TÉCNICO LISBOA

Assessment of the potential of short sea shipping to support Portuguese foreign trade

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Thesis to obtain the Master of Science Degree in

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DECLARATION:

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Signature

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ABSTRACT:

This thesis consists in a study of the current modal split of the transportation of containerized cargo between Portugal and Western European countries based on statistical data of cargo flows. The final objective is to analyze the potential of modal shift from road transportation to short sea shipping (SSS) if new supply chains are considered.

The thesis begins with a literature review dedicated to studies on SSS, gravity models and logit models applied to maritime transportation problems. Next, statistical information on transport flows between Portugal and Western European countries is collected. The information is analyzed in order to estimate the current modal split of transportation per country. A gravity model is used to estimate the dispersion of cargo throughout geographical regions of these countries and a multinomial logistic regression model is implemented and calibrated to estimate the modal split per country. The transport chains considered in the calibration are to mirror closely the current offer of transport options in operation between Portugal and several countries in Western Europe.

A set of new intermodal chains is introduced and the new modal splits are calculated for this network. Maps were developed to illustrate regional preferences regarding the modal distribution and potential modal shift in the countries studied. The analysis of the results allows to conclude that the introduction of new intermodal chains based on SSS show good potential to support Portuguese foreign trade and can produce relevant modal shift to SSS, with most promising results belonging to coastal, farthest from Portugal countries.

Keywords:

Short sea shipping, Intermodality, Gravity model, Logistic regression, Modal split.

RESUMO:

Esta tese consiste em um estudo da atual distribuição modal do transporte de carga contentorizada entre Portugal e países da Europa Ocidental baseado em dados estatísticos de fluxo de carga. O objetivo final é analisar o potencial de mudança modal do transporte rodoviário para *short sea shipping* (SSS) ao contar-se com novas cadeias de transporte.

Esta dissertação começa com uma revisão de literatura dedicada a estudos sobre SSS, modelos gravitacionais e regressões logísticas aplicados a problemas de transporte marítimo. Em seguida, são coletadas informações estatísticas sobre os fluxos de transporte entre Portugal e os países da Europa Ocidental para estimar a atual divisão modal de transporte nos países. O modelo gravitacional é utilizado para estimar a dispersão da carga pelas regiões desses países e um modelo de regressão logística multinomial é implementado e calibrado para calcular a divisão modal por país. As cadeias de transporte consideradas na calibração buscam espelhar a oferta atual da rede de transporte em operação entre Portugal e os países considerados.

Um conjunto de novas cadeias intermodais é introduzido e novas divisões por modal são calculadas. Mapas foram desenvolvidos para ilustrar as preferências regionais em relação à distribuição modal e potencial de mudança modal nos países estudados. A análise dos resultados permite concluir que a introdução de novas cadeias intermodais baseadas em SSS apresentam um grande potencial de apoio ao comércio externo português e podem produzir uma transferência modal relevante para SSS, sendo os resultados mais promissores provenientes de países costeiros, mais afastados de Portugal.

Palavras-chave:

Transporte marítimo de curta distância, Intermodalidade, Modelo gravitacional, Regressão logística, Distribuição modal.

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ACRONYMS:

CENTEC: Centre for Marine Technology and Ocean Engineering.

ECA: Emission Control Area.

EU: European Union.

FEU: Forty feet equivalent unit.

GTC: Generalized transportation cost.

HFO: Heavy fuel oil.

GDP: Gross domestic product.

IA: Intermodal Analyst software.

IMO: International Maritime Organization.

INE: Portuguese National Institute of Statistics.

IST: Instituto Superior Técnico.

IWT: Inland waterway transportation.

LNG: Liquefied natural gas.

Lo-Lo: Lift-on/Lift-off vessels.

MoS: Motorways of the Sea.

NUTS: Nomenclature of territorial units for statistics.

OD: Origin-destination.

PBL: Netherlands Environmental Assessment Agency.

Ro-Ro: Roll-on/Roll-off vessels.

SADC: Southern African Development Community.

SECA: Sulphur Emission Control Areas.

SHP: Shaft horsepower.

SSS: Short sea shipping.

TEU: Twenty feet equivalent unit.

UK: United Kingdom.

ULSFO: Ultra low sulphur fuel oil.

VoT: Value of time.

SYMBOLOGY:

T_{OD}: trade between bodies O and D.

G: gravity model parameter.

V_p: variable of interest of the bodies O and D.

d: distance between bodies O and D.

β_n: model parameters.

n: number of variables considered.

v_p: logarithm of a given variable V_p.

α_p: parameter associated with v_p.

t_{OD}: logarithm of T_{OD}.

L: number of links in the transportation network.

p: determined path.

k: determined set.

i: determined link.

D_{l_i}: length of the link.

S_{l_i}: speed of operation of the link.

δ_{l_i}: binary, defines whether the link *i* is active (operational) or not.

δ_{kp_i}: binary, defines whether link *i* is used in path *p* of set *k*.

δ_{Rd_i}: binary, identifies whether the link *i* is of road type or not.

$T_{RD_{kp}}$, $T_{RL_{kp}}$, $T_{IW_{kp}}$, $T_{RR_{kp}}$, $T_{CC_{kp}}$: transportation time in road, rail, inland waterway, Ro-Ro and containership paths.

$T_{TR_{kp}}$: transportation time along path *p* of set *k*.

T_{kp}: total time.

δ_{kp_j}: binary, defines whether or not node *j* belongs to the path *p* of set *k*.

T_{Dw_j}: average dwell time in node *j*.

$D_{RD_{kp}}$: total distance travelled for a specific mode of transportation.

$C_{RD_{kp}}$: cost associated with distance travelled in one mode of transportation.

c_{RD}: cost coefficient of the mode of transportation.

$f\left(D_{RD_{kp}}\right)$: specific cost function of the mode of transportation.

$C_{TR_{kp}}$: total transportation cost.

C_{u_j} , C_{l_j} : unloading and loading costs in node *j.*

δ_{n_j}: binary, indicates if node *j* is active.

δ_{kp_j}: binary, indicates if node *j* is used in path *p* of the set of paths *k.*

C_{kp}*:* total cost of path *p* in set *k.*

VoT: value of time.

GTC_{kp}: generalized transportation cost on a path *p* of set *k.*

β: parameter of the logit model.

P_{kp}*: probability of transportation on the path p of set k.*

Q_k: cargo volume flow in set *k.*

Q_{kp}*:* cargo volume flow in path *p* of set *k.*

$Q_k^{Maritime}$: maritime cargo volume flow in set *k.*

$Q_{kp}^{Maritime}$: maritime cargo volume flow in path *p* of set *k.*

V_M: total maritime loaded volume.

V_C: loaded volume in containerships.

V_{RR}: loaded volume in Ro-Ro vessels..

$S_{\%}$: containerized cargo percentage.

V_{EM}: total exported maritime volume.

V_{EC}: total exported containerized volume.

V_{ER}: total exported road volume.

V_{EA}: available cargo.

1. INTRODUCTION

1.1 Background and Motivation

Short sea shipping (SSS) is one of the keyways to haul cargo in intra-European Union trade, being responsible of approximately 33% of intra-EU transportation in ton-kilometers in 2017 (van den Bos & Wiegmans, 2018), having a significant competition with land-based transportation beginning in the end of the 90s with the liberalization of the cabotage market. The European SSS market is divided into a number of major regional markets consisting of the Black Sea, Mediterranean, the Atlantic Range, North Sea and the Baltic. Out of the total EU maritime goods transported, short sea shipping accounted for 59% of it in 2014[1], making it a vital option for cargo flow in the continent whose development is of general interest.

The official definition of short sea shipping, stated by the European Commission (EU Commission, 1999), is “the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports situated in non-European countries having a coastline on the enclosed seas bordering Europe”. Public policies to support it are generally seen as a matter of increasing trade competitiveness, relieving links of land transportation and reducing emissions of greenhouse gases and air pollutants (European Conference of Ministers of Transport, 2001). One of those policies related with short sea shipping is the creation of the Motorways of the Sea (MoS), supported by the European Commission and the Marco Polo Program. The concept of MoS regards regular SSS Ro-Ro services integrated in the transportation network that allows door-to-door shipping. The development of MoS is supported by European Union through the Marco Polo funding, a program destined to projects that provide shift freight from road to sea, rail and inland waterways, and, on its second edition from 2007 to 2013 had an annual budget of approximately 60 million euros.

In the Portuguese trading context, short sea shipping is especially relevant given the proximity of its coastline close both to the Atlantic corridor directing to Northern Europe and to the Strait of Gibraltar, a doorway to the Mediterranean Sea. Figure 1.1 shows the role that SSS plays in the Portuguese intra-EU trade, being it responsible for more than 28% of the Portuguese exports to EU countries according to data from Portuguese National Institute of Statistics (INE)[2]. It must be pointed that this value is not close to the 65% that road transportation represents. However, the Portuguese trade with Spain (by far its biggest partner in the EU) is almost exclusively made by road, bringing the average contribution of SSS down. Despite that, the role of moving almost 30% of the cargo volume brings the potential of SSS in the country to the interest of local public policies and viability studies.

[1] The European Short Sea Shipping Market. (2017, november 12). The Geography of Transport Systems | The Spatial Organization of Transportation and Mobility. https://transportgeography.org/contents/chapter5/maritime-transportation/short-sea-shipping-europe/

[2] Statistics Portugal - web portal. (n.d.). Ine.Pt. Retrieved July 26, 2022, from https://www.ine.pt/

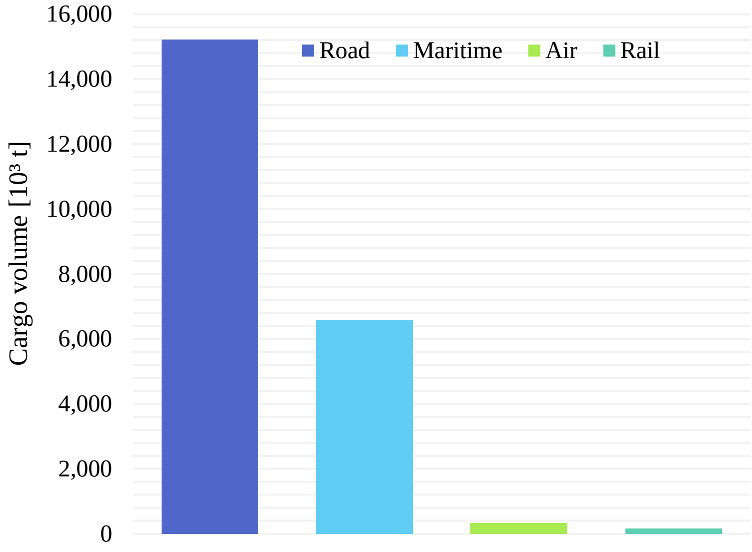

Figure 1.1: Portuguese intra-EU exported cargo volume by mode of transportation.

In the context of competition in the medium/large distance freight market, short sea shipping is regarded as one of the freight modes, along with rail and inland waterways, that can induce a modal shift from road transportation, i.e., create a “switch” from road to intermodal haulage. A modal shift is caused by an advantage of a mode towards another, such as lower freight rates, faster shipping, higher reliability, higher security of cargo and environmental benefits.

As transportation time is generally higher in SSS and freight rate competition with land-based transportation is tight, the relevant advantage that makes it attractive to induce a modal shift to SSS is the possibility to reduce environmental damage and alleviate road congestions and travel delays by removing some of the cargo flows from the highways (Mulligan & Lombardo, 2006).

In the transportation network currently available, short sea shipping is more competitive in the geographical area limited to a determined distance from the ports of origin and destination. As the distance from the ports increases the competition with road haulage gets tighter and SSS tends to lose freight market. Said so, the modal shift to SSS in some geographical areas could be potentially induced through the reduction of costs related to intermodality by introducing new transportation chains in the network, which is the scope of this thesis.

In the latest years, the literature concerning quantitative calculations estimating modal split has focused on avoiding modal shift back to road transportation due to the higher freight rates that come from the market adaptation to new sulphur and nitrogen regulations. This thesis in particular seeks to assess the potential of modal shift to SSS pushed by increased supply in the transportation chain. The current transportation network is, generally, composed by a direct roadway connecting an origin and destination. In some cases, the road network is complemented by a SSS link if a regular service connecting ports relatively close to the origin and destination is available. In other cases, a railway connection is included if the regions are well supplied with railway lines. This thesis considers the extension of the network including regular SSS services that are currently not available, use of inland waterways, railway connections and, overall, intermodal chains.

The scope of this thesis and the processes comprised on it are shown in a flow chart scheme in Figure 1.2. Given the final objective of assessing the modal-shift potential to SSS, this thesis covers the estimation of the cargo demand between Portugal and the NUTS 2 regions (Nomenclature of Territorial Units for Statistics) of the countries considered, which is done through a cargo dissipation from the known data of cargo demand of their respective countries. This is accomplished using a gravity model calibrated with historical trade data between Portugal and the regions. With the cargo demand of each region determined, a logit model is used to allocate them either as maritime or road cargo, i.e., determine the modal split. A transportation network to simulate real conditions is used to calibrate the model and determine the first modal split (to be as close as possible from the current one). The adapted network considering an expansion of the number of available transport chains is then applied in the calibrated model, resulting in a different modal-split. The comparison between the results from the two scenarios allows an analysis of the potential of modal shift to SSS to be done and conclusions to be taken.

