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Measuring Market Accessibility of Insular Areas based on Network Distance and Shipment Cost: The case of Greek Islands

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Abstract. In this paper, we calculate the two-sided (consumer and producer) market accessibility of the Greek islands, based on different measures of transport cost, namely, the actual network distance and the freight shipment cost from/to mainland regions and between them. For this purpose, we employ a unique micro-dataset of 1,026,469 shipments for the year 2021 originated from the platform of Islands' Transport Equivalent for firms. The shipment cost refers to the receipts of payments made by firms for outsourcing transport services to companies with public-use truck vehicles. The findings show the importance of the population size, geographical proximity to large markets and network connectivity, and underscore the severe imbalances among consumers' (importers') and producers' (exporters') accessibility to and from the Greek islands. Moreover, the use of shipment cost significantly alters the accessibility hierarchy and trade imbalance inequalities among islands, as it incorporates insularity theory-consistent and inherent characteristics of the logistics and product markets. Relevant policy implications are made to support the design of more effective island policies aimed at supporting the competitiveness of local businesses, the living standards of inhabitants and the territorial cohesion of the country.

Key words: Accessibility, Freight transport, Shipment cost, Network distance, Island Transport Equivalent, Greece

1 Introduction

Trade between the mainland and island regions, as well as between and within island areas, plays a fundamental role in the economic and social development of islands, and the extent of regional integration and territorial cohesion. The implementation of targeted policy measures to enhance the accessibility from/to islands is important to maintain their population and employment, as well as to increase the productivity and competitiveness of local businesses. A crucial component of insular policies in countries with island regions refers to the reduction of transport costs to and from the islands. This is because increased transport costs, compared to the mainland, not only negatively affect the ease of access, but also relate to significant negative externalities that are highly differentiated among island areas. These externalities are associated with conditions of

limited competition (e.g., monopolistic or oligopolistic conditions on smaller islands), unavailability and/or inefficient use of natural resources, inability to develop economies of agglomeration and economies of scale (Auty 2019), limited access to socio-economic opportunities, and a lack of a highly skilled labour force as well as specialised intermediate goods and services.

The increased cost and time required to transport goods to/from the islands can have a direct or indirect effect on many different aspects of business activity. These aspects include decisions to retain existing and/or create new businesses and expand branches of current businesses, sectoral diversification, expansion into domestic and foreign markets, recruitment and education/training of employees, and selection for employment in these businesses. By extension, the effects of changes in transport cost on the total turnover or production costs of enterprises may have an impact on the prices, quality and quantity (e.g., due to limitations on the supply and the variety) of goods and services, the propensity to consume and the real disposable income of island residents (Hayakawa et al. 2020). The impact of changes in transport cost may considerably vary, depending on the type of economic activity of enterprises, their size, and the degree of their extroversion and integration into supply networks and regional and global value chains.

Greece is characterised by a complex geomorphological landscape, with a significant heterogeneity and diversity of island clusters, which cover approximately 18.7% of the total surface area and 15.8% of the total population of the country (or 13.6%, when the islands of Evia and Lefkada, which are accessible by road, are excluded). It is estimated that at least 25% of the country's Gross Domestic Product (GDP) comes from marine-related activities, mainly related to shipping and tourism (Kotios 2022). Despite their importance for economic growth and territorial cohesion, island regions lag behind mainland regions in terms of innovation (except Crete or Kriti) and public investment, and remain more dependent on the service sector (in particular, tourism) and vulnerable to climate change. Taking into account the high heterogeneity that characterises the Greek islands, the effectiveness of island policies may relate to the local economic environment, the size of the market, the regulatory compliance, the existence and degree of competition, the travel distance/time from/to mainland ports of call and nearby (large) islands, the availability and quality of physical infrastructure, and the quality of transport services.

Furthermore, it is noted that changes in the cost and conditions of transporting goods from/to an island can have a competitive and/or complementary impact on the socio-economic development of other islands, depending on the type of connectivity, ease of access and degree of integration between them (for instance, in Greece, the economic integration of the island of Naxos with the neighbouring – belonging to the same municipality – small Cyclades islands of Iraklia, Schinoussa, Koufonisia and Donoussa). Inefficient maritime logistics can drive higher logistics costs and create trade flow imbalances between islands and the mainland country, hampering the competitiveness of insular areas and amplifying regional disparities (Yudhistira, Sofiyandi 2018). Therefore, decisions concerning the development and territorial cohesion of island regions should be holistic in nature, based on factual evidence and knowledge, specific to the location and connectivity of each island, and according to its particular needs and prospects.

Coastwise transport-related subsidies to support the residents and businesses of insular regions have been deployed in various forms in the EU (Jiménez et al. 2018), but their impact on price affordability and the welfare of island communities remains questionable. The efficiency of maritime trip-based freight cost subsidies on (food) commodity prices has also not been proven in large archipelagic developing countries such as Indonesia (Sofiyandi et al. 2023). Given that the direct impact of the price affordability of island residents and firms cannot be easily determined, cost-based accessibility can provide a practical and useful metric to examine the insularity and policy needs and challenges in island regions worldwide, with or without the presence of a relevant insular policy regime.

Accessibility metrics have been widely studied at the level of region (NUTS-2) or regional unit (NUTS-3) in Europe, since actual cost measures are typically unavailable at the subregional level, that is, at the (upper or lower) local administrative units (LAUs).

Previous efforts in the related scholarly literature to estimate the (one-sided or unidirectional) accessibility of selected islands in Greece were focused on the estimation of the actual travel time (Spilanis et al. 2012, Karampela et al. 2014) or the trip distance, travel time, and ticket cost (Perra, Boile 2026) required for passengers to travel among the islands and between the islands and the mainland. Other accessibility indices based on transport-model estimates of the generalised transport cost from/to island regions at the regional unit (NUTS-3) level (Tsekeris 2023) cannot depict the particular conditions of accessibility at the level of each island.

To the best of our knowledge, the present accessibility analysis covers for the first time the whole population of islands in Greece, namely, not only in the Aegean islands, but also in the Ionian islands, Kriti (the largest island in Greece), and a considerable number of so called 'coastal' islands, which are connected through regular ferry transport services with different regions of mainland Greece. In turn, this analysis includes regions at different geographical settings and levels of development, including Attiki, which, in this database, encompasses the islands of Aegina, Agistri, Hydra, Poros, Spetses, and Kythira, and is the only Greek region in transition, compared to the remaining ones that are considered as less developed regions in the EU (Dijkstra et al. 2023).

Moreover, the current study considers the national policy context of the Island Transport Equivalent for firms, which was launched in the middle of 2018, while from 2020 the island of Kriti (Crete) has also been included in the measure for selected Activity Code Numbers. Its implementation relies on the harmonisation of the cost of transporting goods to and from the islands with the corresponding land transport cost (within the mainland country). The subsidy (compensation) for these increased costs is provided from resources of the Public Investment Programme, under rules compatible with the EU State aid regulations, to the extent that the cost of maritime transport is harmonised with the cost on the mainland. The objective of the measure is to ensure equal treatment and to minimize the economic disadvantage of island companies, reflecting the increased cost of transporting goods, compared to (similarly sized) mainland companies.

