.10	-0.04	-0.33	86.28
2016	-11.69	2.11	-10.20	119.79	15.24	4.76	3.80	76.20

LPK (Landings per kilowatt), KPV (Kilowatts per vessel), VPF (Vessels per fisher), FPP (Fishers per population).

5. Discussion and conclusions

The international distribution of resources has transcended the normative role traditionally assigned to it [82] and is recognized as a path for expanding global economic growth and enhancing well-being [1–4,83]. With regard to the international distribution of natural resources, the consequences of their allocation additionally extend to the future availability of those resources [14,15,84] and among these natural resources, fisheries are no exception [85].

Fishery resources represent more than half of global fish production and are mostly used for human consumption. Fishing has very significant socioeconomic effects, given that as at least 39 million people are estimated to be engaged in the industry [86]. Because the proportion of fish stocks exploited in excess of sustainable limits keeps increasing, international agreements need urgently to be implemented if fisheries are to be conserved [4,86]. However, inequity in the distribution of fishery resources undermines the cooperation required for the conservation of the marine environment and in numerous cases at a global level leads to serious conflict [43,87–90].

The CFP implemented by the EU in the 1970s is an example of the international agreements that are required to target sustainable exploitation of fisheries. This framework sought to protect EU fisheries against overexploitation by controlling the fishing activity of MSs whilst also allowing them to obtain the best possible socioeconomic returns. Apart from the objective of decreasing overall fleet capacity, additional controls were established for each fishing area [24,25]. EU fishing activity is mainly concentrated in the ATW and MBS areas, which accounted for more than 80% of the value of EU landings between 2008 and 2016. Only a few MSs (i.e. Spain, France, Lithuania, Poland, Latvia, Portugal, Netherlands and Germany) fished in Other areas during this period [60]. In ATW, fishing activity is mainly regulated through Total Allowable Catches (TACs), which specify the amount of each species that can be landed [26]. These TACs are set annually and split into quotas amongst MSs safeguarding the Principle of Relative Stability (PRS). The PRS prioritizes the fishing activity of countries that originally harvested a given area, in order to protect communities historically dependent on those resources [24,25,91]. By contrast, the most common regulations in the MBS area are the technical measures limiting certain fishing practices as well as the size, number and selectivity of fishing gears [92]. In general, the CFP appears to have succeed in reducing the EU's fleet capacity. Between 2008 and 2018, the number of vessels fell by 5.5%. Simultaneously, the total power (kWt) and tonnage (GT) of the EU fishing fleet decreased by almost 17% and 10.5% respectively [93]. Nevertheless, the CFP has been called into question on multiple fronts. From the perspective of efficacy, the CFP guidelines have not been enough to safeguard the sustainability of all EU fish stocks [94–97]. From an institutional viewpoint, lack of transparency in definition of the regulation is an obstacle to stakeholder-approval and engagement [98,99]. Indeed, it has been claimed that asymmetries in the bargaining power of different countries and interest groups have been the main reason for inconsistencies in the distribution of CFP benefits [27,100]. In this sense, the undervaluation of small-scale fisheries, which represents 75% of the active EU fleet and half of the EU fishing labor force [93], underlies the heterogeneous impact of different groups on the distribution of benefits in the CFP and the CFP's compliance with the goal of sustainable development [54,56]. From an ecological perspective, variations in the distribution of fish stocks resulting from factors such as climate change threaten the current regulation on fishery resources allocation [101,102].

Moreover, the EU recently adopted several initiatives to promote Blue Growth. This project aims to increase the profitability of economic activities performed in marine areas by encouraging new technologies that will ensure the sustainability of the environment. Given their capacity for innovation and generation of new jobs, the sectors primarily considered in this initiative are: ocean energy generation, aquaculture, tourism, biotechnology and exploitation of marine mineral resources [57,58]. The omission of fishing from this plan, particularly the activity of the small-scale fleet, has raised concerns, due to the large reliance on fishery resources and the difficulties in re-allocating a labor force historically dependent on fishing [5,48,103,104]. A lack of references to social aspects -such as equity- has also raised concerns that it may compromise sustainable development [5,85].