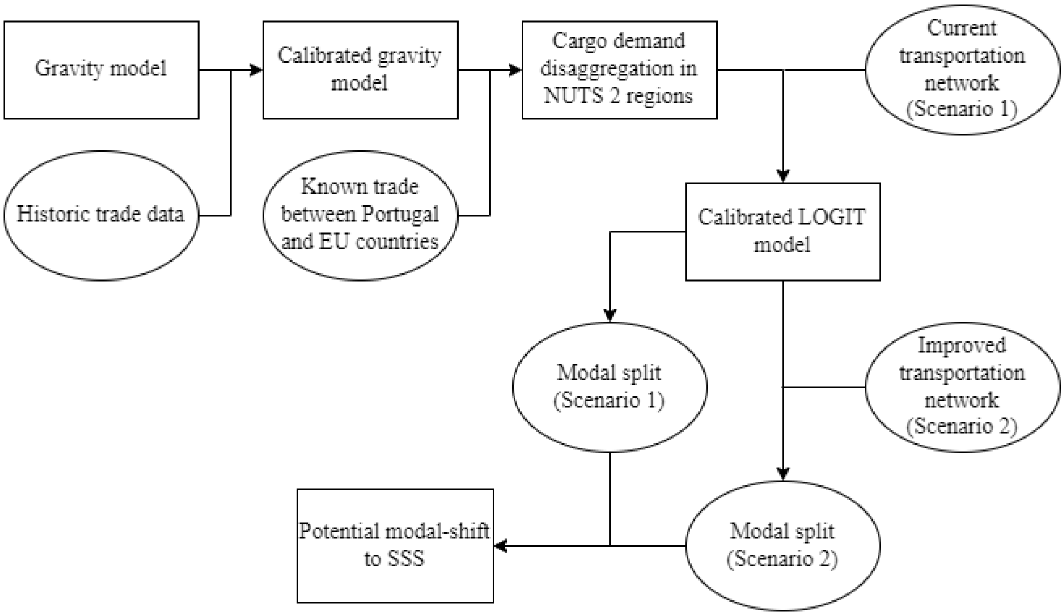

Figure 1.2: Flow chart regarding the scope of this thesis.

1.2 Objectives

The final aim of this thesis is to assess the modal shift potential from road transportation to short sea shipping (and intermodal chains including SSS) between Portugal and Western European countries, by comparing the modal split of the current transportation chains with the split if new chains, predominantly intermodal, are considered.

The objectives of this thesis are:

- Determine the cargo demand of statistical NUTS 2 given the cargo demand of their respective countries, i.e., a disaggregation of freight is required. To do so, a gravity model to be detailed in Chapter 3 is applied.

- Determine the transportation costs in the transport network between Portugal (Porto) and the NUTS 2 regions, along with the time of transport. For that, a numerical software developed in the research unit CENTEC of IST, University of Lisbon, is used.
- Estimate the modal split between road and intermodal chains using a logit model based on the cargo flows and transportation cost and time. The parameters of this model are calibrated so that the estimated results are the closest to the real modal split per country, available in data from INE.
- The calibrated model is used to assess the potential modal shift if new transportation chains are considered, which is the final objective of this thesis.

1.3 Structure of the Thesis

The main body of this thesis is divided in six chapters and respective subchapter. Chapter 1 introduces the thesis through the definition of the concept of short sea shipping and exposing its competition context with road transportation in the European freight market, followed by the objectives of this thesis and how it presents relevance in the field of transportation studies.

Chapter 2 consists in a literature review dedicated to studies on short sea shipping, transport chains (including SSS), gravity models and logit models applied to maritime transportation problems, which provided a consistent base before engaging in the thesis.

Chapter 3 introduces the mathematical methodology applied in the development of this thesis, namely the gravity model for freight segregation, the multinomial logit to calculate the modal split and the numerical software for calculations of time and cost of the transportation networks.

Chapter 4 defines the case study here considered, detailing the cargo demand, transportation chains, cost, time and other relevant parameters.

Chapter 5 shows the results of the segregated transportation demand obtained with the gravity model; the comparison between real modal split vs. estimated modal split per country; the modal split estimation if new transportation chains are considered.

The analysis of the results allows the elaboration of some conclusions, which are discussed in Chapter 6 along with recommendations for further work.

2. LITERATURE REVIEW

2.1 Short sea shipping in the European continent

It is a matter of fact that short sea shipping has gathered relevant attention from the European Union since the end of the 90’s when benefits generally attributed to this mode of transportation started to be highlighted and the main direction of financial resources started to be redirected from development of land transport to short sea shipping (Douet & Cappuccilli, 2011). From then on, the proposal around investing on the expansion of SSS along the European transportation network has always been based on the will to alleviate road congestion, provide an alternative to the connection of West and East Europe, increase competitiveness in the transportation sector – and so, reduce costs -, and diminish the environmental impact related to the haulage of goods. In the latest years, the global concern regarding the sustainability of supply chains around the world has increased the relevance of the environmental benefits of SSS, which are a result of the economies of scale that maritime transportation brings along.

In order to compose the studies destined to quantify this environmental benefit, (Mulligan & Lombardo, 2006) proposes a methodology to estimate the impact of a modal shift from land-based transportation. It does so by estimating the fuel consumption for a determined route length and operating speed using a set of equations to determine the shaft horsepower (SHP) of a theoretical vessel. It compares this result with the estimation of the fuel consumption with overland trucking. The quantified results support the thesis that the fuel economy provides a relief on the environmental degradation in transportation networks and, in the matter of public policies, government subsidies and investment in SSS could be seen as relevant factors for the competitiveness of SSS and, therefore, its success.

In the context of assessing these short sea policies, (Becker et al., 2004) evaluates the proposal of including high-speed vessels in short sea freight transport due to the benefits of decreasing lead-time. At first order, the final objective of promoting modal shift would be better reached with the stimulation of the right conditions in order to benefit the use of SSS in the supply chains of shippers and providers of logistics services. Said so, SSS policy should be promoted focusing on the growth of transport volumes at first with the objective to attract markets and goods that still prior land-based transportation. With the development of the maritime network to a mature level, high speed vessels may find market demand in the future that turns faster service into a viable service.

There are several study cases that consider regional conditions to assess the potential of modal shift against road transport. (Lupi et al., 2017) analyses SSS routes linking Sicily with the Italian mainland by modelling the network and comparing cost and travel times from relevant origins in Italy to relevant destinations in the island. The results show that routes in the Adriatic should be improved to gain competitivity and that the low number of SSS routes and their low frequency are a strong reason why short sea freight is still a small percentage of road traffic in Italy. In the Northern European context, (Ng, 2009) presents intra-European routes between Belgium and the Baltic Region with the objective to model, calculate and compare their generalized costs with road haulage. The results highlight the relevance of port efficiency as a determinant in the size of a route’s catchment area.

Bringing the context to the competitiveness of SSS to the transportation corridors between Portugal and Northern Europe, (Rascão & Santos, 2019) evaluates the amount of cargo that can potentially shift to intermodality. It does so by modelling transit time and transport costs associated with unimodal (road) and intermodal (road + SSS) transportation for a supply chain with origin in Portugal and destination in Northern Europe. A decision making process based on a cost and time (both usually higher for SSS) tolerance determines the potential of modal shift, with the conclusion that under specific operating conditions that would favor SSS, such as lower freight rates and lower transit time, a liner service connecting Portugal to Northern Europe would be competitive.

It is important to be aware, however, that the recent IMO 2020 sulphur resolution, which limits the global fuel sulphur to 0.50%, can produce a counter shift effect to road transportation, given that internal costs of transportation are highly dependent on fuel costs, and can represent a financial threat to the competitiveness of short sea shipping.

The sulphur limitation came as an addition to the 0.10% sulphur limit in the North American, US Caribbean, North Sea and Baltic Sulphur Emission Control Areas (SECAs). Among the market concerns regarding fuel prices escalation and loss of competitiveness, the modal shift to road transportation appears to be the largest threat to short sea shipping.

As an attempt to forecast the proportion of the modal shift, (Zis & Psaraftis, 2017) presents a model that estimates modal shifting and applies it to seven routes affected by regulations in the European Ro-Ro market. Given the obtained results, the authors propose recommendations to mitigate and/or reverse the modal shift in routes that are affected the most according to their forecast. The presented results are highly dependent on the fuel cost: using the very low values for fuel prices in 2015 barely shows no threat for short sea shipping competitiveness. However, the scenarios that considered higher ULSFO prices revealed that the Ro-Ro sector would be shrinking and losing cargoes to land-based modes. If the latter was the case, the need to examine measures and policies that would mitigate and reverse such an outcome would be reinforced.

Already considering a possible future inclusion of the Mediterranean Sea in the SECA's group, (Panagakos et al., 2014) also applies a modal split model for transportation between Greece and northern Germany. The model compares two different chain alternatives - road, exclusively, and Ro-Pax ferry + truck-on-train combination - using as decision variables the time and cost of transportation. From the obtained results, (Panagakos et al., 2014) argues that, among the three compliance options available to the shipping industry, switching fuels from HFO (S-content 1%) to ULSFO (S-content 0.1%) is the preferred one in the short run, as the scrubber technology is fairly new on ships and LNG is more likely to be used as a marine fuel in newbuildings.

In order to avoid the negative effects of the low-sulphur regulation, such as a tendency towards modal shifting to less expensive transportation solutions, (Zis et al., 2019) examines a set of policy options that could restrain possible harms in the European Ro-Ro sector, such as internalizing external costs of transport, repaying fuel surcharges to shippers and subsidizing technological investments of ship operators. The results disclaim that the most promising policy would be the internalization measure, as all transport modes would become more expensive, but maritime modes would be attracting more market shares due to the lower external costs of short sea shipping in comparison with road modes. With the same purpose, (Zis et al., 2015), (Zis & Psaraftis, 2019) and (Zis et al., 2020) quantify the effects of mitigating proposals that are, actually, not unusual for few shipping companies nowadays, such as slow steaming, cold ironing, change of service frequency, near-port speed-reduction and investing in abatement technologies.

Thinking through these mitigating measures, (Psaraftis & Kontovas, 2010) ponders that, despite being effective in meeting environmental objectives, these policies can produce side effects on the economics of the logistical supply chain. The authors argue that such measures are likely to increase maritime costs - specially for short-sea shipping - and, therefore, result in a modal shift to cheaper and more environmental damaging land transport modes.

Even though prior to the IMO sulphur resolution, (Bergqvist & Weddmark, 2015) expressed the same feeling of concern in 2015 when the seas around Sweden were included in the North Sea ECA. The Swedish study case was predicted, in that time, to go through a freight transfer to land transportation. For the companies that did not transfer to land transportation, it would be more likely for them now to ship via the west coast instead of east in order to reduce the transportation time inside the control area.

2.2 Applications of gravity models

Gravity models have consistently been applied in the literature as a methodology for estimating trade flow between bodies, usually countries. The gravity word arises as these models generally use the distance between the bodies as an inversely proportional variable to the trade flow, just as in Newton's gravitational law. One of the first publications to mathematically describe these models, (Ball, 1967) formulates a model of the interaction between demand and supply for trade of goods, using the country's GDP, population and distance as determinant variables to the potential trade demand of a country to another.

Extending previous works, (Anderson, 1979) provides a theoretical appliance of the gravity approach to commodities, highlighting that the gravity approach has acquired legitimacy and background as a mechanism of economic estimations, consolidating its position as a methodology for trade flow calculations. In order to consider other attractive factors to the trade between countries, (Tinbergen, 1962) adapts the model to estimate the global trade flow – exports and imports – for 42 countries. This adaptation is made with the inclusion of dummy variables (binary) that would represent a factor that would facilitate or not the trade between them. They were, for that case, dummy variables for neighboring countries, Commonwealth preference and Benelux preference.

The same principle is applied in (Miron et al., 2019) in order to analyze Romanian trade flows between 2001 and 2015. The scope of the study is to evaluate factors that can influence the dimension and dispersion of the Romanian trade patterns, but does not include as determinant factor the historical trade relations with neighboring countries in their communist era. The results from (Miron et al., 2019) show that a border-share variable presents the highest value of the parameters, reflecting an intense cross-border trade with neighboring countries. The final conclusion is that, even though the comparison between estimated trade flows with and actual observed one is expected to show some difference, the results present themselves as a relevant tool for aiding policymakers in the task of developing policies to support national trade – in the study case, the Romanian one.

In a more contemporary approach, (García et al., 2013) applies the gravity model to MERCOSUR trade flows with the objective to verify how the trade agreement has affected the involved countries. For that, 75 countries are considered over a period of 29 years, including all the countries belonging to MERCOSUR and the ones likely to join. Despite considering the GDPs and distance between the countries, dummy variables are also taken there to include common language, sharing borders, common colonizer and, of course, if one (or both) of the countries belongs to the agreement.

Surpassing the limitations of traditional applications of global trade between countries, (Bialynicka-Birula, 2015) applies the model to estimate international trade in works of art in European countries. Despite using a nonlinear (power function) regression based on the turnover art markets and distance between countries, it offers a breakdown in the theory of the gravity approach, describing simple and more complex models.

In another use of this type of model, (Morley et al., 2014) applies the background of the gravity model in international trade to bilateral tourism flows after a re-emergence of the topic in the field. In the work, (Morley et al., 2014) states that spatial and structural factors have been considered lately in the literature, such as the inclusion in the model of factors like temperature, coastline, travel infrastructure, among others, which highlights the versatility and applicability of the gravity approach.

Gravity models are also relevant in international migration studies. (Vanderkamp, 1977) highlights that economists have treated trade flows successfully using the gravity approach, but that the appliance of these models surpass the economy field and can be extended to studies on some human behaviors, such as migration flows. With the objective to test this hypothesis (Vanderkamp, 1977), applies an adapted model to a Canadian study case of migration, and, with the R^2 results from the regression, suggests that the use of a gravity model to predict migration flows can be potentially useful.

Closer to the maritime field, (Russo et al., 2014) uses the gravity approach to estimate demand flow on maritime container transport in the Mediterranean. A set of variables, such as GDP, industry value added, population, inflation, unemployment, and others., have their parameters calibrated, with the objective to forecast the response of the containerised flow. The authors highlight that the results are of relevant support not only for market operators and analysts but also for researchers developing freight models. In a way, the relevance of the gravity approach in the maritime and logistics field extends beyond the estimation of demand flows and disaggregation of cargo, since these results can be used as base elements for other studies, as it is the case for this thesis.

2.3 Applications of logistic regression models

The LOGIT family is widely consolidated in the literature for analysis of travel demand, being the logit models a group of extensions of the original binomial logistic regression. (Ben-Akiva & Bierlaire, 1999) provides a good first theoretical approach to discrete choice models in the logit family, defining the utility theory and the deterministic term of each alternative. It defines the multinomial logit model, used in the present thesis, as a generalization of the binomial logistic regression to more than two alternatives. It extends the theoretical definitions to the nested logit model, which impose conditional probabilities to the model, and other variations, such as the cross-nested model.

One of the key differences between a multinomial and a nested model is regarding the decision-making process. As in (Zis & Psaraftis, 2017), a hierarchical/conditional choice is made previously to the choice of the path to be taken, which is the choice regarding the transportation mode that will be taken. These two splits – first split, mode choice; second split, path inside the chosen mode – demand that the calibration process is also conducted in two steps, which expands the data requirement to calibrate the model.