Greece's Transport Equivalent policy is a direct user-oriented cost equalisation mechanism that reimburses island firms (and passengers), in contrast with several other EU island policy regimes, such as Spain's Canary and Balearic Islands, where support is often operator-centred. Besides, Public Service Obligation-based systems guarantee (maritime and air transport) service frequency and network continuity, functioning as a parallel social measure rather than a formalised mainland cost benchmark (Fageda et al. 2017, Martínez Raya, González-Sánchez 2021). Scotland's island ferry model similarly prioritises lifeline connectivity and long-term service planning via subsidised ferry contracts, embedding discounts within wider accessibility and socio-economic sustainability goals, rather than an explicit cost-equivalence index (Cowie 2012, Laird 2020). Outside Europe, Australia's Tasmanian Freight Equalisation and Bass Strait Passenger Vehicle Equalisation schemes come closest in logic to Greece's approach, as both compensate maritime transport cost disadvantages relative to mainland surface transport, yet they are corridor-specific and freight-oriented (Productivity Commission 2007, 2014), lacking the multi-island, multi-sector cohesion framing of the Greek Transport Equivalent. In Small Island Developing States (SIDS), policy emphasis shifts from strict cost equalisation to overcoming structural remoteness, high freight rates and systemic vulnerability, through infrastructure financing, resilience investment and broader affordability measures, rather than a unified domestic price benchmark (UNCTAD 2014, 2020, Soomauroo et al. 2023). Last, the world's largest archipelagic country, i.e., Indonesia, applies a trip-based freight subsidy (the Sea Toll Programme), through the operation of dedicated ships for the supply of specific food commodities along pre-determined shipping routes (Sofiyandi et al. 2023). Overall, Greece's Transport Equivalent stands out internationally for its explicit mainland-referenced rebate formula and equity-driven design, whereas most other island systems prioritise service provision, sector-specific freight support or development-oriented accessibility.

The main objective of this paper is to offer an original and detailed analysis of the trade accessibility of island areas for a nation-wide transport network setting in Greece, taking into account both sides of importers and exporters of Greek islands. The measure

of accessibility is calculated on the basis of the well-known measure of market access (Harris 1954), which provides a potential accessibility metric (Yoshida, Deichmann 2009), with the use of two alternative measures of the average – per itinerary – transport cost: the traditional one based on the actual network distance traveled by trucks (along the road and inside ferries) and the actual transport (freight shipment) cost, that is, the price paid by the firms located in an island to the transport companies for the movement of goods from/to mainland regions and other islands. The latter cost intrinsically considers market forces shaping the transport conditions and, hence, can be regarded as appropriate for making practical policy recommendations. In contrast with the previous studies mentioned before for Greece, suitable accessibility indices are calculated here from both the consumer (import) and producer (export) side, for a total of 73 inhabited islands of the country. It is noted that the term "consumer" here refers to the purchasing firms and not the individual (household) consumers.

Regarding the organisation of the paper, Section 2 provides scholarly literature and theoretical underpinning about the formulation and calculation of the accessibility. Section 3 reports the data sources and describes the collection and processing of variables and their brief statistics. Section 4 includes the empirical results and their discussion, encompassing several types of comparative analyses with the use of accessibility indices, statistical grouping and cartographic illustrations, correlation analyses and nonparametric (Wilcoxon signed-rank test) statistics. Finally, Section 5 summarises and concludes by providing several policy implications and suggestions.

2 Accessibility: Definition, theoretical relevance and calculation

The use of population-based accessibility indicators to measure the number and size of markets available at low trade cost can be traced back to Harris (1954) and Isard (1960). Such an indicator expresses a metric of the geographical centrality of a region, i.e., how central or accessible it is relative to the population as a measure of market size (since the GDP or the total number of sales are not available at the level of islands) and the network distance or transport cost to access all the other regions (including the other islands) in the country. This measure can represent the degree of accessibility (or affordability of access) as the potential capacity of firms to import and export their primary/intermediate resources and final goods from the regional economics and trade perspectives (Behrens, Thisse 2007). It directly relates to Hansen's (1959) gravity-based accessibility measure, since it conceptualises market accessibility as the potential for spatial interaction and controls for population size, allowing the comparability of the levels of access to transport cost-weighted opportunities of different groups among different geographical areas (Reggiani et al. 2011, Klaesson et al. 2015). Such measures provide empirically tractable indicators of effective market size and have been widely applied to assess regional accessibility patterns and the economic impacts of transport infrastructure, especially roads and railways (Chen et al. 2015). Relevant literature (Peña Carrera 2002, Wieland 2020, Santana Palacios, El-Geneidy 2022) has also emphasised the role of such measures within broader frameworks of regional analysis using various model specifications and impedance functions.

Market access and transport costs play a pivotal role in shaping the spatial organisation of economic activity and, particularly, the economic performance of islands. In models of monopolistic competition, reductions in transport costs enlarge effective market size, intensify competition, and allow firms to exploit increasing returns to scale, thereby raising productivity and welfare (Krugman 1980). New Economic Geography (NEG) formalises these mechanisms by showing how transport costs interact with scale economies and demand linkages to determine the location of firms and workers, potentially leading to core–periphery outcomes (Krugman 1991, Fujita et al. 1999). For islands, geographical separation inherently raises trade costs, weakening market access and limiting agglomeration forces, which, in turn, constrains diversification and amplifies dependence on external markets. Thus, accessibility is not merely a logistical concern but a fundamental determinant of spatial economic structure, with markedly pronounced implications for islands facing persistent barriers to market integration.

Modern insularity theory, as articulated by Baldacchino (2020) and Briguglio (1995), reframes island disadvantage as a structural and relational condition based on the real cost of flows rather than a simple function of geographical distance, thereby providing a theoretical foundation for both island cost-compensation schemes and shipment cost-based accessibility metrics. Specifically, Baldacchino's relational view of insularity emphasises that islands occupy constrained and asymmetric positions within transport and market networks, where limited modal choice, service frequency, backhaul imbalances and market thinness shape the real experience of separation. Briguglio's economic vulnerability framework formalises these features as persistent, exogenous cost penalties linked to small scale, import dependence and high transport costs. From this perspective, higher shipment costs are not signs of inefficiency but manifestations of structural disadvantage, which normatively justifies cost-compensation schemes as territorial equity corrections that restore functional equivalence in market access rather than distort competition. This logic also supports replacing traditional distance-based accessibility formulations (where impedance is physical or network distance) with shipment cost-based measures. This is because distance fails to capture the network frictions that constitute insularity, whereas observed shipment costs internalise frequency constraints, transshipment needs, reliability risks and operators' market power into the impedance term, turning accessibility into a measure of effective economic reach consistent with both relational insularity and structural vulnerability theory.

Therefore, in comparison to standard accessibility specifications concerning the distance (or time) to reach the island port or the mainland port of call (Schmitt, Kramer 2009, Blumfield et al. 2018), or the distance (or time) weighted sum of population residing on the same island and all other origin-destination regions, the suggested alternative formulation of accessibility encompasses the actual shipment cost. Such a specification is regarded as particularly relevant, suitable and useful for countries like Greece with a wide range of island typologies and insularities, ranging from very small islands, which are municipal units of larger island municipalities, to Kriti, which is a single administrative region made up of four regional units. In such cases, maritime transport cost is much more sensitive to the efficiency and quality of services, which reflects the actual shipment cost, rather than solely to geographical factors like distance (Martinez-Zarzoso, Nowak-Lehmann 2007).