Within the European region, Brexit is a clear recent example of the relevance of equity in the distribution of resources. Unfavorable and unequal distribution of fishery resources in recent years was one of the key arguments for the UK's leaving the European Union [61–64]. However, this is not the only case of tension associated with unequal distribution between MSs (and former MSs). [105] describes how different potential frameworks for regulating fishing activity under the CFP would affect either small-scale or industrial Spanish fisheries. Each of these fleet segments would prefer to see the regulation that is less harmful to their sector being implemented. Thus, implementation of a single policy favors one fleet segment over the other. [106] highlight the strong opposition to the CFP among small-scale Croatian fisheries, who claim that the regulation does not take into account geographical and socioeconomic idiosyncrasies in fishing areas and communities. They believe CFP benefits small-scale fisheries from other regions of Europe, but not their own. [107] compare different perceptions of CFP implementation in Great Britain and Germany. The results show very different expectations of CFP implementation between the two countries. Whereas in Great Britain the regulation is seen as a tool for fulfilling the needs of EU's fisheries, in Germany the CFP is perceived as an instrument for achieving their national goals. [108] outline the difficulties in allocating fishing activity among different stakeholders in the wild Atlantic salmon fisheries in Scotland, where each stakeholder believed themselves to have a better justification than the others for exploiting these scarce fishery resources.

The present analysis aims to contribute to the reduction of fishing pressure pursued by the CFP while ensuring that fishing remains an active industry within the Blue Growth strategy. For this purpose, it focuses on two aspects. Firstly, it examines whether the heterogeneous distribution of the value of landings per capita between EU countries is motivated by idiosyncrasies in their harvesting areas or by differences in fishing activity. Secondly, it compares the contribution of each production factor to the heterogeneity of the value of landings per capita of countries within the main EU fisheries (the ATW and the MBS areas). Combining these questions, the analysis presents evidence on ways in which fleet capacity reduction could be efficiently proposed in each of the main fishing areas while ensuring homogeneous distribution of fishery resources between countries.

From a methodological viewpoint, the analysis is based on different decompositions of the Theil inequality index with a parameter value of 0 [77,78]. Inequality metrics have already been implemented to analyze the distribution of multiple natural resources and environmental capacities such as CO_2 emissions [109–111] coal use [34], water use [112] and ecological footprint [33]. By contrast, fewer studies exist based on inequality metrics in the field of fishery resources. Among such studies, the research question is very diverse in nature: the distribution of resources in a particular fishery between different fleet segments and its relationship to total production [38]; the concentration of market power among a few large fishers caused by the ITQ system [44]; and the consequences of diverse quota management methods for different fleet segments [40]. Despite applying the same type of methodology, the present analysis focuses on the heterogeneity between countries' fleets rather than between fleet segments of the same fishery. In this regard, this analysis more closely resembles the study in [47], which examines inequality in high seas catches of countries in the period 1960–2014. Despite the decrease in such heterogeneity during the period analyzed, the authors found that at the end of the period, major dissimilarities persisted between countries, mainly due to technological factors. Following this evidence, the present analysis initially decomposes heterogeneity in the per-capita landings of MSs between and within major fishing areas. The two components of heterogeneity give an interesting insight into the reasons for total heterogeneity. On the one hand, heterogeneity between fishing areas reflects dissimilarities caused by the ecological features of each area. On the other hand, heterogeneity within fishing areas results from technological dissimilarities between fleets. After isolating the technological inequality, the multiplicative factor decomposition [49] was analyzed to estimate the contribution of each production factor (technological productivity, technical progress, capital-intensity and fishers per capita) to heterogeneity.

The dataset used for this analysis contains information from 23 MSs for the period between 2008 and 2016 (including the United Kingdom, which was still a Member State during the period analyzed). Several additional aspects should be noted in consideration of this sample. Firstly, the availability of data for certain countries explains their later incorporation to the sample (France has been included from 2010 onwards, Croatia from 2012 onwards and Greece from 2014 onwards). Secondly, the poor quality of data-indicators for some of the countries is an obstacle to comparison [30]. Moreover, there are several factors that should be mentioned regarding the structure of the analysis and data used. Although the analysis considers the size of countries when weighting the allocation of resources by population, other criteria may underlie their current allocation of fishery resources [27,100]. Since the analysis focuses on the distribution of EU resources, it omits the operation of foreign countries in the same fishing areas, which may affect fishing activities in several dimensions such as the status of the stocks [113] and stakeholder participation in management [114].