In this context, (Russo et al., 2016) applies a binomial logit in order to analyze the competition and modal-split inside the maritime SSS market, comparing Ro-Ro (roll-on/roll-off) with Lo-Lo (lift-on/lift-off) services in the Mediterranean. The generic attributes for the alternatives used in the thesis are the monetary cost and travel time, and, with the parameters calibrated, the results of the modal-split are aligned with the characteristics of the services, i.e., the Ro-Ro services are less competitive over longer distances than Lo-Lo services. It highlights that its analysis could be used to support the decision-making process of transport operators of unitized cargos.

As for non-binomial regressions, (Morales-Fusco et al., 2018) compares three alternatives of freight movement between Spain and Italy using a multinomial logit. It highlights that the choice of using this model instead of a nested logit had the purpose to avoid the effect of hierarchical layers and its complex calibration. On the same way, (Konstantinus et al., 2020) assesses the introduction of SSS in the Southern African Development Community (SADC) as an option to assist on the development of their regional freight transport. A multinomial model is used to estimate the freight mode choice between SSS and land corridors in three OD sets, resulting in the conclusion that the mode choices are, for that case, mainly determined by transit time and frequency of service, which allows the SADC to develop these aspects in SSS to induce a modal shift.

(Russo & Chilà, 2009) suggests that a high-speed mode - combining road and sea - in the motorway of the sea is a competitive alternative to road transport for perishable and high valued freight. In order to test the thesis, a multinomial logit is applied with several attributes belonging to the utility. The results confirm the hypothesis of the authors, in which the introduction of the high-speed combined mode would cause a mode shift from land and produce a new rate of freight demand. It should be highlighted that attributes to be included in the utility can vary according to the needs and interests of the researcher, and, for transportation effects, cost and time of transportation (and variations of them) are mostly adopted in the utility. An example of that is the case of (Russo & Chilà, 2009), which includes as attributes the distance to terminals, handling time at terminals and several dummy variables.

(Santos et al., 2021) presents a methodology to improve the design of short sea shipping intermodal transportation chains within the transportation network. In order to combine cost and time attributes of the utility, (Santos et al., 2021) used the generalized transportation cost (GTC) as the attribute in an intermodal transportation chain comprising Portugal and Morocco. For that, a value of time (VOT) parameter is introduced to the multinomial logit. This approach simplifies the model and, depending on the study case, can produce results as reliable as if the utility was determined with cost and time attributes separately. In all the scenarios analyzed, the inclusion of the Ro-Ro service reduced the freight transportation demand for the containership services, which shows that the proposed Ro-Ro service presents a relevant potential of attracting cargo volume demand. The research presents itself as a background contribution to support policies that could aid on the development of such liner services, which is of general interest in the region.

3. METHODOLOGY

3.1 Estimation of containerized cargo demand with gravity approach

This chapter presents the methodology for obtaining an estimation of the containerized cargo trade between Portugal and the NUTS 2 (2016) regions of the European countries considered using relevant statistical data of the referred countries. The objective is to introduce a methodology based on the gravity approach capable to disaggregate the imported cargo volumes of a country between their NUTS 2 regions considering variables that are found to be relevant, i.e., provide a good fit between real historical data and estimated values. The diagram in Figure 3.1.1 exemplifies the logic of disaggregation of cargo demand of a country into the cargo demand of the country's regions.

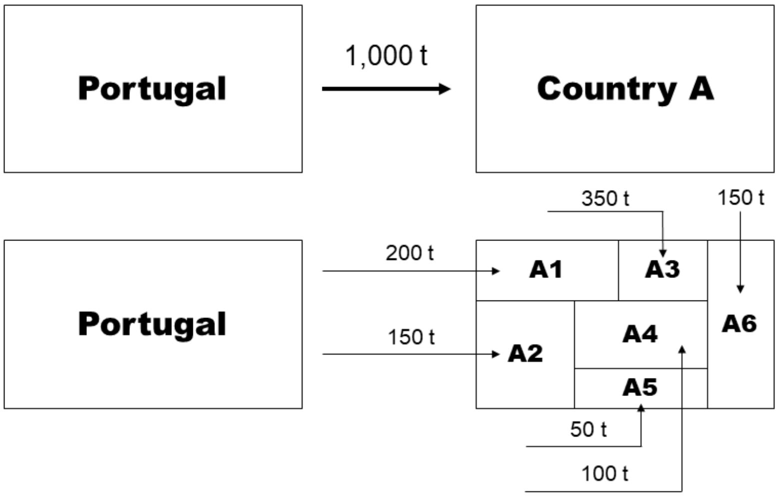

Figure 3.1.1: Fictious example of cargo demand disaggregation.

As mentioned in Chapter 2.2, a gravity model states sets a relation of proportionality between the volume of trade between two countries (or "bodies") and their economic mass. An introductory gravity model is represented in Equation 1, in which the variables and the calibrating constant G are linearly related and have the exponent one. In this case, the *O* variable (origin) is always Portugal and *D* (destination) refers to the NUTS 2 regions of the countries studied.

$$T_{OD} = G\ \frac{V_O . V_D}{d_{OD}} \tag{1}$$

where T_{OD} is the trade between bodies O and D, G is a model parameter, V is the variable of interest of the bodies O and D - such as GDP or population - and d is the distance between them.

A more general model can be described by Equation 2, though. In this model, nonlinearities are introduced to the proportional relation between the variables and the trade.

$$T_{OD} = \beta 0 . V_O^{\beta 1} . V_D^{\beta 2} . d_{OD}^{\beta 3}$$

(2)

where β_n are model parameters to be determined. In the general case of Equation 2, the addition of exponents to the variables as parameters to be calibrated in the model increases its potential accuracy.

In order to be able to use the gravity to estimate future trade between regions, it is necessary to consider that, such as other regression models, the model in Equation 2 requires calibration and estimation of its parameters. Assuming that historical data of variables and trade volume is available, the model parameters can be determined by linearizing the terms in Equation 2 and performing a multivariable regression, allowing the calculation of future trade flow when new data is input in the model.

To do so, Equation 3 describes the linearization of the model using the logarithmic function in a way that allows the determination of these parameters:

$$\log(T_{OD}) = \log(\beta 0) + \beta 1 \log(V_O) + \beta 2 \log(V_D) + \beta 3 \log(d_{OD})$$

(3)

Given that the trade flow estimations will always have Portugal as one of the involved bodies - the calculations are always regarding the container exports from Portugal to a NUTS 2 region -, the values of Portuguese variables will be input in the model as a constant. In other words, given that Portugal is the body O and an unnamed NUTS 2 region is the body D, the value of V_O will be a constant along the calculations, and, therefore, $\beta 1 . \log(V_O)$ will be as such.

Said so, the model for this particular thesis can be generalized as:

$$t_{OD} = \alpha_0 + \sum_{p=1}^{n} \alpha_p . \ v_p$$

(4)

where n is the number of variables considered, v_p is the logarithm of a given variable V_p, α_p is its parameter associated with v_p and t_{OD} is the logarithm of the trade volume between the two bodies.

With such mathematical arrangement of the model, it is now easy to obtain the numerical values of the parameters with the assistance of a linear regression. The regression, to be performed with historical data of known values of the variables and the trade flow, shall output values of the linear (α_0) and angular (α_p) coefficients (or so-called model parameters), as well as statistical parameters to evaluate the relevance of the regression performed, namely R^2 and p-value.

In the present thesis, combinations of three most used variables in the literature were analyzed: GDP, population and distance. Table 3.1.1 associates the models tested with the chosen variables.

Table 3.1.1: Variables associated with the models tested.

Variables	GDP	Population	Distance
Model 1	X		
Model 2		X	
Model 3			X
Model 4	X	X	

In order to determine the parameters for each model, historic data from 2010 for the GDP, population and trade between Portugal and NUTS 2 regions was used. With these values, the linear regression was performed for each model and countries of interest. Then, with the α parameters and the performance indicators (R^2, p-value) determined, the four models are evaluated in order to select the most appropriate one to proceed with in this thesis. Finally, for the chosen model, Equation 4 is used to estimate the flow of containerized cargo using now recent data of the variables for each country.

The data used to calibrate the models and to estimate the Portuguese trade with the NUTS 2 regions will be presented in Chapter 4.1.

3.2 Quantitative assessment of transport chains

Numerical calculations of decision parameters (namely cost and time) of the transportation chains are based on a numerical model for the quantitative assessment of intermodal chains and on a model of the transport networks as from (Santos et al., 2022). The numerical model is implemented in a software coded in Fortran called *Intermodal Analyst* developed to calculate the cost and time of transport between sets of origin and destination. The software was developed in the research unit CENTEC of IST, University of Lisbon.

The methodology mainly consists in the definition of the network as a series of various links between two points in the space. The number of links in the transportation network is defined as *L*. If a series of links is organized in a logical sequence so that an origin and a destination are connected, a path *p* is formed. Paths with the same origin and destination are organized in a set *k*. All different paths in a set (eventually using different transport modes) represent alternatives for the transportation of cargo units between that pair O/D. Every link, here denoted as *i*, is attributed with characteristics that define them, such as length (distance) D_{l_i}, mode of transportation and speed of operation S_{l_i}. The combination of these characteristics into a mathematical formulation is what allows calculation of transportation time and cost.

Before engaging in these formulations, a set of binary variables are defined:

- δ_{l_i} defines whether the link *i* is active (operational) or not.
- δ_{kp_i} defines whether link *i* is used in path *p* of set *k*.
- δ_{Rd_i} identifies whether the link *i* is of road type or not.

The transportation time taken by a cargo unit along a given path, using road type links, is given by the following summation over all links existing in the database:

$$T_{RD_{kp}} = \sum_{i=1}^{L} \delta_{l_i} . \delta_{kp_i} . \delta_{Rd_i} . \frac{D_{l_i}}{S_{l_i}}$$

(5)

Generalizing Equation 5, it is possible to calculate the time taken in links of other types, namely rail, inland waterways, and maritime (using Ro-Ro or container ships), denoted as, respectively, T_{RL}, T_{IW}, T_{RR}, and T_{CC}. Given that paths can be intermodal - and so comprise more than one mode of transportation - the transportation time taken along path *p* of set *k* is then given by the overall summation of transportation times in every mode:

$$T_{TR_{kp}} = T_{RD_{kp}} + T_{RL_{kp}} + T_{IW_{kp}} + T_{RR_{kp}} + T_{CC_{kp}}$$

(6)

In addition to the transportation time, the model comprises the possibility of delays at certain nodes in the path. The number of nodes defined in the transport network is here referred as *N.* Each node *j* is user specified and can represent, for example, dwell time in a container terminal. This dwell time is assumed to represent the unloading time (from a truck, rail, or barge), the storage time in the container terminal stockyard and the loading time (in the ship).

The total time spent in a path *p* of a set *k* is, then, defined by Equation 7 as the sum of actual transportation time, given by Equation 6, with the time taken in nodes *j* along the path:

$$T_{kp} = T_{TR_{kp}} + \sum_{j=1}^{N} \delta_{kp_j} . T_{Dw_j}$$

(7)

where δ_{kp_j} is a binary variable representing whether or not node *j* belongs to the path *p* of set *k* and T_{Dw_j} represents the average dwell time in node *j*.

In order to obtain the costs of freight transportation in a path *p* of a set *k,* a similar methodology is applied. The first step is to determine the total distance travelled in path *p* of set *k*. In the case of road transportation, the total distance travelled is given by Equation 8. Of course, it can be generalized to other modes of transport.

$$D_{RD_{kp}} = \sum_{i=1}^{L} \delta_{l_i}.\delta_{kp_i}.\delta_{Rd_i}.D_{l_i}$$

(8)

To every distance travelled, a cost associated with it can be calculated with Equation 9 by introducing a cost coefficient c_{RD}.

$$C_{RD_{kp}} = D_{RD_{kp}}.c_{RD}$$

(9)

where the cost coefficient c_{RD} is, itself, a function of the distance travelled by road, that is:

$$c_{RD} = f\left(D_{RD_{kp}}\right)$$

(10)

This coefficient is obtained by interpolation over a non-linear function of specific cost $f\left(D_{RD_{kp}}\right)$ (monetary units per km for a cargo unit), specified according to the applicable market conditions.

The same principle is applied to calculate the costs of sub-paths that use other modes of transportation in the path, which are represented by $C_{RL_{kp}}$, $C_{IW_{kp}}$, $C_{RR_{kp}}$, and $C_{CC_{kp}}$. Each of these costs is a function of the respective cost coefficient which, in turn, is a non-linear function of the total distance travelled using the applicable transport mode.

The total transportation cost in a given path is then the sum of the costs associated with each mode of transport:

$$C_{TR_{kp}} = C_{RD_{kp}} + C_{RL_{kp}} + C_{IW_{kp}} + C_{RR_{kp}} + C_{CC_{kp}}$$

(11)

As well as additional time delays in the nodes can be added in the total time (see Equation 7), the same can be done for the costs incurred from nodes. In other words, the total cost is the summation of the cost incurred in the transportation operations plus costs associated with cargo handling between transport modes occurring in nodes of the network:

$$C_{kp} = C_{TR_{kp}} + \sum_{j=1}^{N} \delta_{n_j}\delta_{kp_j}.\left(C_{u_j} + C_{l_j}\right)$$

(12)

where C_{u_j} and C_{l_j} represent the unloading and loading costs in node *j*, δ_{n_j} is a binary variable which indicates if node *j* is active, and δ_{kp_j} is a binary variable that indicates if node *j* is used in path *p* of the set of paths *k*.

A combination of the total time and the total cost can be used to produce another cost variable. The generalized transportation cost (GTC) is the sum of the monetary and non-monetary costs of a journey, including the cost of the time spent undertaking the journey. This non-monetary cost is calculated with the total time spent on the voyage and the Value of Time (VoT) parameter, which represents the cost of the hours "lost" traveling. The GTC on a given path, *p*, is calculated by:

$$GTC_{kp} = C_{kp} + VoT.T_{kp}$$

(13)

where *VoT* represents the value of time for the cargo in monetary units per hour.

The definition of the transportation network available is presented in Chapter 4.2, while the cost and time parameters applied to this mathematical model are presented in Chapter 4.3.