As it was found for the case of a small-island developing state (the Comoros), the enhancement of accessibility through reducing the transport costs to bring goods to island cities, as well as through improving the access to intermediary services, such as cooperatives and collectors, can increase crop production and market sales (Iimi 2019). The use of information for monetary costs in estimating the gravity-based accessibility for transport services can shed light on inequalities and (un)affordability issues which cannot be otherwise considered (Giannotti et al. 2022). Thus, a shipment cost-based accessibility metric can support the deployment and evaluation of a national insular policy, which takes into account various types of connectivity from very large to small and very small islands connected with each other and the mainland with radial plus modal transport networks.

First, we use a measure of the distance-based accessibility, which is defined as the distance-based discounted sum of the island's population plus the population of all other partner mainland regions and islands. The distance-based accessibility can be expressed from both the consumer (CDA) and the producer (PDA) side as follows:

$$CDA_j = \ln\left(\sum_i a_{ij} P_i D_{ij}^{-\sigma}\right)$$

$$PDA_i = \ln\left(\sum_j a_{ij} P_j D_{ij}^{-\sigma}\right)$$

where a_{ij} denote the elements of an adjacency matrix $A = \{a_{ij}\}$, which take the value $a_{ij} = 1$ if island i is trading with region j, and $a_{ij} = 0$ otherwise. P_j is the population of the trade partner region j, D_{ij} is the transport network distance (in km) between the

island i and its trade partner j (mainland regional unit or other island). The distance-decay parameter σ depicts how accessibility attenuates with distance from the destination island (from the consumer side) or the origin island (from the producer side). This value is typically set equal to $\sigma = 1$, implying that the effect of region j on the accessibility of trade partner region i is inversely proportional to the distance (or transport cost) between them. The intra-regional travel distance D_{ii} within a region (island) i is calculated as (Batty 1976):

$$D_{ii} = \frac{r_i}{\sqrt{2}}$$

The above measure relies on the assumption that the shape of region i can be represented as circular and that its population is spread evenly across the area. Then, r_i is the radius of the circle equivalent in area to region i, which can be defined as $r_i = \sqrt{A_i/\pi}$, where A_i is the area (in km^2) of region i.

Similarly, the shipment cost-based accessibility of an island is defined as the cost-based discounted sum of the island's population plus the population of all other partner mainland regional units and islands. The cost-based accessibility can be expressed from both the consumer (CCA) and the producer (PCA) side as follows:

$$CCA_j = \ln\left(\sum_i a_{ij} P_i C_{ij}^{-\sigma}\right)$$

$$PCA_i = \ln\left(\sum_j a_{ij} P_j C_{ij}^{-\sigma}\right)$$

where C_{ij} is the freight shipment cost (in euro) between regions i and j (with $\sigma = 1$). Given that there is no available information about the cost of shipment within each region (island), this cost is calculated by the following product:

$$C_{ii} = DC_i \times D_{ii}$$

where DC_i is the average distance cost coefficient (in euro per km) corresponding to region (island) i. These accessibility metrics account simultaneously for the relative position of a region in the domestic market (as it is interconnected by the road and the coastwise shipping transport networks) and its *relative* market size, in terms of the population, considering both its own population and the population of all the other regions. In this sense, they can express a gravity index of the centrality and accessibility of each island, according to its geo-economic position in relation to all other island and mainland trading regions (Tsiapa 2019).

They capture both the effect of external demand and the local demand of region i itself in order to account for the whole spatial extent of agglomeration economies. High values of distance-based and cost-based accessibility relate to increased market size and more central position, compared to regions having lower index values, due to their lower population size and poor access or peripheral position in the domestic market. All accessibility indexes from both the consumer (import) and producer (export) side are normalised and expressed in the scale from 0 to 1. In this way, the suggested metrics can measure the relative accessibility conditions of firms on each island on the basis of the network distance and shipment cost.

The present definition of accessibility provides two basic advantages. First, it can plausibly incorporate road/coastwise network improvements, through changes in trip distance/vessel routing, shipment cost reductions via subsidies or compensation, like those from the Island Transport Equivalent, decrease in fuel taxes, impacts of reduction (e.g., due to the COVID-19 pandemic) or increase (due to the recent energy crisis) in fuel cost, and price changes because of ferry market competition. Second, it explicitly accounts for spatial externalities, i.e., the possible existence of spatial spillover effects across other regions, thus, reducing the potential for biased results in the econometric estimation (Combes et al. 2008, Matas et al. 2018, Baum-Snow et al. 2020). Moreover, relevant studies have shown that population-based market access indicators are a good proxy

for more model-dependent accessibility measures derived from formal structural gravity trade models (Eaton, Kortum 2002, Donaldson, Hornbeck 2016). It is also stressed that the above definitions have been widely proved to be qualitatively robust to the use of alternative (or more sophisticated) transport/trade cost functions and distance-decay parameter values ($\sigma > 1$), thus, providing reliable estimates of accessibility (Bruna et al. 2016, Matas et al. 2018, Baum-Snow et al. 2020). The use of a decay parameter $\sigma = 1$ can also be justified as a neutral (rather than an estimated behavioral) facilitator of benchmarking and policy-oriented diagnostics, for comparing and ranking islands in terms of their distance-based versus shipment cost-based accessibility, as it avoids over-parameterisation and it allows structural differences to emerge from cost heterogeneity alone. Specifically, fixing the decay parameter $\sigma = 1$ is consistent with the relational insularity conditions of the theoretical framework of Baldacchino (2020), which does not require a specific decay rate. This is because the shipment cost embeds as a relational structural disadvantage of islands, wherein insularity is experienced through cost penalties, not distance, and accessibility differences emerge from the network connectivity structure, not parameter tuning. In addition, according to the vulnerability framework of Briguglio (1995), the use of observed cost differentials offers a direct indicator of vulnerability, compared to the parameter tuning, which may lead to excessive decay calibration and, hence, double-counting vulnerability.

Particularly for the case of island regions, accessibility can be considered as an inverse measure of insularity, also referred to as 'islandness' (Spilanis et al. 2012, Karampela et al. 2014), which is typically expressed as a function of two variables: population size and distance (or transport cost) (Alasia et al. 2017). More specifically, insularity can be considered as increasing with the decrease of population (or market) size as well as with the increase in transport cost between the island and the port of correspondence in mainland country. This expression of insularity is similar to that of 'remoteness', which is typically found in the international trade literature (Wei 1996, Deardorff 1998, Nitsch 2000, Deidda 2016) and it denotes that more remote countries/regions are expected to trade less than geographically well-positioned nearby large markets, while if nearby countries/regions are large, then, the magnitude of distance (transport cost) becomes less relevant.