The present analysis shows that more than 90% of the heterogeneity in landings per capita of MSs between 2008 and 2016 is due to heterogeneity in their fishing activity (the within component) rather than to particular features of their fishing areas (the between component). Heterogeneity in ATW represents the largest share of total within inequality (between 50% and 60%). By contrast, heterogeneity in areas other than ATW and MBS (Other Areas) represents less than 1% throughout most of the period analyzed. The negative trend in total heterogeneity reflects the fact that countries' landings homogenized by more than 26% between 2008 and 2016. This reduction in heterogeneity was mainly caused by the decrease observed in heterogeneity within areas (almost 27%). The largest decrease in heterogeneity was observed in the MBS area, whose contribution to the within component was reduced by around 38%. In the ATW area, the contribution to the within component decreased by 22%.

Since most of the value of EU landings during the period analyzed (around 84%) comes from the ATW and MBS areas, with Other Areas contributing in less than 1% to within heterogeneity, the multiplicative factor decomposition was only applied to the ATW and MBS areas. This decomposition reflects the fact that the contribution of production factors to heterogeneity within areas varies significantly. The only exception that can be appreciated in both areas is the large contribution of the labor factor. Indeed, fishers-per-capita is the largest contributor to the heterogeneity in both areas. In the ATW area, factors related to technology have a much smaller effect (technical progress) or even contribute negatively to heterogeneity (technological productivity and capital-intensity). In MBS, the second largest contributor to heterogeneity is the technological productivity although its contribution is far behind that of the labor factor. From 2008 to 2016, the contribution of the labor factor has increased noticeably in both areas. By contrast, the greatest decrease was experienced in the contribution of technological productivity.

Based on the evidence of this analysis, the adjustment in fishing capacity sought by the CFP could be advanced by impacting the labor force and kWt per vessel in the ATW area and the labor force and technological productivity in the MBS area. Since lower fishing pressure is considered necessary for the conservation of marine ecosystems, these factors could be homogenized using countries with medium or low landings levels as a benchmark. Special care should be taken with regard to the fishing labor force factor, since the fishing industry is a major support for coastal communities. In absolute terms, the proportion of fishers in the labor force fell in all countries, mainly but not exclusively as a result of aging and a lack of replacement by younger workers. This has even led to the creation of professional fishing schools such as *Enaleia* in Greece and *Instituto de Pesca Marí*tima del Atlántico in Spain. Nonetheless, this decrease is more significant, in relative terms, in Northern European countries where young fishers face difficulties entering the industry because of the large capital investment required in acquiring vessels and quotas [115] than in Southern countries. Considering equity in the burdens of conservation will help to avoid the tensions that have arisen between countries under unequal distributions of resources, increasing the long-term probabilities of the CFP's success. Implementing flexible quota managament [28,116] or increasing the involvement of fishers in the regulation process [99,117,118] could help achieve sustainability of the marine environment whilst also keeping the fishing industry alive.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. OFR landings

The tables below Tables 4, 5, 6, 7 and 8 show the percentage of the value of 2008–2016 landings coming from each OFR for Spain, France, Lithuania, Portugal and Italy. For the purposes of clarity, information on OFRs that represent less than 1% of the value of landings during the period analyzed has been omitted.

Table 4
Origin of OFR landings value 2008–2016, Spain.

Subregion	% OFR Landings (in Euros)	FAO area
51.5	21.00	Somalia, Kenya and Tanzania
41.3.2	11.71	Southern Patagonian
41.3.1	7.05	Northern Patagonian
34.3.1	5.84	Cape Verde Coastal
34.1.3	5.43	Sahara Coastal
77	4.95	PACIFIC, EASTERN CENTRAL
87.2.6	3.07	Central Oceanic
34.3.3	2.58	Sherbro
34.4.2	2.31	Southwest Oceanic
51.6	2.26	Madagascar and Mozambique Channel
34.4.1	2.24	Southwest Gulf of Guinea
34.3.6	2.13	Southern Gulf of Guinea
34.1.2	1.94	Canaries/Madeira Insular
51.4	1.91	Eastern Arabian Sea, Laccadives
47.1.1	1.68	Cape Palmeirinhas Division
41.2.4	1.66	Central Oceanic
47.1.3	1.56	Cunene Division
34.3.4	1.37	Western Gulf of Guinea
47.1.2	1.37	Cape Salinas Division
71	1.35	PACIFIC, WESTERN CENTRAL
81	1.33	PACIFIC, SOUTHWEST
87.1.4	1.30	Northern Oceanic
34.3.2	1.20	Cape Verde Insular
51.7	1.13	Oceanic
51.8	1.12	Mozambique
47.1.5	1.07	Orange River Division

Table 5
Origin of OFR landings value 2008–2016, France.