3.3 Estimation of the modal split based on multinomial LOGIT

Given that the ultimate objective of the present thesis is to determine the modal-split of the cargo between road and maritime modes, a model for the allocation of cargo must be described.

In the numerical model, every OD pair is assigned with distinct paths, which consist either of road or maritime transportation. On a given set, the probability of transportation on the path p of the set k is calculated through the multinomial logit model that has the GTC as the attribute in the utility:

$$P_{kp} = \frac{e^{-\beta.GTC_{kp}}}{\sum_{p=1}^{P} e^{-\beta.GTC_{kp}}}$$

(14)

where β is the parameter of the model and P is the number of paths in set k. Equation 14 represents the formulation of the multinomial logistic regression when the utility has the GTC as attribute. This logistic regression model is classified as a multinomial logit since it is as a generalization of the binomial logistic regression to more than two alternatives, given that every available path p is an alternative in the set k.

As the cargo volume transported in a set k is determined from Chapter 3.2., it is possible to estimate the cargo dispersion for each path p of set k:

$$Q_{kp} = Q_k \, .P_{kp}$$

(15)

being Q_{kp} the dispersion of the cargo from set k to the path - or transportation chain – p, expressed in yearly volumes (in tons). The objective of the expressions in Equations 14 and 15 is to represent, mathematically, the fact that:

1. The more expensive it is to haul cargo using a path, the least likely the use of this path will be. Equation 14 is used to calculate each of the probabilities of using each path in a set. Of course, the sum of the probabilities in one set equals 100%.
2. The cargo will be distributed along the paths by following the distribution of probabilities between them. In other words, if one path holds 50% of the probability of transportation in a set, 50% of the cargo volume available in this set will be transported by using this path.

In order to calibrate the model, a base case scenario composed of chains that are present in the current transportation network is proposed (to be defined in Chapter 4.2). The chains considered in this scenario are either classified as road or maritime networks, therefore, the modal-split of the cargo of the set k can be obtained with the summation of the cargo distribution per paths, i.e., the maritime cargo in set k is the summation of the cargo of paths that are classified as a maritime chain.

$$Q_k^{Maritime} = \sum_{p=1}^{P} Q_{kp}^{Maritime}$$

(16)

$$Q_k^{Road} = \sum_{p=1}^{P} Q_{kp}^{Road} = Q_k - Q_k^{Maritime}$$

(17)

With the model of the logistic regression described, it becomes clear that, in order to obtain the desired results of the modal split, the model must be calibrated. In other words, the parameter of the dispersion model β must be adjusted so that the smallest deviation between numerical and actual modal split is obtained.

To do so, statistical data available in INE is used. The data, available at INE's website, discloses the split of the cargo exported from Portugal to European countries into modes of transportation, i.e., it provides the actual modal-split data needed for the calibration. Therefore, the β parameter can be determined with the objective function to minimize the difference between the actual modal split provided by INE and the values estimated by the model. Additional comments about the use and treatment of these data are exposed in Chapter 4.

With the model calibrated considering the base case scenario and the value of β determined, the logistic regression in Equation 14 can be used to estimate the modal split in other configurations of the transportation chain.

4. CASE STUDY

4.1 Transport demand and cargo flows definition

This thesis evaluates the potential of short sea shipping to support the foreign trade from Portugal to European countries, mainly to Western Europe. The countries present in the scope of this thesis are: Spain, France, Germany, Belgium, Netherlands, Luxembourg, Switzerland, Italy, Austria, Czech Republic, Denmark and United Kingdom. Such countries were selected for this study case given the role they play in the Portuguese foreign trade inside the selected regional scope (Western Europe). The chart in Figure 4.1.1 shows the total volume of cargo exports from Portugal to these countries in 2020.

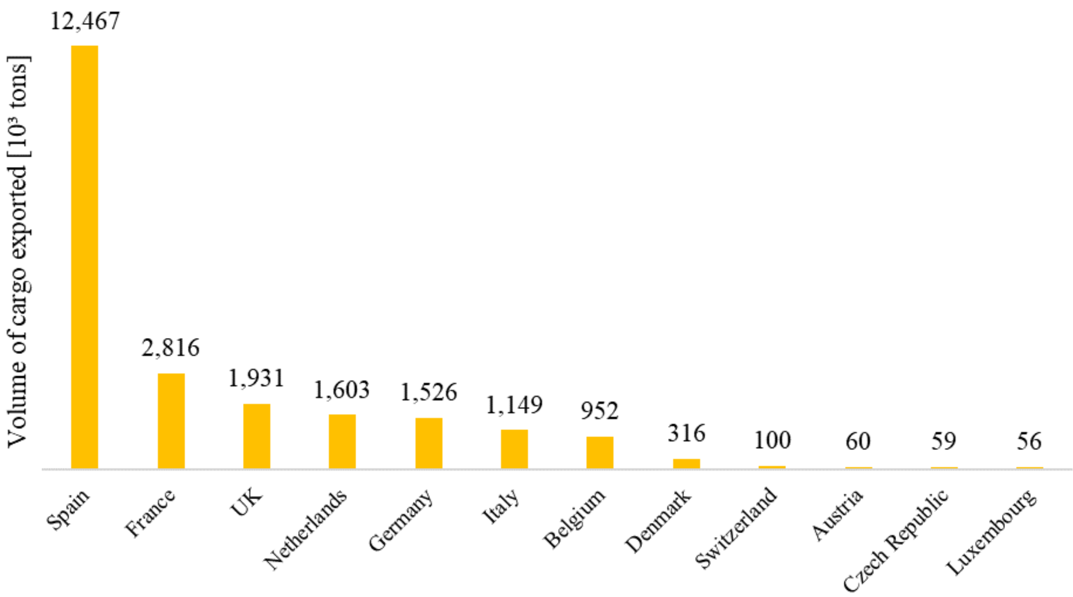

Figure 4.1.1: Total cargo exports to the countries considered in the case study.

Given that the total exported volume from Portugal to the EU + UK was 25,374 10^3 tons in 2020 [1], the selected countries represent almost 91% of the Portuguese intra-European exportation market, which covers the most relevant players in the case study.

An immediate pattern can be noticed regarding the most relevant countries observed in Figure 4.1.1. The large market (population) and the geographical advantage (border sharing) support the disproportional Spanish demand of cargo when compared to other countries. The proximity cheapens general transportation expenses and stimulates trade between them. The same factors apply to the French case, in other proportions.

The large market, regular maritime services and traditional commercial bonds put the United Kingdom as the third most important partner in the intra-European trade. The Netherlands, Germany and Italy come as relevant partners as well but ones that are more affected by the higher geographical distance, which enhances general expenses for moving cargo from Portugal to the destination. The combination of the factors of distance, market size and how well the countries are connected in the transportation network can usually justify the trade relation between them.

The cargo demand of these countries from the Portuguese market is well described in statistical sources, such as in the Portuguese National Institute of Statistics (INE). There, the intra-EU cargo flow from Portugal to a country is detailed, displaying information as total exports by modes of transportation (in tons and millions of euros) and maritime exports by type of cargo (containerized, general cargo, liquid and solid bulks, Ro-Ro).

With this data, it is possible to obtain the amounts of cargo exported by road, containerships and trailers in Ro-Ros. Besides these three modes, the freight exported from Portugal is also moved in trains, aircrafts, general cargo vessels and bulk carriers. However, the cargo transported exclusively in these modes are not considered in this thesis since the present objective is to evaluate potential of modal shifting from road to short sea shipping in intermodal chains (performed in containerships and Ro-Ro vessels).

For the sake of an example, the raw data of Portuguese exports to Spain in 2020 obtained from [2] is left in Tables 4.1.1 and 4.1.2.

Table 4.1.1: Cargo exported to Spain by mode of transportation – 2020.

Mode of Transportation					
Total [t]	Road [t]	Maritime [t]	Air [t]	Rail [t]	Others n.e. [t]
12,467,000	10,017,000	1,566,000	980	124,517	757,972

Table 4.1.2: Maritime cargo loaded to Spanish ports by type of cargo – 2020.

Total [t]	Liquid Bulk [t]	Solid Bulk [t]	Containers [t]	Ro-Ro [t]	General Cargo [t]
2,925,996	1,144,556	557,490	1,190,809	839	32,302

While Table 4.1.1 shows the share of exportations to Spain by mode of transportation, Table 4.1.2 shows how the maritime cargo loaded to Spain (being the country its final destination or not) is dispersed into the main types of cargo. It is important to notice that Table 4.1.2 does not show values of exportation to Spain, but values of cargo loaded in Portugal to Spain, where the cargo can stay as final destination or be forwarded to other countries (notice that the total in Table 4.1.2 is higher than the maritime volume in Table 4.1.1). However, the data present in Table 4.1.2 is very relevant to recognize the pattern of maritime transportation and estimate how much of the maritime cargo flow from Portugal to a country is transported in containerized cargo (containerships + Ro-Ro):

$$S_{\%} = \frac{(V_C + V_{RR})}{V_M} \tag{18}$$

Where $S_{\%}$ is the containerized share of the loaded volume to a country, V_C is the volume loaded in containerships, V_{RR} is the volume loaded in Ro-Ro vessels and V_M is the total maritime volume loaded.

In the Spanish case, for example, the value of the containerized share is 40.7%. This value is, then, applied to the maritime volume exported to the countries (Table 4.1.1), so that the value of containerized volume exported is obtained:

$$S_{\%} \cdot V_{EM} = V_{EC}$$

(19)

where V_{EM} is the maritime exported volume and V_{EC} is the containerized exported volume.

The motivation to perform these calculations is to obtain what will be called in this thesis as “available cargo”, which is the summation of the road volumes exported with the containerized volume exported. Cargo volumes exported by air or rail are not considered given that the objective of this thesis is to assess the potential modal shift from road transportation to short sea shipping. Also, non-containerized maritime cargo (bulk and general cargo) is not considered given that they cannot be interchanged between modes without rearrangement of the cargo, which allows multimodality but not intermodality.

Therefore, the available cargo for this study consists of:

$$V_{EA} = V_{ER} + V_{EC}$$

(20)

Where V_{ER} is the road exported volume and V_{EA} is the available exported volume.

This is the volume of cargo to be disaggregated in the gravity model and to be used as input in the multinomial logit. The Table 4.1.3 below shows the data of available cargo for each country.

Table 4.1.3: Available cargo demand to be disaggregated.

Country	Short Sea Shipping	Road	Total
	Containerized Vol. Exported [t]	Road Vol. Exported [t]	Available Cargo [t]
Spain	637,773	10,017,000	10,654,773
France	104,440	2,181,000	2,285,440
UK	646,353	571,511	1,217,864
Netherlands	534,854	555,000	1,089,854
Germany	307,431	784,000	1,091,431
Italy	247,593	499,000	746,593
Belgium	270,251	295,000	565,251
Denmark	19,314	124,280	143,594
Switzerland	12,943	73,323	86,267
Austria	17,963	38,817	56,780
Czech Rep.	2,662	54,948	57,610
Luxembourg	2,072	45,267	47,339

The images below show visually the data present in Table 4.1.3 with the comparison between the goods exported to each country by road and short sea shipping. Figure 4.1.2 is divided in two so that the visualization of the data is facilitated - notice that the scale of the axis is not the same. Again, these values were obtained by treating the data as per Equations 18 to 20 and the raw data was taken from INE's website [1].

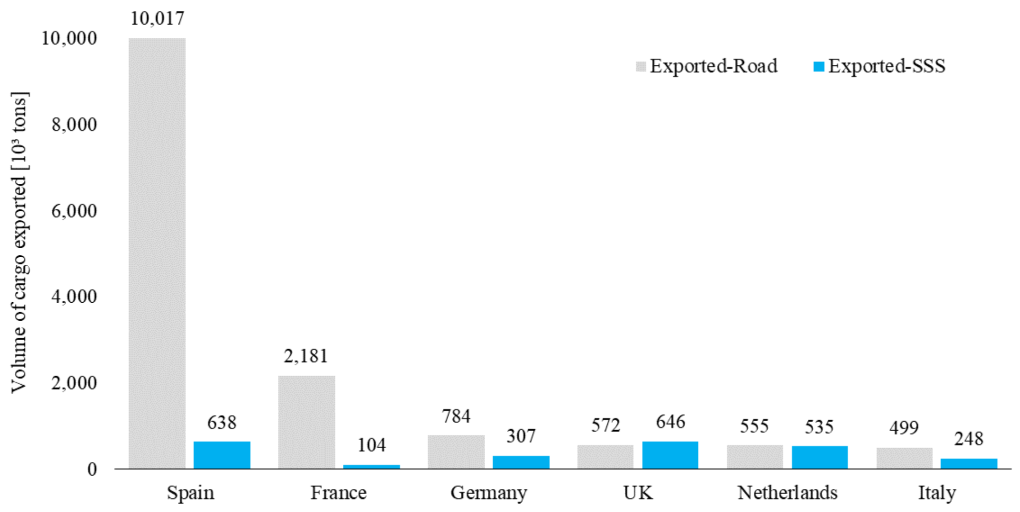

Figure 4.1.2.a: Volume of cargo exported by road and short sea shipping.

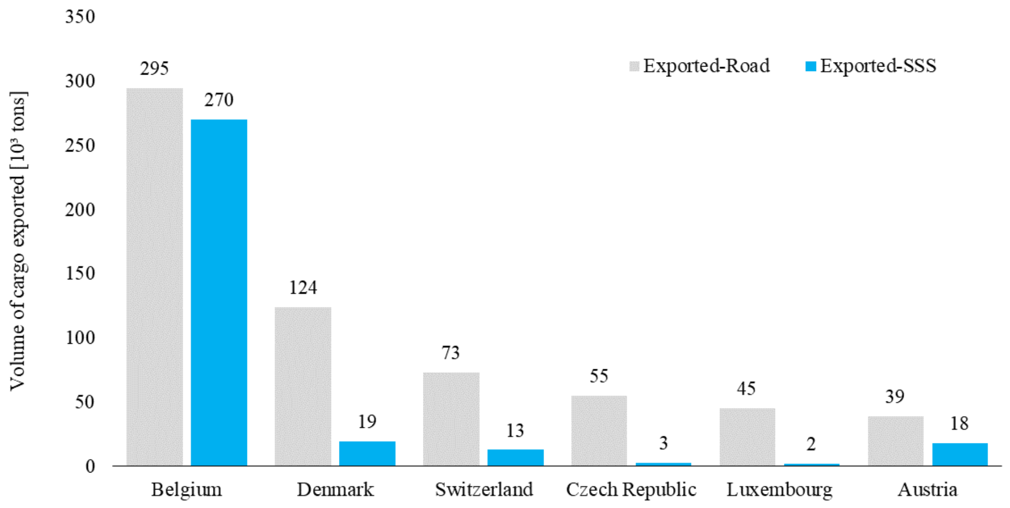

Figure 4.1.2.b: Volume of cargo exported by road and short sea shipping.