3 Data: Sources and description

The data used in this paper are derived – to a large extent – from the micro-database of the digital platform of Islands' Transport Equivalent for firms, which is operated by the Greek Ministry of Maritime Affairs and Insular Policy. This platform, together with the others that accompany the implementation of the Islands' Transport Equivalent for passengers and fuels, offers important management capabilities for the implementation of relevant insular policies, but also a valuable tool for evidence-based research and policy-making with use of empirical micro-data. In particular, the given database constitutes a unique source of information at the shipment (freight consignment) level and, after appropriate processing, at the firm level, for 73 inhabited islands of the country. The rest of the inhabited islands are not included in this database (namely, they have no beneficiary firm), either because they have road bridge access to the mainland country (Evia and Lefkada), or they are located less than a few kilometres from the mainland with very frequent ferry connections (Salamina, Ammouliani), or they are very small with only a handful of permanent residents and firms (if any). The beneficiaries are registered firms established on islands with a Unique Island Enterprise Number (https://metaforikoisodynamo.gr/companyregistration) and enter the required information about their firm, shipments, commodities and trip structure. The data used in this study correspond to the year 2021 (the latest year with information available), including a total of 1,026,469 shipments with an overall cost amounting to 76,062,793 euro (about 41.4% of which was subsidised), servicing 10,789 beneficiary companies which have been established in the Greek islands.

Based on the data originating from the platform of Transport Equivalent at the shipment level, several variables are constructed at the aggregate level for each island.

Table 1: Descriptive statistics of the population, distance and shipment cost

	Population (000s)	Distance (km)	Total shipment cost (€)	Average shipment cost (€)
Mean	19046.2	206.0	1101806.0	69.9
1st Quartile	746	75.9	18817.9	37.7
2nd Quartile	2466	200.0	207384.2	55.4
3rd Quartile	8934	296.3	784680.6	86.5
Standard Deviation	75144.3	149.2	3124833.1	47.9
Minimum	142	2.7	226.2	9.8
Maximum	624408	699.7	23700000	208.6

Notes: Population refers to the results of 2021 Population-Housing Census, ELSTAT. Travel distance refers to the actual network km-distance traveled (by ship or combination of ship and truck) for shipping a good between an island and any other island or mainland region of the country in 2021. The travel distance is averaged across all shipments and over the whole year so as to account for seasonal variations due to changes in the ferry connections and travel frequencies. The total shipment cost refers to the total cost (without VAT) paid by firms for shipping goods through a transport company between an island and any other island or mainland region of the country in 2021. The average shipment cost refers to the total cost (without VAT) paid by firms for shipping a good through a transport company between an island and any other island or mainland region of the country divided by the number of shipments in 2021 and hence also accounts for seasonal variations.

Among them, these variables include:

1. the average travel network distance (in km) between an island and its trade partners (mainland regional units or other islands), that is the ratio between the total travel distance (sea travel distances from/to the islands to/from the mainland ports of call and between islands, and land travel distances on the mainland, as obtained from the location of the port of correspondence and the postal addresses included in the bill of lading), and the corresponding number of itineraries (shipments) per origin and destination, and

2. the average shipment cost (in euro) between an island and its trade partners (mainland regional units or other islands), that is the ratio between the total payment receipts for freight transport by public-use truck vehicles and the corresponding number of itineraries (shipments) per origin and destination.

By extension, these data can offer the possibility of carrying out a wide range of scientific analyses and studies on issues relating to freight transport and supply chain in the island regions, the economic geography of islands, and the degree of connectivity and economic integration between them and the mainland country. In addition to the above database originating from the Transport Equivalent platform, data from other sources have also been used. Specifically, the population data refer to the number of permanent residents per island, on the basis of the results of the recent 2021 Census of Population and Housing conducted by the Hellenic Statistical Authority (ELSTAT). The data concerning the surface area (in km^2) of each region (island) were also obtained from the ELSTAT. Last, the average distance cost coefficient (in euro per km) corresponding to each region (island) was obtained from the processing of the regional transport cost database of the European Commission's Joint Research Centre (JRC) (Persyn et al. 2020).

Table 1 provides the descriptive statistics of the population of islands, the distance in terms of the actual network kilometres traveled, as well as the total and the average shipment cost paid by firms for shipping goods through a transport company between an island and any other island or mainland region of the country. As shown in the table, the average transport cost (without VAT) per shipment amounts to approximately 70 euros, ranging from 10 euros to 209 euros. These shipment cost variations among islands can be attributed to a multitude of factors, including the distance to the mainland country and other (large) islands, the market (population) size, the commodity types, and the nature and size of firms (Tsekeris et al. 2023).

4 Results and analysis

4.1 Results of the metrics

This subsection presents the accessibility results in the terms of correlations, index values and cartographic illustrations. First, Table 2 shows the Pearson's r correlation coefficients of the variables of distance- and cost-based accessibility, from both the consumer's and producer's sides, with the islands' population size, network distance and travel time required for ferries to reach the mainland port of call. The results indicate that the network distance and travel time are significantly negatively correlated with the *CDA*, while only the travel time is found to be significantly negatively correlated with the *CCA*. It is noted that the correlations of both network distance and travel time with the exporters' accessibility measures are found to be nonsignificant at the conventional (95%) level of confidence. Thus, the consumers' (importers') accessibility of firms in Greek islands can be considered as significantly more sensitive to or reliant on distance and travel time than the producers' (exporters') accessibility. Specifically with regard to the network distance, it should be stressed that it correlates negatively with distance-based accessibility since both the *CDA* and *PDA* were calculated as functions of distance.

Table 2: Correlation between coefficients of variables

	Population	Distance	Travel Time
Population	1.000*		
Distance	-0.030	1.000*	
Travel Time	0.043	0.921*	1.000*
CDA	0.035	-0.358*	-0.362*
PDA	0.010	-0.073	-0.023
CCA	-0.123	-0.170	-0.254*
PCA	-0.003	0.118	0.149

Note: * denotes statistical significance at the 5% confidence level. Travel time (in hours) refers to the actual network travel time required for freight shipping (by ferry or combination of ferry and truck) between an island and any other island or mainland region of the country in 2021.

Besides, the population size per se is not found to be significantly correlated with either the distance-based or the cost-based accessibility, from both sides of consumers and producers. Therefore, the size of islands cannot be regarded in isolation as significantly correlated with either the consumers' or the producers' accessibility. Hence, the sole consideration of the islands' population, distance, or cost variables cannot sufficiently describe the accessibility conditions in the Greek islands.

Next, Table 3 shows the estimates of consumers' and producers' accessibility indices of the Greek islands based on the actual network distance and the freight shipment cost from/to mainland regions and between them, together with their basic descriptive statistics. It also shows the accessibility (im)balance, which is defined as the difference between the producer's (export) and consumer's (import) accessibility. A negative difference implies an accessibility deficit, while a positive difference implies an accessibility surplus.

Furthermore, Figures 1-4 illustrate the geographical mapping of the values of consumers' and producers' accessibility based on network distance and shipment cost, respectively. In these figures, the accessibility of the islands is classified according to four groups defined by the equal-count quartiles of the corresponding (normalised) accessibility indices. By and large, the results demonstrate the importance of the access (proximity) to large markets, population size, and network connectivity, while actual shipment cost significantly alters the hierarchy of accessibility across islands as it incorporates inherent (unobserved) characteristics of the logistics and product markets. Specifically, on the basis of network distance, the islands with the highest consumers' (importers') accessibility are found to be in close geographical proximity to the region of Attiki, where the capital city (metropolitan area) of Athens is located, including the main ports of Piraeus, Rafina and Lavrio, and, to a lesser extent, to the regional unit of Magnesia (Skiathos, Skopelos).