Subregion	% OFR Landings (in Euros)	FAO area
51.5	26.28	Somalia, Kenya and Tanzania
34.3.6	20.03	Southern Gulf of Guinea
31	19.61	ATLANTIC, WESTERN-CENTRAL
51.6	14.34	Madagascar and Mozambique Channel
51.7	5.08	Oceanic
34.3.4	3.46	Western Gulf of Guinea
34.3.3	2.28	Sherbro
34.4.1	2.08	Southwest Gulf of Guinea
34.3.1	1.38	Cape Verde Coastal
41.1.1	1.23	Amazon
47.1.2	1.10	Cape Salinas Division
34.4.2	1.06	Southwest Oceanic

Table 6
Origin of OFR landings value 2008–2016, Lithuania.

Subregion	% OFR Landings (in Euros)	FAO area
34.3.1	22.52	Cape Verde Coastal
34.1.3	18.40	Sahara Coastal
34.1.3.2	13.23	Subdivision 34.1.32
87.2.6	11.43	Central Oceanic
87.3.3	5.85	Southern Oceanic
34.1.1	4.64	Morocco Coastal
34.3.1.1	3.92	Subdivision 34.3.11
34.1.3.1	3.69	Subdivision 34.1.31
27.14.b	2.50	Southeast Greenland
47.1.3	2.32	Cunene Division
27.1.a	2.00	Barents Sea - NEAFC Regulatory Area
27.4.a	1.71	Northern North Sea
27.7.b	1.15	West of Ireland

Table 7
Origin of OFR landings value 2008–2016, Portugal.

Subregion	% OFR Landings (in Euros)	FAO area
34.1.2	31.20	Canaries/Madeira Insular
51.8	12.34	Mozambique
41.2.4	7.35	Central Oceanic
34.3.1	4.90	Cape Verde Coastal
41.3.1	4.18	Northern Patagonian
51.7	3.98	Oceanic
34.4.2	3.48	Southwest Oceanic
34.1.3	2.42	Sahara Coastal
47.c.1	2.22	47.C.1 SEAFO Division
34.3.3	2.18	Sherbro
41.3.3	2.14	Southern Oceanic
57.3	1.94	Central
34.2	1.94	Northern Oceanic
47.b.1	1.83	47.B.1 SEAFO Division
81	1.81	PACIFIC, SOUTHWEST
34.3.2	1.61	Cape Verde Insular
47.a.1	1.44	47.A.1 SEAFO Division
41.2.3	1.33	Platense
51.6	1.33	Madagascar and Mozambique Channel
41.1.4	1.25	Nothern Oceanic
34.4.1	1.07	Southwest Gulf of Guinea

Table 8
Origin of OFR landings value 2008–2016, Italy.

Subregion	% OFR Landings (in Euros)	FAO area
34.1.3	53.16	Sahara Coastal
34.3.1	21.59	Cape Verde Coastal
51	15.94	INDIAN OCEAN, WESTERN
34.3.1.3	6.16	Subdivision 34.3.13
34.3.1.1	1.61	Subdivision 34.3.11
34.3.3	1.54	Sherbro

B. Concerning the Between - Within Theil Decomposition

The following are the main steps for decomposition of the inequality in landings per capita for a given fishing area g:

$$T(LPC) = \sum_{i=1}^{N} p_i \ln\left(\frac{\overline{LPC}}{LPC_i}\right)$$

$$= \sum_{g=1}^{G} p_g \sum_{i=1}^{n_g} p_{gi} \ln\left(\frac{\overline{LPC_g}}{LPC_{gi}}\right) + \sum_{g=1}^{G} \ln\left(\frac{\overline{LPC}}{\overline{LPC_g}}\right)$$

$$= \sum_{g,=1}^{G} p_g T(LPC_g) + \sum_{g=1}^{G} p_g \ln\left(\frac{\overline{LPC}}{\overline{LPC_g}}\right)$$

$$= T_W + T_B$$

where g denotes each of the G groups (fishing areas in this setting), n_g is the number of countries harvesting in the fishing area g, p_g is the proportion of population attributed to gth fishing area, $T(LPC_g)$ is the inequality index calculated taking into account the population of fishing area g and, $\overline{LPC_g}$ refers to the overall average for landings per capita in the gth fishing area.