In the charts above, the comparison is made between road and SSS (Ro-Ro + containership) since the modal splits to be evaluated consider Ro-Ro SSS and containership SSS as the whole maritime mode of transport. There, it can be seen that short sea shipping has a more expressive role in countries that are well connected through regular maritime services to Portugal (countries in the North Atlantic corridor, for example). At the same time, these countries, such as UK, Netherlands and Belgium, are located at higher distances from Portugal, and, therefore, SSS can profit from the smaller specific costs of transportation compared to road haulage (see further comments about Figure 4.3.1). On the other hand, countries closer to Portugal or inner in the continent, i.e., where road connections from SSS terminals to the destination are longer, have the most expressive role of road transportation, which is the mode able to connect origin to destination without dwelling at an intermodal terminal.

As from the comments and graphics above, it is clear that the available statistical data is able to describe, for each country, the flow of cargo transported by road and short sea shipping. The role of the gravity model described in Chapter 3.1 is, on the other hand, to obtain the information of how this demand of cargo is subdivided in the NUTS 2 regions of each country. To distribute the available cargo, four models of linear regression are evaluated considering different combinations of GDP, population and road distance from Porto as variables (see Table 3.1.1). Said so, it is necessary to obtain these data for all NUTS 2 regions. For GDP and population, the Eurostat[3] tool was used, with data from 2020 when it was available and from 2019 when it was not. To obtain the data of the road distance from Porto, the Google Maps[4] tool was used.

In order to calibrate the models, it was necessary to obtain historical data of a known distribution of demand from Portugal to the NUTS 2 regions of the countries considered. The PBL Netherlands Environmental Assessment Agency[5] was used as source, as it had these data available for the year of 2010. To properly calibrate the linear regression, the data of the variables GDP and population from 2010 also had to be used (road distance was considered to be unchanged between 2010 to 2020). All the data used in the calibration process is shown in Table A1.1 in Annex 1.

When the models were calibrated using GDP and population data from Eurostat in 2010, road distance from Google Maps and cargo distribution in 2010 from PBL source, they were loaded with data from 2020 and results of distribution of cargo were generated. They can be seen in Chapter 5.1 as well as their evaluation and the selection of the most suitable model considering statistical parameters R^2 and p-values. The data used as input in the gravity model to generate the results of disaggregated cargo demand is entirely shown in Table A1.2 in Annex 1, as well as the results.

4.2 Transportation network definition

This chapter defines all the relevant considerations regarding the case study to which the methodology in Chapter 3.2 is applied.

One of these necessary definitions concerns the transportation network considered. The transport network model is used to specify routes (here also referred as "paths") between pairs O/D (here also referred as "set"). These routes represent transport chains (unimodal or intermodal), which connect Portugal to multiple NUTS 2 regions across European countries. Paths have been grouped in sets, each one with a common origin and destination. Paths within a set can be composed by one single mode, as

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[3] *Home - eurostat*. (n.d.). Europa.Eu. Retrieved July 26, 2022, from https://ec.europa.eu/eurostat

[4] Google Maps. (n.d.). Retrieved July 26, 2022, from https://www.google.pt/maps/

[5] EU trade visualisation. (n.d.). Pbl.Nl. Retrieved July 26, 2022, from https://themasites.pbl.nl/eu-trade/index2.html?vis=chord

a road exclusive haulage, or by intermodal combinations of the different modes available (road, rail, container SSS, Ro-Ro SSS, inland waterways).

Figure 4.2.1 shows an example of the structure of transport chains for a specific pair O/D. There, the cargo leaving from the city of Porto has Stuttgart as destination, composing thus one set of transport chains. In this set, there are several possible paths (chains): unimodal road transportation; maritime + road; rail + road; maritime + rail + road; maritime + IWT + road. Each one of those paths is associated with a cost and time of transport, calculated by the software Intermodal Analyst. The combination of these factors is what defines the likelihood of using each one of these paths in this thesis.

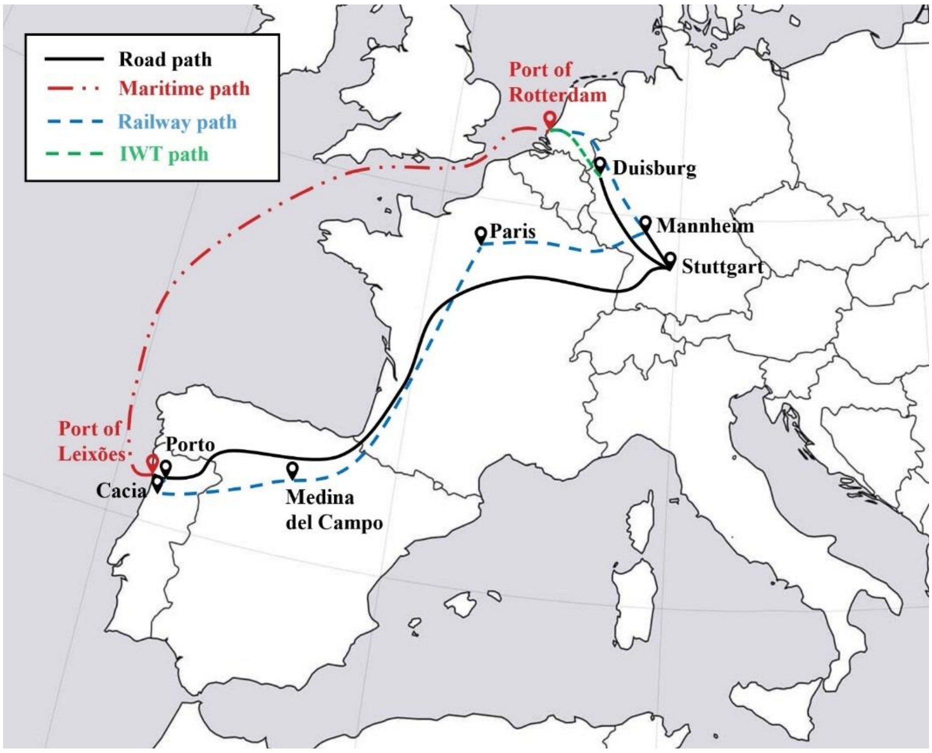

Figure 4.2.1: General example of a transportation network.

The O/D pairs in the network are defined as follows: given that the port of Leixões (northern Portugal) is the most important one in the Portuguese Ro-Ro segment [6] [7], it makes it the most promising Portuguese port to support a modal shift to SSS. With that considered, Porto, the capital city of the North region of Portugal, was considered to be the depart location of the exported cargo from Portugal, i.e., all the sets have the city in northern Portugal as origin.

As the destinations are to be logically spread through the 12 countries considered, the capital cities of each one of their NUTS 2 – 2016 regions were taken as destinations, since they are standardized in

[6] Associação dos Portos de Portugal. (n.d.). Portosdeportugal.pt. Retrieved July 26, 2022, from http://www.portosdeportugal.pt/app/portos/leixoes.php

[7] Nuno Araújo: "O Porto de Leixões é o porto mais importante do país." (2021, September 17). APD Portugal. https://www.apd.pt/entrevista-nuno-araujo-o-porto-de-leixoes-e-o-porto-mais-importante-do-pais/

European levels and regulated by the European Commission, which facilitate the gathering of statistical data of the territories and makes the results more easily replicable and usable in further studies.

The images in Figure 4.2.2 below were obtained from the Eurostat[3] website and show the division of the countries considered into their NUTS 2 regions.

Figure 4.2.2.a: NUTS 2 territories – Spain.

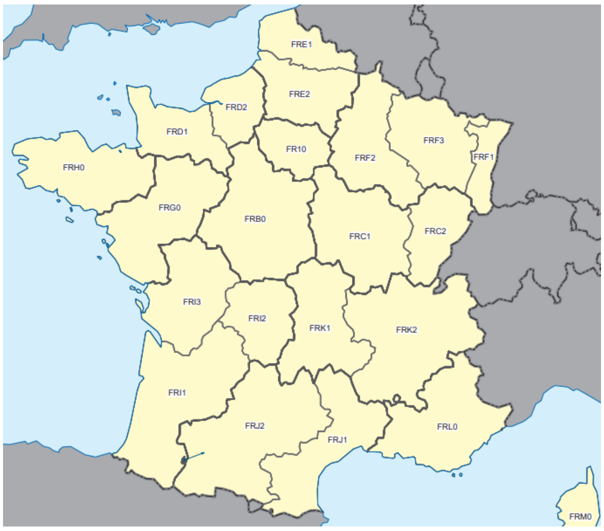

Figure 4.2.2.b: NUTS 2 territories – France.

Figure 4.2.2.c: NUTS 2 territories – Italy.

Figure 4.2.2.d: NUTS 2 territories – Germany.

Figure 4.2.2.e: NUTS 2 territories – Netherlands.

Figure 4.2.2.f: NUTS 2 territories – United Kingdom.

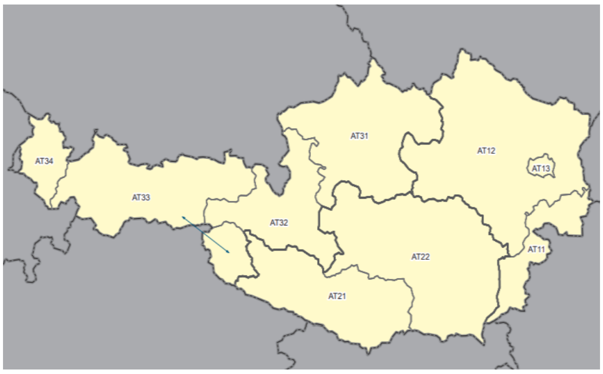

Figure 4.2.2.g: NUTS 2 territories – Austria.

Figure 4.2.2.h: NUTS 2 territories – Switzerland.

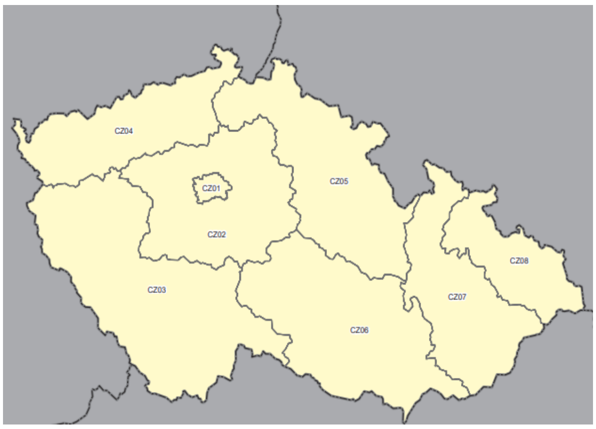

Figure 4.2.2.i: NUTS 2 territories – Denmark.

Figure 4.2.2.j: NUTS 2 territories – Cz. Republic.

Figure 4.2.2.k: NUTS 2 territories – Belgium.

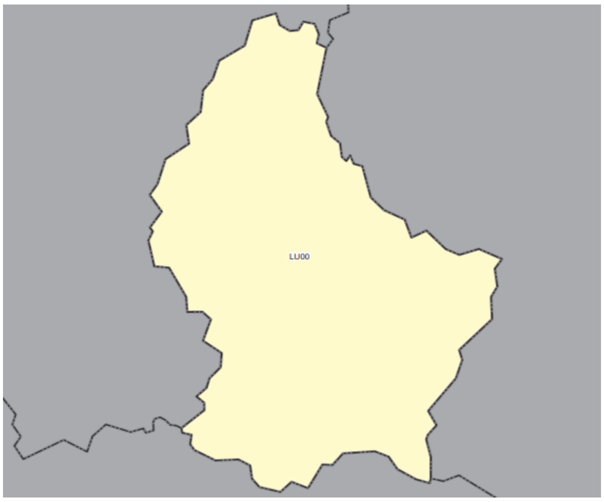

Figure 4.2.2.l: NUTS 2 territories – Luxembourg.

Since each country is divided in different number of regions, each had a variable number of destinations within them. Luxembourg, for example, has only one NUTS 2 region and, therefore, only one set has Luxembourg as destination. France, on the other hand, has 22 NUTS 2 regions – excluding ultramarine territories outside Europe, which was standard criteria –, making it 22 sets from Porto that have France as destination. The Table 4.2.1 below shows the number of NUTS 2 regions per country considered in this thesis.

Table 4.2.1: Number of NUTS 2 regions per country considered.

Country	Country Code	Number of NUTS 2 territorial levels
United Kingdom	UK	40
Germany	DE	38
France	FR	22
Italy	IT	21
Spain	ES	15
Netherlands	NL	12
Belgium	BE	11
Austria	AT	9
Czech Republic	CZ	8
Switzerland	CH	7
Denmark	DK	5
Luxembourg	LU	1

With the sets (O/D pairs) defined in the study case, the transportation chains described by paths between them can be described. The definition of all the transport chains can be seen in Table 4.2.2., where the available paths are described regarding their intermodal terminals, modes of transportation and if it is a road type path or maritime/short sea shipping one. As will be seen shortly, not all these transport chains are available for every pair O/D.

The color code in the table has the following legend:

- ----- Road transportation.
- ----- Ro-Ro transportation.
- ----- Containership transportation.
- ----- Rail transportation.
- ----- Inland waterway transportation.

It is important to be attentive of the color code that represents the mode of transportation. In some cases, such as between paths 2 and 3, the only difference is the mode of transportation used in one connection. In this case, what differentiates the paths is the connection from Leixões to Rotterdam, performed by Ro-Ro vessels in path 2 and containerships in path 3. The same repeats for paths 10 and 14, 11 and 13.

Table 4.2.2: Definition of paths in the transportation chains for a generic destination.