Table 3: Results of consumer and producer distance- and cost-based accessibility

Island	CDA	PDA	Balance	CCA	PCA	Balance
Aegina	11.847	11.738	-0.109	12.799	12.753	-0.046
Agathonisi	9.865	9.742	-0.123	11.711	11.308	-0.404
Agios Efstratios	9.677	8.723	-0.955	11.385	10.117	-1.268
Agistri	11.339	11.338	-0.001	11.311	9.657	-1.655
Alonnisos	10.449	9.942	-0.507	13.075	12.238	-0.837
Amorgos	9.958	9.714	-0.245	12.016	11.217	-0.799
Anafi	9.941	9.557	-0.385	11.096	11.729	0.632
Andros	10.881	10.977	0.096	12.577	12.466	-0.110
Antiparos	10.380	10.127	-0.253	12.286	12.263	-0.023
Astypalaia	9.882	9.803	-0.079	11.692	10.165	-1.527
Cephalonia	10.507	10.422	-0.085	12.535	12.230	-0.306
Chalki	9.607	8.165	-1.442	11.465	10.058	-1.407
Chios	10.625	10.640	0.015	12.498	13.075	0.577
Donoussa	9.837	4.911	-4.926	12.150	4.740	-7.411
Elafonisos	9.437	6.224	-3.213	12.507	6.053	-6.454
Ereikoussa	9.421	7.849	-1.572	9.779	10.119	0.340
Folegandros	10.117	9.897	-0.219	11.878	9.117	-2.760
Fourni	9.854	9.549	-0.305	12.169	9.097	-3.072
Gavdos	9.466	4.104	-5.362	11.946	3.933	-8.013
Hydra	11.126	10.857	-0.269	13.113	13.919	0.806
Icaria	10.167	9.794	-0.374	12.617	11.137	-1.480
Ios	10.232	10.095	-0.137	11.847	12.478	0.631
Iraklia	10.179	9.981	-0.198	11.529	10.865	-0.664
Ithaki	10.434	9.961	-0.473	12.232	12.680	0.448
Kalamos	9.575	9.351	-0.224	12.560	9.914	-2.645
Kalymnos	10.356	10.229	-0.127	12.922	12.818	-0.104
Karpathos	9.879	9.682	-0.198	13.087	12.355	-0.732
Kasos	9.630	7.141	-2.489	11.073	9.321	-1.752
Kastellorizo	8.950	8.939	-0.012	9.387	10.057	0.670
Kea	11.201	11.707	0.506	12.041	12.702	0.661
Kerkyra	10.493	10.467	-0.026	12.272	12.992	0.721
Kimolos	10.358	10.101	-0.256	11.663	10.980	-0.682
Kos	10.360	10.301	-0.059	12.183	13.192	1.008
Koufonisia	10.140	6.511	-3.629	12.137	5.650	-6.486
Kriti	10.546	10.582	0.035	11.514	10.728	-0.785
Kythira	10.321	9.967	-0.355	11.854	12.240	0.386
Kythnos	10.692	10.864	0.172	11.881	10.586	-1.294
Leipsi	9.686	9.515	-0.171	12.242	11.284	-0.957
Leros	10.193	9.910	-0.282	12.979	12.768	-0.212
Lesvos	10.454	10.453	-0.001	12.301	11.450	-0.851
Lemnos	10.446	10.338	-0.108	12.507	16.340	3.833
Mathraki	9.061	5.589	-3.472	12.513	5.529	-6.984
Meganisi	9.733	6.181	-3.552	11.707	6.009	-5.698
Milos	10.508	10.539	0.031	12.540	12.909	0.368
Mykonos	10.733	10.544	-0.189	12.698	12.865	0.166
Naxos	10.627	10.627	0.000	12.639	13.563	0.924
Nisyros	9.970	7.843	-2.127	13.179	9.263	-3.916
Oinousses	10.057	9.769	-0.288	10.029	9.509	-0.520
Othoni	9.527	5.699	-3.828	12.694	5.528	-7.166
Paros	10.642	10.476	-0.166	12.879	12.855	-0.024
Patmos	10.037	9.614	-0.423	12.663	10.366	-2.297
Paxi	10.278	9.744	-0.535	12.293	10.600	-1.694
Poros	11.001	7.512	-3.489	11.834	11.017	-0.817
Psara	10.110	6.831	-3.280	11.598	10.164	-1.434
Rodos	10.266	10.274	0.008	11.845	12.514	0.669
Samos	10.363	10.147	-0.215	12.467	11.612	-0.855
Samothraki	10.196	9.840	-0.356	12.643	11.877	-0.766
Santorini	10.504	10.362	-0.142	12.295	12.031	-0.264
Schinoussa	9.856	9.948	0.092	12.971	12.956	-0.015
Serifos	10.328	10.284	-0.044	11.732	9.765	-1.967
Sifnos	10.518	10.305	-0.214	12.097	11.871	-0.226
Sikinos	9.892	9.800	-0.092	12.170	13.356	1.187
Skiathos	10.715	10.328	-0.386	12.574	13.174	0.600
Skopelos	10.649	10.452	-0.197	12.930	12.349	-0.581
Skyros	10.471	10.056	-0.415	12.750	9.754	-2.996
Spetses	11.097	11.060	-0.037	12.153	11.275	-0.878
Symi	9.870	9.502	-0.368	12.452	13.314	0.862
Syros	10.878	10.882	0.005	12.846	12.493	-0.352

Continued below ...

Table 3: (continued)

Island	CDA	PDA	Balance	CCA	PCA	Balance
Thasos	10.424	10.145	-0.279	12.492	11.968	-0.524
Thirasia	10.165	5.325	-4.839	12.168	5.154	-7.014
Tilos	9.633	9.419	-0.213	12.679	12.422	-0.257
Tinos	10.770	10.827	0.057	12.956	13.807	0.851
Zakynthos	10.579	10.429	-0.150	12.221	12.346	0.125
Mean	10.246	9.459	-0.787	12.172	11.000	-1.171
1st Quartile	9.879	9.502	-0.423	11.847	10.058	-1.527
2nd Quartile	10.278	9.961	-0.215	12.272	11.612	-0.581
3rd Quartile	10.518	10.429	-0.079	12.639	12.680	0.340
Standard Deviation	0.521	1.662	1.377	0.715	2.430	2.345
Gini coefficient	0.028	0.086	0.616	0.030	0.114	0.357
Minimum	8.950	4.104	-5.362	9.387	3.933	-8.013
Maximum	11.847	11.738	0.506	13.179	16.340	3.833