C. Concerning the multiplicative factor Theil decomposition

Proof of the factor decomposition for the Theil index is provided by [49] for a general setting where a variable of interest can be written as the product of m factors without assuming independence, where μ is the overall mean and $\{\mu_{jf}\}_j = 1^m$ are the means of the factors. Instead of deriving the expression corresponding to a given g fishing area, for the shake of simplicity the subindex g has been dropped without loss of generality. We have adapted the decomposition to our application here. Given $LPC_i = LPK_i \cdot KPV_i \cdot VPF_i \cdot FPP_i$, the decomposition is expressed as follows:

$$T(LPC) = T(LPK) + T(KPV) + T(VPF) + T(FPP) + \ln\left(\frac{\overline{LPC}}{\overline{LPK}\cdot\overline{KPV}\cdot\overline{VPF}\cdot\overline{FPP}}\right) \quad (2)$$

The Theil index can thus be decomposed into two different components: the sum of each factors' Theil index and an additional term, usually referred to as an interaction term which measures the combined dependence of all factors. Note that factors interact with each other by construction, so $\overline{LPC} \neq \overline{LPK}\cdot\overline{KPV}\cdot\overline{VPF}\cdot\overline{FPP}$ and then T(LPC) ≠ T(LPK) + T(KPV) + T(VPF) + T(FPP).

Based on Eq. (2), it can be observed that each T(F) (F=LPK, KPV, VPF, FPP) measures the partial contribution of factor F to overall inequality while the rest of the factors remain unchanged. The total contribution of factor F to overall inequality is obtained by adding the common part to the partial contribution, $T(F) + \ln(\overline{LPC}/\overline{\mathrm{LPK}}\cdot\overline{\mathrm{KPV}}\cdot\overline{\mathrm{VPF}}\cdot\overline{\mathrm{FPP}})$. These contributions are not necessarily non-negative unless factors are independent (see [80]), which is not the case here. Obviously the sum of all total contributions exceeds the overall inequality because the common part is taken into account as many times as there are factors. Given the nonlinearity of the dependence term it is not possible to decompose it into additive functions of the factors. Thus, one way of presenting results is to show the partial contribution plus the common contribution due to the interaction term. Another way, used in many inequality decompositions where there is a common part [80,81] is to attribute the same proportion of the common part to each factor.

Although (2) is the most compact expression for the decomposition, there has been a considerable interest in looking within the dependence component to obtain the factors underlying it. Here we follow the method used in [49,119] to show the main role of the relationships between the factors within this term.

For this purpose, we focus on the overall mean, $\overline{LPC}$, which can be expressed as the sum of the covariances between the production factors. In particular,

$$\begin{aligned}\overline{LPC} &= \sum_i p_i LPC_i = \sum_i p_i LPK_i\cdot KPV_i\cdot VPF_i\cdot FPP_i \\ &= \sum_i p_i LPK_i\cdot KPV_i VPF_i\cdot FPP_i \pm \overline{LPK}\cdot\sum_i p_i\cdot KPV_i VPF_i\cdot FPP_i \\ &= \sigma_{LPK,KPV\cdot VPF\cdot FPP} + \overline{LPK}\cdot\sum_i p_i\cdot KPV_i VPF_i\cdot FPP_i = \ldots \\ &= \sigma_{LPK,KPV\cdot VPF\cdot FPP} + \overline{LPK}\cdot\sigma_{KPV,VPF\cdot FPP} + \overline{LPK}\cdot\overline{KPV}\cdot\sigma_{VPF,FPP} \\ &\quad + \overline{LPK}\cdot\overline{KPV}\cdot\overline{VPF}\cdot\overline{FPP},\end{aligned}$$

where $\sigma_{A,B}$ is the weighted covariance between A and B.

By introducing this expression for $\overline{LPC}$ into the last term in Eq. (2), it can immediately be seen that this term represents the interactions between the production factors:

$$\ln\left(\frac{\sigma_{LPK,KPV\cdot VPF\cdot FPP} + \overline{LPK}\cdot\sigma_{KPV,VPF\cdot FPP} + \overline{LPK}\cdot\overline{KPV}\sigma_{VPF,FPP}}{\overline{LPK}\cdot\overline{KPV}\cdot\overline{VPF}\cdot\overline{FPP}} + 1\right)$$

Finally, if the variable of interest is not the overall inequality (LPC) but the inequality of a given fishing area (LPC_g), just replace the variables according to the area of interest.

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