Path nº	Transportation chain description	Path type
Path 01	Porto ----- Destination	Road
Path 02	Porto ----- Leixões ----- Rotterdam ----- Destination	Maritime
Path 03	Porto ----- Leixões ----- Rotterdam ----- Destination	Maritime
Path 04	Porto ----- Leixões ----- Rotterdam ----- Oberhausen ----- Destination	Maritime
Path 05	Porto ----- Leixões ----- Rotterdam ----- Duisburg ----- Destination	Maritime
Path 06	Porto ----- Entroncamento ----- Mannheim ----- Destination	Road
Path 07	Porto ----- Cacia ----- Mannheim ----- Destination	Road
Path 08	Porto ----- Leixões ----- Rotterdam ----- Mannheim ----- Destination	Maritime
Path 09	Porto ----- Leixões ----- Le Havre ----- Mannheim ----- Destination	Maritime
Path 10	Porto ----- Leixões ----- Le Havre ----- Destination	Maritime
Path 11	Porto ----- Leixões ----- Hamburg ----- Destination	Maritime
Path 12	Porto ----- Leixões ----- Hamburg ----- Wurzburg ----- Destination	Maritime
Path 13	Porto ----- Leixões ----- Hamburg ----- Destination	Maritime
Path 14	Porto ----- Leixões ----- Le Havre ----- Destination	Maritime
Path 15	Porto ----- Leixões ----- Marseille ----- Destination	Maritime
Path 16	Porto ----- Leixões ----- Valencia ----- Napoli ----- Destination	Maritime
Path 17	Porto ----- Leixões ----- Setúbal ----- Genova ----- Destination	Maritime
Path 18	Porto ----- Leixões ----- Setúbal ----- Genova ----- Salerno ----- Destination	Maritime
Path 19	Porto ----- Leixões ----- Bilbao/Valencia ----- Destination	Maritime
Path 20	Porto ----- Leixões ----- Liverpool ----- Destination	Maritime
Path 21	Porto ----- Leixões ----- Tilbury ----- Destination	Maritime
Path 22	Porto ----- Leixões ----- Bristol ----- Destination	Maritime
Path 23	Porto ----- Leixões ----- Livorno ----- Destination	Maritime
Path 24	Porto ----- Leixões ----- Genova ----- Basel ----- Destination	Maritime
Path 25	Porto ----- Leixões ----- Genova ----- Basel ----- Destination	Maritime
Path 26	Porto ----- Leixões ----- Rotterdam ----- Basel ----- Destination	Maritime

The analysis will be carried out for two different scenarios regarding availability of transport chains connecting Portugal to the countries considered are defined: scenario 1 and 2. The intention of scenario 1 is to provide a network that represents closely the current offer of transport options in operation between Portugal and Western Europe. The numerical method described in Chapter 3.2 will be applied in scenario 1 in order to provide cost and time results regarding the transportation several paths for each set. These results are, then, used as input for the methodology presented in Chapter 3.3 with the objective of obtaining the modal split in each country. The ultimate objective of Scenario 1 is to allow the calibration of the multinomial logit model by applying the utility parameters that produce the smallest deviation between actual and calculated modal split in each country.

In Scenario 2, an adapted network that includes intermodal transport chains that are not currently present is used to evaluate the modal shift potential from road to SSS. The parameters of the multinomial logit determined with Scenario 1 are applied to perform the logistic regression in Scenario 2, providing a new modal split result per country. The results of the cargo split for the scenarios can, therefore, be compared and discussed.

Said so, Scenario 1 accounts with transportation chains that are already provided using regular services. Besides the direct connection between origin and destination by road (path 01), it includes, for northern European countries, a liner service between Leixões – Rotterdam (path 03) and Leixões – Hamburg (path 13). For Italy, Austria and Switzerland, a containership connection from Leixões to Genova with a call in Setúbal is considered (path 17). In the Spanish case, a liner service is considered to connect Leixões to Bilbao (for northern Spanish destinations) or to Valencia (for southern Spanish destinations), represented by path 19. In the British case, containership services are offered to Liverpool and Tilbury (paths 20 and 21). In Scenario 2, the existence of regular maritime services (of containerships and Ro-Ros) connecting Leixões to other major European ports is considered, as well as integrated rail and inland waterway services.

In scenario 2, Leixões and Rotterdam are not only connected by regular containership services, but by Ro-Ro vessels as well (path 2). The port of Rotterdam is also connected to other intermodal terminals, as the rail terminals of Oberhausen and Mannheim (paths 4 and 8) and the inland waterway ports of Duisburg (path 5) and Basel (path 26). Two Portuguese cities enter the transportation network because of their rail terminals of Entroncamento and Cacia, both leading to Mannheim (paths 6 and 7). The French port of Le Havre is now considered in scenario 2, having direct services from Leixões in both containerships (path 14) and Ro-Ro vessels (path 10). This port also presents a railway to Mannheim (path 9). The port of Hamburg is now additionally connected to Leixões by a regular Ro-Ro service (path 11) and offers a rail service to Wurzburg (path 12). The French port of Marseille is added in scenario 2, offering a regular containership service from/to Leixões (path 15). Italy becomes better connected to Portugal with the additional services of a Ro-Ro vessel from Leixões to Napoli with a port call in Valencia (path 16), and the service of path 17 from scenario 1 is extended from Genova to Salerno (path 18). Also in the Italian case, a Ro-Ro service from Leixões reaches Livorno in path 23. In the UK, a new service with Bristol as destination is stablished in path 22. Finally, a now direct line from Leixões connects to Genova (without making a port call in Setúbal), with additional rail transportation to Basel, in Switzerland, in paths 24 and 25. By analyzing Table 4.2.2, however, paths 24 and 25 may seem identical at first glance, since they use the same intermodal terminals and modes of transportation. However, the difference between them concerns the rail transportation way performed from Genova to Basel, i.e., the "route" that the train takes in scenario 24 is different of the one used in scenario 25, which is represented in the numerical software by a different sequence of links between Genova and Basel.

The figures shown next show the availability of maritime, rail and inland waterway lines of transportation available in the scenarios to better visualization. Figure 4.2.3 shows the available lines of transportation in scenario 1, while Figure 4.2.4 shows the additional lines of transportation that become available as well in scenario 2.

Figure 4.2.3: Available lines of transportation in scenario 1.

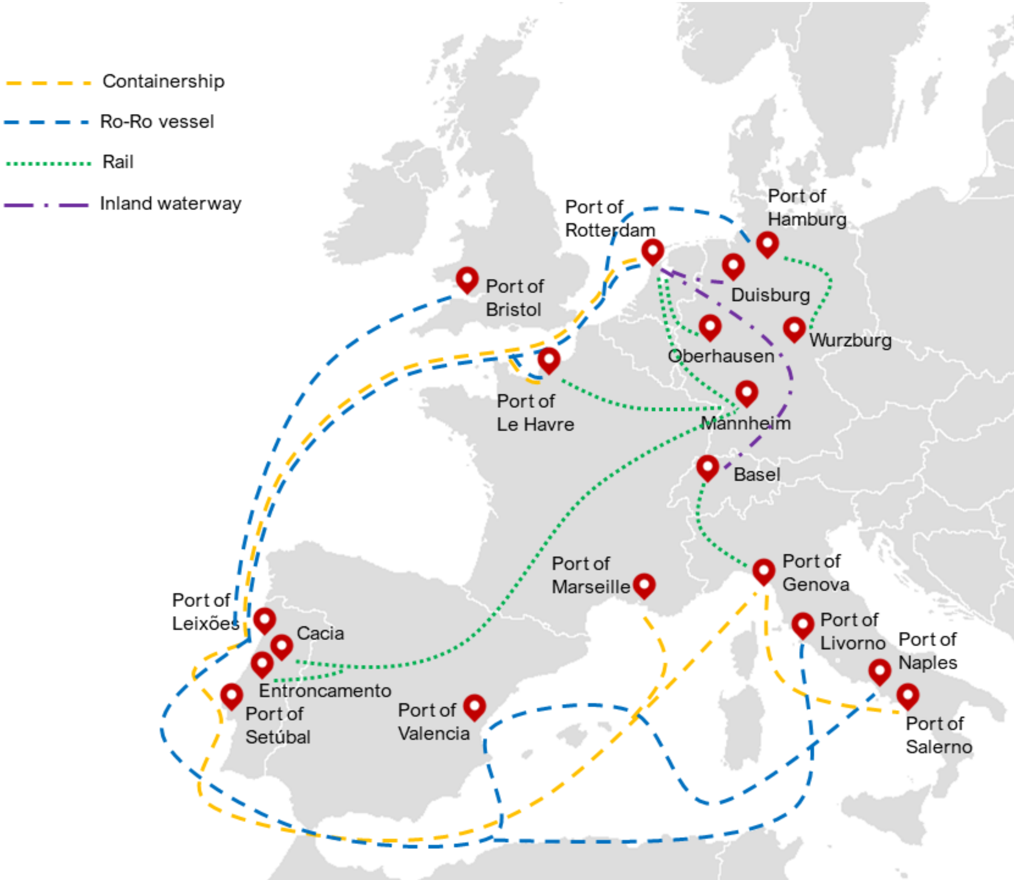

Figure 4.2.4: Additional available lines of transportation in scenario 2.

Table 4.2.3 breaks down the availability of paths for each of the countries considered in Scenario 1 and 2. If the path is available in the country in scenarios 1 and 2, it is signed as “1, 2”; if it is available only in Scenario 2, it is signed as such; if the path is not available in the country, the cell is left empty.

Table 4.2.3: Definition of scenarios 1 and 2.

Path nº	NE	BE	LU	DE North	DE South	FR North	FR South	IT North	IT South	ES	AT	CH	CZ	DK	UK
Path 01	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2
Path 02	2	2	2	2	2	2	-	-	-	-	-	-	2	-	-
Path 03	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	-	-	-	-	1, 2	1, 2	1, 2	1, 2	-
Path 04	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-
Path 05	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-
Path 06	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-
Path 07	2	2	2	2	2	2	-	-	-	-	2	2	2	-	-
Path 08	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-
Path 09	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-
Path 10	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-
Path 11	2	2	2	2	2	2	-	-	-	-	-	-	-	2	-
Path 12	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-
Path 13	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	-	-	-	-	1, 2	-	1, 2	1, 2	-
Path 14	2	2	2	2	2	2	2	-	-	-	-	2	-	-	-
Path 15	-	-	-	-	-	-	2	2	-	-	-	2	-	-	-
Path 16	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-
Path 17	-	-	-	-	-	-	-	1, 2	1, 2	-	1, 2	1, 2	-	-	-
Path 18	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-
Path 19	-	-	-	-	-	-	-	-	-	1, 2	-	-	-	-	-
Path 20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1, 2
Path 21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1, 2
Path 22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Path 23	-	-	-	-	-	-	-	2	2	-	-	2	-	-	-
Path 24	-	2	2	-	2	2	-	-	-	-	2	2	-	-	-
Path 25	-	2	2	-	2	2	-	-	-	-	2	2	-	-	-
Path 26	-	2	2	-	2	2	-	-	-	-	2	2	-	-	-

As an example, it will be shown next how these data is used as input for running the numerical software *Intermodal Analyst.* Consider that the software will be first run for scenario 1. The paths data must be input for all of the NUTS 2 regions (sets) of the 12 countries considered. A file has been created with the definition of all these paths, constituting a transport path database. For example, the part of the input file that concerns the NUTS 2 region of Prague, in Czech Republic, is shown in Figure 4.2.5.

```
137RoutePortoPrague
5
1     1          538 620 540 541 528 526 523 521 520 516 466 468 508 509
2     0          538 539 619 628 783 3322 3323 3324 3325 3326 1242 1240
3     1          538 539 619 628 544 3328 3329 3330 3331 3332 1239 1238 1
7     0          538 620 535 531 594 439 436 429 411 407 399 400 401 405
13    1          538 539 619 628 544 3805 3806 3807 3808 3809 3810 3811 2
```

Figure 4.2.5: Example of the input of paths in a set.

The first line displays the code of the set in question: set number 137, Porto as origin and Prague as destination. The second line shows the number of existing paths for this set (as it can be verified in Table 4.2.2, regions in Czech Republic have five available paths among scenarios 1 and 2). The following lines describe each one of those paths with the data of, from left to right: the code number of the path (verify in Table 4.2.3); if the path is available in this scenario; the sequence of nodes that define the path (as per Chapter 3.2, a path is defined by a sequence of nodes or links), which continues further and is not completely shown in the figure.

For this pair O/D - Porto to Prague -, paths 1, 3 and 13 are considered in scenario 1 (verify in Table 4.2.3). The description of each path, from Table 4.2.2, is:

- Path 1: Unimodal direct road transport from Porto to Prague.
- Path 3: Road transportation from Porto to Leixões, followed by maritime transportation in containership from Leixões to Rotterdam, with a final road connection from Rotterdam to Prague.
- Path 13: Road transportation from Porto to Leixões, followed by maritime transportation in containership from Leixões to Hamburg, with a final road connection from Hamburg to Prague.

In the intention was, then, to run the software for scenario 2, the availability of paths 2 and 7 would be changed from 0 to 1 – non-available to available (Table 4.2.2). The description of these paths, from Table 4.2.2, is:

- Path 2: Road transportation from Porto to Leixões, followed by maritime transportation in Ro-Ro vessel from Leixões to Rotterdam, with a final road connection from Rotterdam to Prague.
- Path 7: Road transportation from Porto to Cacia, followed by rail transportation from Cacia to Mannheim, with a final road connection from Mannheim to Prague.

Notice that all of the paths start in the same node 538, which represents the center of the city of Porto. From this node on, the paths differentiate along the way until it reaches the node that represents the destination. The input file that contains the definition of paths is, basically, a repetition of what is shown in Figure 4.2.5, for all of the sets from 1 to 189.

Once the transport paths database is completely defined, it is included in this input file and the software is partially ready to perform the calculations. Before running it, though, it is also necessary to define the transportation cost and time parameters.

4.3 Transportation cost and time definition

The generalized transportation cost (GTC), used in the present work as the variable for utility in the multinomial logistic regression, is a composition of the monetary and non-monetary costs of a journey. Contrasting with the usual internal cost of transportation, its objective is to account also for the non-monetary cost of the time undertaking the journey, which is done by introducing the Value of Time (VoT) parameter. The formulation that describes the calculation of the GTC is detailed in Equation 13, Chapter 3.2. Beyond considering a value for the VoT, it is necessary to determine, for each path within a set (pair O/D), the values of time spent on the journey and total costs related to it, as per Equation 13.