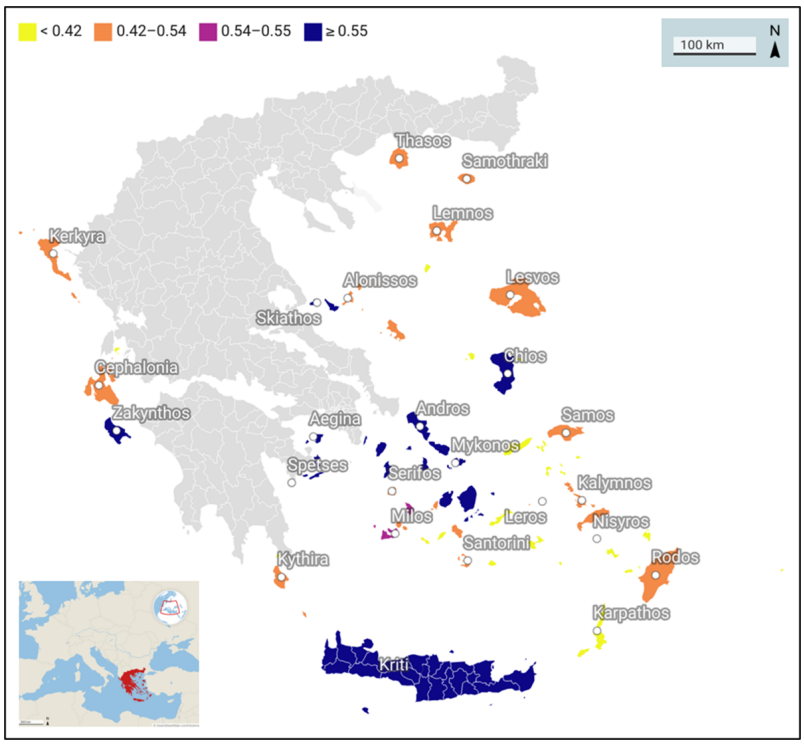
Note: The distance-based and cost-based accessibility balances are defined as the difference (negative as deficit, or positive as surplus) between the PDA and CDA, and between the PCA and CCA, respectively.

The former group having the highest accessibility refers to islands located in the Saronic Gulf, such as Aegina, Agistri, Hydra, Poros, and Spetses (in the Argolic Gulf), or Cyclades (particularly, the northern part of them), including Kea, Andros, Syros, Tinos, Mykonos, Kythnos, Paros and Naxos. Additionally, islands with increased *CDA* are a few of those having large population size, such as Chios, Zakynthos and Kriti. On the contrary, several islands with very small size are those belonging to the fourth group, having the lowest *CDA*, such as Kastellorizo, Mathraki, Erikousa, Elafonisos, Gavdos, Othoni, Kalamos, Chalki, Kasos, Tilos, Agios Efstratios, Leipsi, Meganisi, Donoussa, Fourni, Schinoussa, Agathonisi and Symi.

Similar are the results for the producer's (export) distance-based accessibility. Namely, islands having the highest *PDA* refer to those located in close geographical proximity to the region of Attiki, i.e., in the Saronic Gulf and the northern part of Cyclades, as well as the large islands of Chios and Kriti. Other large-size islands, such as Kerkyra, Lesvos, Zakynthos and Cephalonia, belong to the second group of *PDA* in terms of order of magnitude. Briefly, the distance-based accessibility indices show a significant spatial heterogeneity among islands, and it is mostly influenced by the geographical proximity to the region of Attiki and/or the size of the island. This increased heterogeneity reflects that the distance-based accessibility imbalances present severe disparities among islands, based on the Gini coefficient value (0.616), which are considerably higher than those estimated for the cost-based accessibility imbalances, having a Gini coefficient value equal to 0.357 (Table 3).

The findings about the accessibility based on the actual transport (shipment) cost entail a considerably higher heterogeneity in market size and across space, as well as a different hierarchy across islands, compared to the distance-based accessibility. More specifically, on the basis of the shipment cost, the islands with the highest *CCA* are found to be several small- or medium-size (except for Cephalonia) ones located in close proximity to the regions of Attiki (Aegina, Hydra) and Magnesia (Alonnisos, Skiathos), in Cyclades (Andros, Milos, Mykonos, Naxos, Paros, Syros, Tinos), as well as several others scattered across the eastern part of the Aegean sea, in Dodekanisa, such as Kalymnos, Karpathos, Leros, Nisyros and Patmos, and the North Aegean (Icaria, Samothraki). The islands having the lowest *CCA* are some very small ones, such as Kastellorizo, Erikousa, Oinousses, Kasos, Anafi, Agistri, Agios Efstratios and Chalki.

The islands with the highest *PCA* include several ones located in close geographical proximity to the regions of Attiki (Aegina, Hydra) and Magnesia (Skiathos), in Cyclades (Kea, Milos, Mykonos, Naxos, Paros, Sikinos, Syros, Tinos), in the eastern part of the Aegean sea (Kalymnos, Leros, Limnos), but also large-size islands, like Chios, Kerkyra, Kos and Rodos. On the contrary, the lowest *PCA* is observed in several very small-size islands, like Donoussa, Elafonisos, Fourni, Gavdos, Koufonisia, Mathraki, Meganisi, Othoni and Thirasia.



Notes: The colours classify the four equal-count quartiles of the normalised consumer distance-based accessibility index. Due to scale limitations, the island of Kastellorizo (about 130 km east of Rodos), that has CDA index value equal to 0, is not shown in the map.

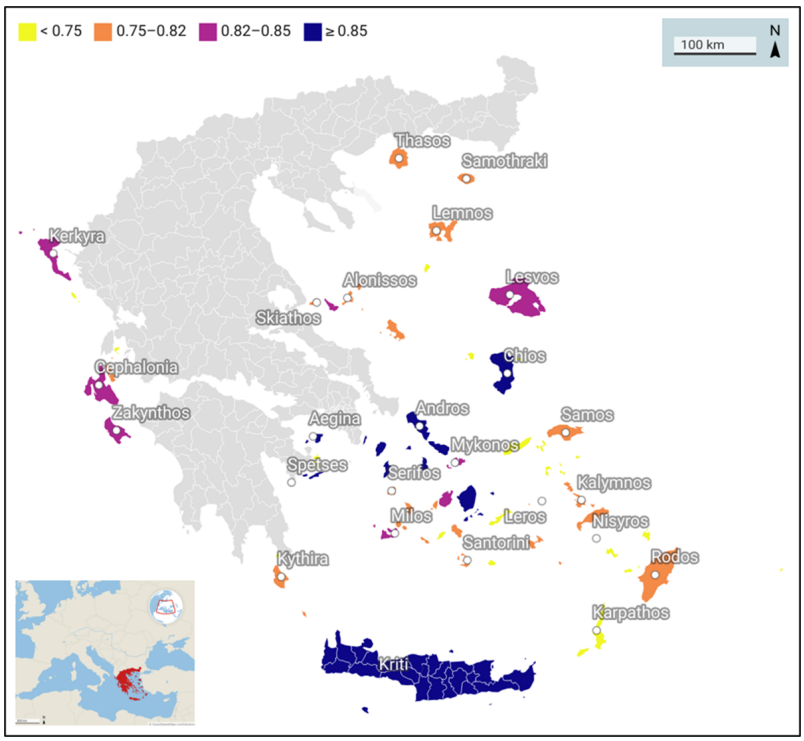
Figure 1: Map illustration of the consumer (import) distance-based accessibility

4.2 Discussion of the results

This subsection provides a discussion of the results using correlation analysis and non-parametric statistics. More specifically, the Wilcoxon matched-pairs signed-ranks test (Wilcoxon 1945, Mann, Whitney 1947) is employed to probe the null hypothesis of the equality of matched pairs of accessibility indexes, namely, that they have the same distribution, as it relaxes the assumption of normal distribution in paired-data comparison and it is highly robust to outliers and skewed data. The outcome concerning the relatively increased cost-based accessibility of several small and distant (from Attiki) islands, which are either close to each other and/or in proximity to large-size island markets, arguably denotes the existence of transport capacity sharing and variable returns to scale. These variable economies of scale may suggest that, for long distances, it is possibly more profitable – from a logistics perspective – to group shipments in those small islands, so that trucks of larger capacity and load factor are selected to operate along the shipping routes, compared to operating many individual shipments (see also McCann 2005).