As it is described in Equations 5, 6 and 7, the calculation of the total time spent in a path is a composition of the time taken by a cargo unit along the links and the dwell time in the intermodal terminals. The first share is calculated with the distance and speed in the links i (Equation 5), while the dwell times - here considered to cover only loading and unloading times - come from a database of the terminals present in the transportation network (Table 4.3.2 to be presented further). For terminals whose data was not available, values from similar terminals were taken.

Regarding the cost calculations, they are a composition of the cost of hauling a cargo unit along the links *i* and the cost with loading and unloading the cargo in the intermodal terminals. While the costs with cargo handling come from a database of the terminals considered, the cost with transportation is based in the interpolation of a non-linear function of specific cost of transportation (monetary unit per km of a cargo unit), as it was described in Chapter 3.2. The functions of specific cost vary for each mode considered and have distinct sources as references.

In the case of road transportation, the European Road Freight Rate Development Benchmark by (Ti et al., 2021) of the second quarter of 2021 was used to obtain average values of road freight rates between relevant European cities in the market, which were divided by the travelled distance to obtain the specific cost. For the freight moved by rail, the specific costs of transportation were calculated from the rates available in (CEGE, 2014) (with data for short distances up to 150km), (Janic, 2007) (with data for distances between 300 and 1300km) and (Lupi et al., 2021) (with data for 250 and 1200km distances). In the case of container SSS, (Lupi et al., 2021) was used to obtain the costs for deep sea shipping on transportation chains connecting New York and Shanghai to Rotterdam and La Spezia and data from the Searates[8] website for freight rate simulation were used to determine costs on SSS routes. For Ro-Ro SSS, data from the websites Direct Ferries[9] and Freightlink[10] were used, simulating intra-European rates for unaccompanied trailers. Last, costs for inland waterways were taken from (CEGE, 2014).

The references mentioned above provided a series of data dispersions of the cost of transport – disregarding loading and unloading tariffs – and their respective distance. In order to combine the diverse data and estimate the cost function for each mode, the general procedure was to perform an exponential regression using MS Excel and generate an equation that would fit the data and represent the expected exponential decrease of specific costs with the increase of distance travelled. This equation was, then, used to determine values of specific cost given certain distances, which is used as input in the numerical software and can be seen in Table 4.3.1.

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8 SeaRates. (n.d.). International container shipping. SeaRates. Retrieved July 26, 2022, from https://www.searates.com/

9 Ferries para Madeira, Canárias, Espanha, Inglaterra, horários de ferry, bilhetes. (n.d.). Directferries.pt. Retrieved July 26, 2022, from https://www.directferries.pt/

10 Freightlink. (n.d.). Freightlink. Retrieved July 26, 2022, from https://www.freightlink.co.uk/

Table 4.3.1: Specific costs of transportation adopted.

Road		Rail		IWT		Containership		Ro-Ro	
[km]	[EUR/unit.km]	[km]	[EUR/unit.km]	[km]	[EUR/unit.km]	[km]	[EUR/unit.km]	[km]	[EUR/unit.km]
1	9.80	1	6.80	1	2.03	1	11.59	1	8.49
10	7.91	10	5.51	10	1.33	50	8.19	50	6.41
20	6.02	20	4.22	20	1.17	100	4.78	100	4.34
30	5.13	100	2.27	100	0.87	200	2.80	200	2.93
40	4.58	140	1.99	140	0.82	500	1.37	500	1.75
50	4.20	260	1.57	260	0.73	1000	0.80	1000	1.18
60	3.90	360	1.39	360	0.69	1500	0.59	1500	0.94
75	3.58	460	1.26	1000	0.57	2000	0.47	2000	0.80
100	3.19	700	1.07	1500	0.53	2500	0.39	2500	0.70
200	2.43	1000	0.94	2000	0.50	4000	0.27	4000	0.54
300	2.07	1500	0.80						
500	1.69	2000	0.72						
1,000	1.29	2500	0.66						
1,500	1.10	3000	0.61						
2000	0.98								
2500	0.90								
3000	0.84								
3500	0.79								

These data can also be visualized in the chart format (see Figure 4.3.1), which allows the perception of the exponential behavior and some comments to be pointed. In the figure, not all the data present in Table 4.3.1 can be visualized since the clearness of data visualization was prioritized and horizontal and vertical axis were limited to some values.

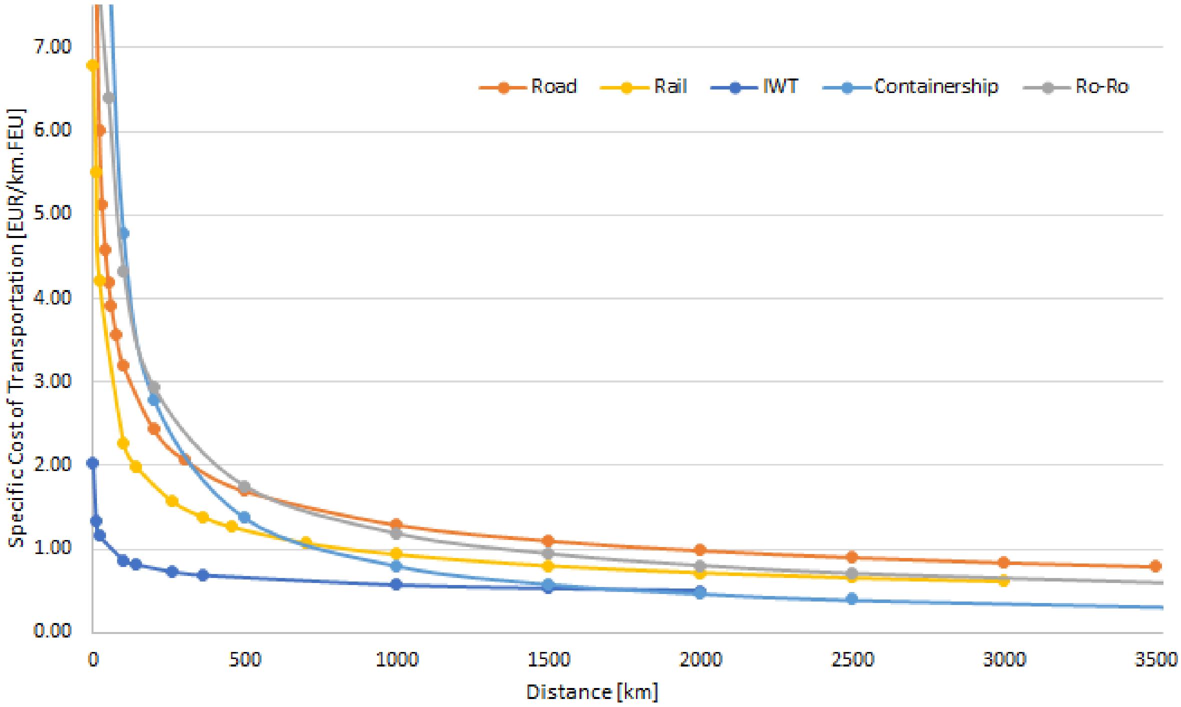

Figure 4.3.1: Specific costs of transportation.

In the figure, it can be seen that, for short and medium distances, waterborne transportation is the least expensive option, which is a reasonable and expected observation given the slow speed that vessels move in inland waterways and the possibility to travel in large convoys. For larger distances, the most expensive mode of transportation is road haulage given the dis-economy of scale that the mode has by generally just transporting one cargo unit at a time.

For small and intermediate distances, though, trucks are able to compete with considerable cost advantages, and road just starts losing cost competitiveness to maritime modes around 500km of distance travelled. Regarding SSS options, although there are some differences in cents when comparing Ro-Ro to Lo-Lo services, they become the most expressive in higher distances, when containerships reach costs of half of the ones for Ro-Ro services - 0.27 EUR and 0.54 EUR for 4000 km distance.

With the specific costs of transportation defined, the data from Table 4.3.1 is uploaded in a file to be used as input by the numerical software *I*ntermodal *Analyst*. The image below shows how the input file is organized.

```
Definition of costs of transportation ------------------------------------------------
Road
18
1.0  10.0  20.0  30.0  40.0  50.0  60.0  75.0  100.0 200.0  300.0  500.0  1000.0 1500.0 2000.0 2500.0  3000.0  3500.0
9.8  7.9  6.0  5.1  4.6  4.2  3.9  3.6  3.2  2.4  2.1  1.7  1.3  1.1  0.98  0.9  0.84  0.79
Rail
14
1.0  10.0  20.0  100.0  140.0 260.0 360.0 460.0 700.0 1000.0 1500.0 2000.0 2500.0 3000.0
6.80  5.51  4.22  2.27  1.99  1.57  1.39  1.26  1.07  0.94  0.80  0.72  0.66  0.61
Inland Waterway
10
1.0  10.0  20.0  100.0  140.0 260.0 360.0 1000.0 1500.0 2000.0
1.60  1.50  1.50  1.05  0.80  0.65  0.60  0.52  0.52  0.52
Short Sea Shipping (RoRo)
10
1.0  50.0  100.0  200.0  500.0 1000.0 1500.0 2000.0 2500.0 4000.0
8.49  6.41  4.34  2.93  1.75  1.18  0.94  0.80  0.70  0.54
Container
10
1.0  50.0 100.0  200.0  500.0 1000.0 1500.0 2000.0 2500.0 4000.0
11.6  8.2  4.78  2.80  1.37  0.80  0.59  0.47  0.39  0.27
```

Figure 4.3.2: Input file where specific costs of transportation are defined.

For every mode of transportation considered, the cost function is input in the file following the same structure: first, a line describes which mode of transportation the data refers to ("Road" or "Container", for example); the following line numbers the amount of points in which the cost function is defined; next, the x coordinate of the data (distance) is listed in ascending order; finally, the y coordinate associated with each distance (specific cost) is listed.

It is important to recall that these specific costs of transportation do not include cargo handling costs, which are relevant for the final cost of transportation and can be a defining factor for the decision of which mode is chosen by a shipper.

Table 4.3.2 shows the cargo handling times and costs for the terminals considered in this thesis's network. Again, when time and tariffs data was not available, values were taken from similar terminals (same terminal category and/or country where it is located). It is important to remember that these tariffs are typically based on the average weight or volume of the cargo being handled, the type – and efficiency – of the equipment used in the operation, which also relates to the time spent in the terminal. Also, differently from handling tariffs in bulk terminals, which usually charge a per-ton rate, the terminals charge, for containerized cargo, either a tariff per box (independently of being 20 or 40 feet unit) TEU/FEU. In the present case, as the study case considers trailers hauling 40 feet units, the tariffs are displayed in EUR/FEU unit.

In the Table 4.3.2, the most common behavior that can be noticed regarding the cargo handling tariffs is the adoption of the same value for loading and unloading the units. However, some cases which the charges are different are present as well. In those cases, the difference in charge can be related with two distinct factors. The first is that the terminal can be experiencing different costs for loading and unloading activities due to distinct equipment used - and it repasses the cost to the shipowners. The other reason is a possible commercial strategy of a terminal, charging only for loading handling tariffs (as the container terminal in Leixões does), for example, but charging significantly more in this operation.

Table 4.3.2: Cargo handling tariffs and time spent at intermodal terminals.

Terminal Category	Location	Country	Cargo Handling Tariffs [EUR/FEU]		Time at Terminal [h]
			Unload	Load	
Rail	Cacia	PT	12.5	12.5	2.0
Rail	Entroncamento	PT	12.5	12.5	12.0
Rail	Oberhausen	DE	25.0	25.0	6.0
Rail	Wurzburg	DE	17.5	17.5	12.0
Rail	Mannheim	DE	17.5	17.5	12.0
Container	Leixões	PT	0.0	142.2	48.0
Container	Setúbal	PT	29.5	102.0	72.0
Container	Hamburg	DE	29.0	105.0	36.0
Container	Bilbao	ES	29.0	105.0	48.0
Container	Valencia	ES	29.0	105.0	24.0
Container	Marseille	FR	29.0	105.0	48.0
Container	Le Havre	FR	29.0	105.0	48.0
Container	Salerno	IT	29.0	105.0	48.0
Container	Genova	IT	29.0	105.0	48.0
Container	Rotterdam	NL	25.0	120.0	36.0
Container	Tilbury	UK	90	90	48.0
Container	Liverpool	UK	90	90	48.0
Ro-Ro	Leixões	PT	25.0	25.0	6.0
Ro-Ro	Hamburg	DE	25.0	25.0	12.0
Ro-Ro	Valencia	ES	47.7	47.7	2.0
Ro-Ro	Le Havre	FR	25.0	25.0	12.0
Ro-Ro	Calais	FR	25.0	25.0	12.0
Ro-Ro	Naples	IT	47.7	47.7	2.0
Ro-Ro	Livorno	IT	25.0	25.0	6.0
Ro-Ro	Rotterdam	NL	50.0	50.0	6.0
Ro-Ro	Dover	UK	25.0	25.0	6.0
Ro-Ro	Bristol	UK	25.0	25.0	6.0
Fluvial	Ruhrort	DE	25.0	25.0	6.0

With all the cost and time specifications defined, the last parameter in Equation 13 that has to be discussed so that it is possible for the numerical software to calculate the generalized transportation cost is the Value of Time.

The value of time in the shipping industry refers to the importance of timely delivery in the transportation of goods. In this industry, time is a valuable commodity given that delays can have significant consequences for businesses and other organizations that rely on the movement of goods. For example, delays in the delivery of raw materials can disrupt the production process, while delays in the delivery of finished products can result in lost sales and damage to a company's reputation. As a result, the value of time in shipping is often considered when determining transportation costs, route planning, and other aspects of the transportation process.

There is not a consensual established value for the VoT parameter in the literature, mainly because it is highly dependent on the content of the cargo transported regarding specially its value, nature and urgency and, therefore, can vary substantially between studies. It is also depending on the current economic and political situation worldwide, varying according to internal return rates, for example, and political conditions in the region where the goods are being transported. For example, in regions with high return rates, timely delivery may be especially important in order to avoid costly delays and disruptions to the supply chain. Similarly, in regions with unstable political conditions, the value of time may be higher due to the increased risk of delays and disruptions. In both cases, the value of time in shipping can be translated into transportation costs and other decisions related to the movement of goods.