The above outcomes depict the inherent (unobserved) characteristics pertaining to the logistics and product markets, which are incorporated into the prices of the services offered by transport companies. In particular, the average shipment cost is established in free market conditions, since transport companies may charge according to the availability, routing and frequency of service, the level of competition (number of transport/logistics companies), the size and the number of destination markets to be served along the itinerary, as well as the packaging, the type of goods, and the possibilities of cargo consolidation in collaboration with other transport companies servicing the same or neighbouring or intermediate destinations.

Table 4 demonstrates the results, in terms of the z-values and significance levels, of the Wilcoxon signed rank test of the differences among the consumer vs. producer and the distance-based vs. cost-based accessibility. The results clearly indicate the strong statistical significance (at the 99% level of confidence) pertaining to the difference between consumers' and producers' accessibility, as well as the difference between the distance-



Notes: The colours classify the four equal-count quartiles of the normalised producer distance-based accessibility index. Due to scale limitations, the island of Kastellorizo (about 130 km east of Rodos), that has PDA index value equal to 0.63, is not shown in the map.

Figure 2: Map illustration of the producer (export) distance-based accessibility

based and cost-based accessibility. Furthermore, the comparison between consumers' and producers' accessibility shows that consumers' accessibility is statistically significantly higher than the producers' accessibility, as reflected by the positive signs, for both cases of distance and cost.

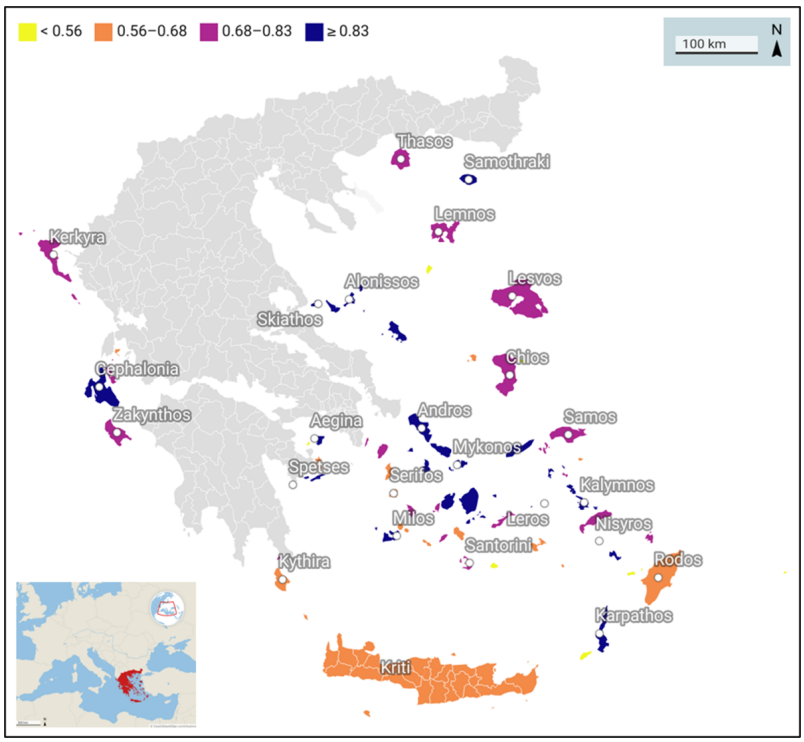
Table 4: Results of the Wilcoxon signed rank tests of the consumers' vs. producers' accessibility and the distance-based vs. cost-based accessibility

	Distance	Cost
Consumer vs. producer	z = 6.490 Prob > |z|= 0.0000	z = 4.013 Prob > |z|= 0.0001

	Consumer	Producer
Distance vs. cost	z = -6.484 Prob > |z|= 0.0000	z = -7.408 Prob > |z|= 0.0000

By and large, the above outcomes, which relate to the import-export trade accessibility deficit (see also Table 3), may signify the lack of a substantial production base and the limited trade competitiveness characterising the economy of Greek islands, since the accessibility (insularity) of their export trade is significantly lower (higher) than the accessibility (insularity) of their import trade. This fact arguably suggests that, by and large, the imported goods are less expensive than exported goods, because of the comparative advantages of origin regions/countries in producing a higher variety of particular products, via exploiting their increased resource availability, scale economies, production efficiency and specialisation, which are typically limited in island areas, whose production is commonly focused on very specific goods.

Besides, the comparison between the distance-based and cost-based accessibility shows that the distance-based accessibility is statistically significantly lower than the cost-based accessibility, as reflected by the negative signs, from both sides of consumer (import) and



Notes: The colours classify the four equal-count quartiles of the normalised consumer cost-based accessibility index. Due to scale limitations, the island of Kastellorizo (about 130 km east of Rodos), that has CCA index value equal to 0, is not shown in the map.

Figure 3: Map illustration of the consumer (import) cost-based accessibility

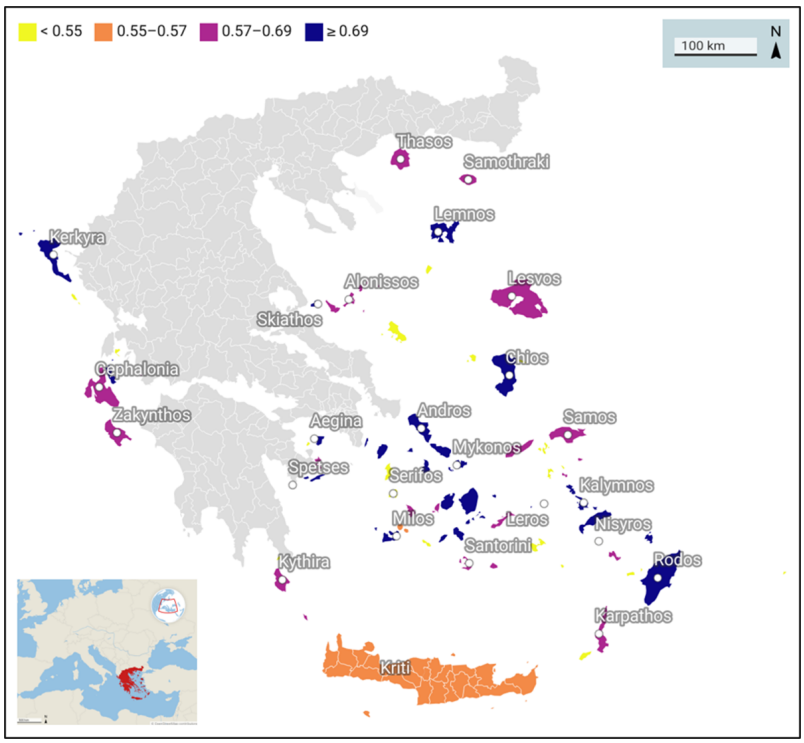
producer (export). These results can be related to the considerable trade cost imbalances characterising the ingoing and outgoing trade flows of Greek islands, which tend to import much larger amounts of commodities than those they export to the mainland country. The latter outcomes are consistent with those of Kizos et al. (2023) regarding the severe trade imbalances found in six selected medium-large Greek islands as well as with other research findings verifying the heavy import dependence of the Greek island regions (Rodousakis, Tsekeris 2025).

Nevertheless, it is worth noting that there are several islands which exhibit either no deficit (a balance) or even a surplus in the producers' accessibility, compared to the consumers' accessibility (see Table 3). More specifically, in terms of the network distance, some islands located in Cyclades (Kea, Kythnos, Andros, Tinos, Syros, Naxos, Milos) and a few large islands (Kriti, Chios, Rodos) are found to be more accessible to exports, compared to imports, while Lesvos presents a balance between the consumers' and producers' distance-based accessibility. In terms of the shipment cost, more islands belonging to different regional units and of different size (small, medium and large ones) are found to have an accessibility surplus (Lemnos, Sikinos, Kos, Naxos, Symi, Tinos, Hydra, Kerkyra, Kastellorizo, Rodos, Kea, Anafi, Ios, Skiathos, Chios, Ithaki, Kythira, Milos, Ereikoussa, Mykonos, Zakynthos). Overall, the Cycladic islands of Naxos, Tinos, Kea and Milos, and the large-size islands of Rodos and Chios, present an accessibility surplus, in terms of both network distance and shipment cost.

5 Conclusions

5.1 Discussion of main findings and possible extensions

This paper used a unique database regarding the Islands' Transport Equivalent for firms to calculate the two-sided accessibility of Greek islands, from both the consumers' and producers' sides, relying on two alternative transport cost measures: the actual network distance and the freight shipment cost. The findings concerning the distance-based ac-



Notes: The colours classify the four equal-count quartiles of the normalised producer cost-based accessibility index. Due to scale limitations, the island of Kastellorizo (about 130 km east of Rodos), that has PCA index value equal to 0.49, is not shown in the map.

Figure 4: Map illustration of the producer (export) cost-based accessibility

cessibility are largely consistent with the theory, in the sense that islands trading with regions of larger population and in closer geographical proximity to them are found to be more accessible than those islands trading with regions of smaller population and in less proximity to them. Nonetheless, the use of shipment cost significantly alters the hierarchy and imbalance inequalities of accessibility across islands, due to inherent characteristics underlying the operation of product distribution logistics, particularly in such insular areas. Besides, significant changes are found to exist between the (higher) import and the (lower) export accessibility, signifying the limited competitiveness of the economy of the Greek islands.

The outcome that only a few islands located in Cyclades (Naxos, Tinos, Kea and Milos) present an accessibility surplus (in addition to Rodos and Chios), suggests that a short distance to Attiki or other mainland areas such as Magnesia, a large market size (except for Rodos and Chios), or even a combination of these factors, are not adequate conditions to render Greek islands competitive from the market access viewpoint. Especially regarding the island region of Kriti, the fact that it has an accessibility surplus only in terms of network distance, but not shipment cost, implies the significant adverse impact of local market conditions on its cost-based accessibility.

The proposed metric of accessibility essentially highlights the specificities of each island and, hence, can support the systematic and place-based evaluation of insular policies in a more transparent and effective manner. In particular, the present analyses can potentially support the evaluation and rationalisation of the deployment of Islands' Transport Equivalent, through examining changes in consumers' and producers' accessibility in specific commodity categories, following the subsidisation of shipment cost in a range of islands over a series of years after the commencement of implementation. By extension, the current analysis could facilitate the treatment of several problems associated with the management and implementation of transport-related island policies, since the suggested accessibility metrics can provide a suitable benchmark for evaluating improvements in transport cost.

Last, for a more holistic and detailed evaluation of the role of accessibility and the implementation of the Islands' Transport Equivalent, it would be appropriate to collect primary data originating from survey-based methods, like the completion of suitable questionnaires to island businesses. Such sources of primary data can be obtained from the processing of firms' responses to the relevant part of a questionnaire about the Transport Equivalent that is included in the newly established 'Island Entrepreneurship Barometer' launched by the Ministry of Maritime Affairs and Insular Policy. The next subsection describes some of the challenges and possible solutions associated with the practical implementation of policies seeking to address the (mostly, transport-related) insularity cost.

5.2 Policy implementation challenges and solutions

The economy and the overall business environment of the Greek islands are related to several structural problems. As far as the transport and logistics side is concerned, such problems refer to the increased transport cost, the reduced quality of related services, the inflated prices of goods supplied to local businesses – partly attributable to the high tourist demand – and disruptions in the operation of supply chains to/from the islands. Some challenges in addressing these problems include political-economy and administrative frictions from port authorities, passenger/cruise ship operators, and local tourism actors whose revenues depend on peak-season passenger throughput, creating conflicts of interest with cargo operators, given that port governance is fragmented and there are overlapping competencies between port funds, municipalities, etc. Moreover, (small) island municipalities are constrained by limited fiscal space and weak technical capacity to design and maintain transport infrastructure, while there is often a lack of inter-municipal cooperation, land-use conflicts, high land prices, etc. There may also be unclear and conflicting policy objectives, complex regulatory settings, concerns about competition distortions, and problems with enforcement capacity and the availability, quality and sharing of data at the island level. All these factors underscore how institutional fragmentation, limited administrative capability, and stakeholder conflicts can obscure otherwise technically sound solutions.

Possible solutions to address some of the aforementioned practical transport-related problems in Greek islands encompass:

1. Fair and effective mechanisms for the spatial organisation of freight activities and berth allocation at island ports to address difficulties in transporting products by commercial ships, due to the priority often given to either passenger/cruise ships or cargo ships from abroad, resulting in delays and increased charges per pallet, especially during the tourist season.

2. Investments for the safe and efficient distribution of goods within the islands to tackle problems related to the design/pavement conditions and adequacy of the road network, the unavailability and unsuitability of delivery vehicles and congestion problems, particularly during the tourist season.

3. Construction and/or maintenance of intermediate storage facilities for goods, particularly during the tourist season, to resolve stock shortages.

4. Development of regional maritime hubs on islands which are either large or central in their own region (e.g., Naxos, Rodos), with the aim of subsequent distribution of goods from there to spokes servicing smaller islands. This hub-and-spoke network design approach is expected to mitigate the problem of overconcentration of freight flows from the mainland to the islands (and vice versa) at the main hub port of Piraeus, which results in obvious problems of delays and additional charges.

5. Deployment of truck arrival systems to reduce long waiting times/delays, giving particular priority to ships carrying sensitive/vulnerable products, especially during periods of unsuitable/adverse weather conditions, to avoid the spoilage of these products (e.g., fruits, vegetables, bottled water, pharmaceutical products).

Finally, it must be stressed that, during the last years, the Greek government has made serious efforts to account for insularity in strategic policy-making at the regional, national, and EU levels, particularly through the development of a National Strategy for Integrated Maritime Policy on Islands. This strategy includes specific development policy objectives in such fields as port policy, maritime transport and related infrastructure, island competitiveness and entrepreneurship, investment and labour in the blue economy, and research and innovation for the sea and the development of island areas.

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