The choice of a reasonable value of the VoT is extremely relevant for this thesis since the GTC is directly proportional to it and faulty estimate values can lead to misleading results. In other words, a poor pick of the VoT can easily produce results of GTC non compatible with the reality and generate unrealistic modal split results, invalidating the conclusions and discussions to be presented on this thesis.

In order to bypass these possibilities, it was decided to proceed with the calculation of the GTC using two different values of VoT coming from distinct sources. Using (Feo et al., 2011) as first source for the VoT, (Lupi et al., 2017) assumes a value of 6.82 EUR/h, which is not the lowest value of time but it is definitely not one for high value, urgent or perishable cargo. Meanwhile, (Santos et al., 2022) runs through the literature around the topic and ponders that values vary between 2 and 47 EUR/h, with an average of 20.8 EUR/h.

Said so, it was chosen to run the numerical software with the two values for the VoT 6.82 and 20.8 EUR/h, which will evidently generate two series of GTC results. Furtherly, the calibration of the multinomial logit for scenario 1 will be also performed with the two series of results, producing two different models and, therefore, results of modal split for this scenario. Finally, the VoT that is able to produce the smallest average difference between the results of scenario 1 and the actual values of modal split will be the one chosen to proceed with in the further phases.

It is important to highlight here that a proper definition of costs and time is essential to this thesis's proposal, since they are used to calculate the decision variable (utility) for the modal split calculations using the multinomial logit.

5. NUMERICAL RESULTS

5.1 Application of the gravity models

The four models presented in Section 3.1 were evaluated in order to determine which of them would be the most appropriate to be used in the present problem of cargo disaggregation. The difference between these gravity models tested is regarding the deterministic variable used to estimate the trade volume of exportations from Portugal to the NUTS 2 regions of the countries considered in the study. Model 1 uses the total GDP of the regions to disaggregate the cargo, while model 2 uses the population of each region to do so. Model 4 uses a combination of GDP and population as variables, while model 3 has the distance from Porto to the capital of the region as disaggregating variable.

The models were tested for the countries of Belgium, Netherlands, Spain, Italy, France and Germany, given that they are the most relevant share of the Portuguese exportation market in Europe. The chosen model was applied to all of the countries studied in this thesis.

The relevance of each model of regression is assessed with the statistical parameters R^2 and p-value. The results of these parameters for each country that the tests were performed are displayed in Table 5.1.1.

Table 5.1.1: Statistical parameters resulting from the gravity models.

Model	Parameter	Belgium	Netherlands	Spain	Italy	France	Germany
Model 1 (GDP)	R^2	0.88	0.78	0.80	0.93	0.91	0.73
	P-value	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
Model 2 (Pop.)	R^2	0.92	0.83	0.89	0.90	0.89	0.71
	P-value	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
Model 3 (Dist.)	R^2	0.01	0.01	0.02	0.02	0.02	0.12
	P-value	75.4%	70.6%	65.6%	60.0%	56.2%	3.4%
Model 4 (GDP, Pop.)	R^2	0.94	0.83	0.90	0.93	0.91	0.74
	P-value	19.1%	62.9%	29.7%	1.3%	7.1%	4.8%
	P-value	2.5%	12.4%	1.4%	52.5%	99.1%	25.2%

As good statistical measures for the selection of the most appropriate model, it was demanded that the model to be selected presented, in all of the countries, an R^2 of at least 0.7 and p-values up to 5%. Following these criteria, it is possible to already dismiss models three and four as viable solutions. The next paragraphs comment on the explanation of the deficient performance of these models and justify the selection of the most appropriate one.

From the results presented in Table 5.1.1, it is possible to state that the use of the total GDP of the NUTS regions produce a good fit with the cargo demand data collected, with the minimum R^2 produced of 0.73 and all p-values smaller than 0.1%. In other words, the distribution of the cargo inside the countries tend to follow the GDP of their regions, which is an expected result. The same principles apply to the results of the second model, which presents minimum R^2 of 0.71 and all p-values smaller than

0.1% as well. As in the GDP, the distribution of the cargo tends to follow the distribution of the population inside a country, which is also an expected result.

Both models one and two present good statistical relevance because the variables themselves are usually related. Population and GDP are demographic and economic factors that usually influence on each other, i.e., economic development is generally produced and enhanced with human presence, which, on the other way around, is attracted to regions better economically developed. However, when both variables are combined into the same gravity approach (model four), the result is not as promising.

Even though the fourth model presents good values of R^2, which is the result of combining variables that tend to represent well the historical data, the significance of the variables is way higher than the limit of 5% used in statistics as good measure, which indicates a weak suggestion of effect in the population. The reasoning behind this fact is related to how the grouping of the variables reflects in R^2. In an ideal scenario where two variables are analyzed, the significance of both is combined to produce a good fit of the data with a high R^2. In the present case, however, only one variable is considered to be the relevant - therefore, the mainly used one - for every country, while the other one is neglected. In some cases, the GDP is considered as the significant variable (low p-value) and in other cases, it is the population. Given that both of these variables produce, alone, good R^2, the combination of them does the same, but always with low significance. Said so, the fourth model is excluded from the set of gravity models to be considered.

As it is mentioned on Section 2.2, gravity models have consistently been applied with the use of the distance between trading bodies as variable. This is logical in practical ways given that the stimulation to trade and export to one country diminishes with the increase of the distance, and vice-versa. In the present study case, however, the linear regression using distance as variable shows that it does not present good statistical performance. The reason for that is because the distances from Portugal to the NUTS 2 regions of a country do not vary significantly inside the country in question. In the case of Belgium, for example, the distances vary between 1876 km and 1961 km, which is not even 100 km difference between the closest and the farthest region of Belgium. On the other hand, the trade shares vary a lot from region to region and they do not follow the distance from Portugal as determinant factor.

Another way to see that is to consider that if the cargo is already travelling to a country (far from Portugal) the distance that it has to travel inside the country is way less relevant than the distance travelled between Portugal and the country itself. The actual trade relation with the distance exists and can be seen in other situations, such as in the Portuguese trade with Spain and Belgium, for example. The main reason for Spain being the most important intra-European economic partner of Portugal is because of the fact that both are neighboring countries. Belgium, on the other hand, is almost 2000 km of road apart, which increases costs and time of transportation. Inside Belgium, however, a 100 km difference does not produce relevant influence on where the cargo will have the highest demand, after all it has already travelled almost 2000 km. Given that the data did not find correlation with the road distance proposed in the model, the statistical parameters R^2 and p-value resulted in poor values and the methodology did not proceed with this model.

With the information exposed from the last paragraphs, it can be stated that gravity models three and four do not provide statistical relevance for the estimation of the cargo demand of NUTS 2 regions of a country and, therefore, are excluded from the analysis. Finally, both models one and two produce good fit to the data, high R^2 and low p-values. Given that no significantly relevant difference on the parameters is presented, the choice of the first model is supported and sustained by two other main arguments.

First, gravity models that consider the GDP as variable compose a wide background of studies – as per Section 2.2 - and are one of the most traditional models for the gravity approach, meaning that it is consolidated as a methodology to estimate trade, and, for this thesis's case, can be applied to disaggregate cargo demand of a country without any reservation.

Second, a model depending on the GDP of a region is way more sensitive to immediate impacts of sudden economic change when compared to a model based on population. Human occupancy is determined by a set of distinct factors – including economic development of a region –, which is the object of study of many branches of the demographic science. For this reason, relevant sudden population changes are generally not seen – extreme scenarios excluded – even in context of sudden economical changes of growth and crises.

It is well known, however, that trade between countries and demand of cargo are rapidly affected by the variation of the economic scenario, which is a characteristic that should be represented in the model. In those cases, a model dependent on the population would not communicate numerically a tendency that would be seen in reality due to its low response to such scenarios. In other words, a population dependent model would not be as reliable as a GDP dependent one.

For the reasons mentioned above, it was chosen to proceed in the thesis with the first gravity model.

5.2 Estimation of containerized cargo demand

The use of the chosen gravity approach (model one) to disaggregate the cargo of each country provided the results of cargo demand on every NUTS 2 region. The Table 5.2.1 below shows the total cargo demand per country studied, obtained with data from INE considering the cargo currently transported by road and short sea shipping (containerships and Ro-Ro vessels).

Table 5.2.1: Cargo demand per country to be disaggregated.

Country	Country Code	Maritime Cargo Demand [t]	Road Cargo Demand [t]	Total Cargo Demand [t]
Belgium	BE	270,251	295,000	565,251
Netherlands	NL	534,854	555,000	1,089,854
Spain	ES	637,773	10,017,000	10,654,773
Italy	IT	247,593	499,000	746,593
France	FR	104,440	2,181,000	2,285,440
Germany	DE	307,431	784,000	1,091,431
Austria	AT	17,963	38,817	56,780
Denmark	DK	19,314	124,280	143,594
Switzerland	CH	12,943	73,323	86,267
Czech Rep.	CZ	2,662	54,948	57,610
UK	UK	646,353	571,511	1,217,864
Luxembourg	LU	2,072	45,267	47,339

Using the gravity approach that uses the GDP of the NUTS 2 regions as criteria, the cargo demand of a country is disaggregated in the several regions of this country. The results of the cargo distribution follow in the next tables.

Table 5.2.2.a: Cargo volume distribution through the NUTS 2 (2016) regions.

Germany	Cargo [t]	**France**	Cargo [t]	**Italy**	Cargo [t]	**UK**	Cargo [t]
DE	1,091,431	**FR**	2,285,440	**IT**	746,593	**UK**	1,217,864
DE11	51,012	FR10	377,734	ITC1	55,218	UKC1	19,676
DE12	36,705	FRB0	94,048	ITC2	4,672	UKC2	24,744
DE13	29,719	FRC1	71,342	ITC3	26,160	UKD1	12,688
DE14	28,486	FRC2	55,750	ITC4	121,519	UKD3	42,679
DE21	58,773	FRD1	64,842	ITH1	15,983	UKD4	25,564
DE22	21,051	FRD2	76,910	ITH2	14,104	UKD6	24,355
DE23	20,512	FRE1	124,545	ITH3	63,359	UKD7	25,278
DE24	18,986	FRE2	73,689	ITH4	22,172	UKE1	18,489
DE25	28,244	FRF1	84,156	ITH5	62,569	UKE2	18,568
DE26	22,211	FRF2	62,703	ITI1	50,307	UKE3	22,393
DE27	27,222	FRF3	81,538	ITI2	14,832	UKE4	36,033
DE30	41,986	FRG0	126,114	ITI3	23,401	UKF1	33,247
DE40	27,255	FRH0	114,934	ITI4	73,713	UKF2	31,465
DE50	16,430	FRI1	117,930	ITF1	19,441	UKF3	15,167
DE60	35,893	FRI2	40,865	ITF2	5,828	UKG1	27,503
DE71	49,367	FRI3	75,712	ITF3	47,438	UKG2	26,366
DE72	17,678	FRJ1	95,974	ITF4	36,283	UKG3	40,741
DE73	19,946	FRJ2	111,457	ITF5	9,428	UKH1	39,319
DE80	20,559	FRK1	63,238	ITF6	19,446	UKH2	36,139
DE91	27,385	FRK2	191,635	ITG1	40,588	UKH3	30,329
DE92	29,270	FRL0	153,870	ITG2	20,133	UKI3	80,223
DE93	21,245	FRM0	26,457	**Belgium**	Cargo [t]	UKI4	54,492
DE94	30,560	**Netherlands**	Cargo [t]	**BE**	565,251	UKI5	28,535
DEA1	51,239	**NL**	1,089,854	BE10	76,710	UKI6	25,356
DEA2	47,836	NL11	57,466	BE21	78,661	UKI7	42,498
DEA3	30,265	NL12	54,494	BE22	44,519	UKJ1	50,867
DEA4	28,058	NL13	46,642	BE23	62,064	UKJ2	47,632
DEA5	37,015	NL21	81,789	BE24	59,149	UKJ3	36,672
DEB1	21,585	NL22	111,015	BE25	56,671	UKJ4	30,808
DEB2	11,026	NL23	45,130	BE31	39,614	UKK1	43,074
DEB3	27,636	NL31	107,280	BE32	48,326	UKK2	23,641
DEC0	17,039	NL32	162,918	BE33	46,742	ULK3	12,287
DED2	21,601	NL33	161,887	BE34	22,228	UKK4	21,409
DED4	19,135	NL34	44,094	BE35	30,566	UKL1	27,361
DED5	17,340	NL41	135,824			UKL2	23,132
DEE0	24,717	NL42	81,315			UKM5	15,727
DEF0	32,034					UKM6	12,466
DEG0	24,411					UKM7	35,728
						UKM8	37,529
						UKM9	17,686

Table 5.2.2.b: Cargo volume distribution through the NUTS 2 (2016) regions.

Spain	Cargo [t]	**Czech Rep.**	Cargo [t]	**Austria**	Cargo [t]	**Switzerland**	Cargo [t]
ES	10,654,773	**CZ**	57,610	**AT**	56,780	**CH**	86,267
ES11	572,981	CZ01	23,088	AT11	2,398	CH01	14,941
ES12	193,220	CZ02	5,752	AT12	8,278	CH02	15,548
ES13	111,487	CZ03	4,290	AT13	11,354	CH03	12,738
ES21	650,898	CZ04	2,517	AT21	4,154	CH04	16,696
ES22	171,958	CZ05	5,909	AT22	7,251	CH05	11,151
ES23	68,091	CZ06	8,531	AT31	8,788	CH06	9,433
ES24	329,360	CZ07	3,951	AT32	5,053	CH07	5,760
ES30	2,309,670	CZ08	3,572	AT33	5,683	**Luxemburg**	Cargo [t]
ES41	534,521	**Denmark**	Cargo [t]	AT34	3,820	**LU00**	47,339
ES42	372,455	**DK**	143,594				
ES43	173,113	DK01	51,432				
ES51	2,268,505	DK02	17,754				
ES52	1,058,894	DK03	28,138				
ES61	1,563,559	DK04	30,780				
ES62	276,061	DK05	15,490				

To facilitate the visualization of the data present in Table 5.2.2, the cargo demand can also be shown in the geographical map of the territorial regions NUTS 2 of the countries in question. This map can be seen in Figure 5.2.1 as a color scale map concerning the estimation of the volume of cargo exported from Portugal to these regions.

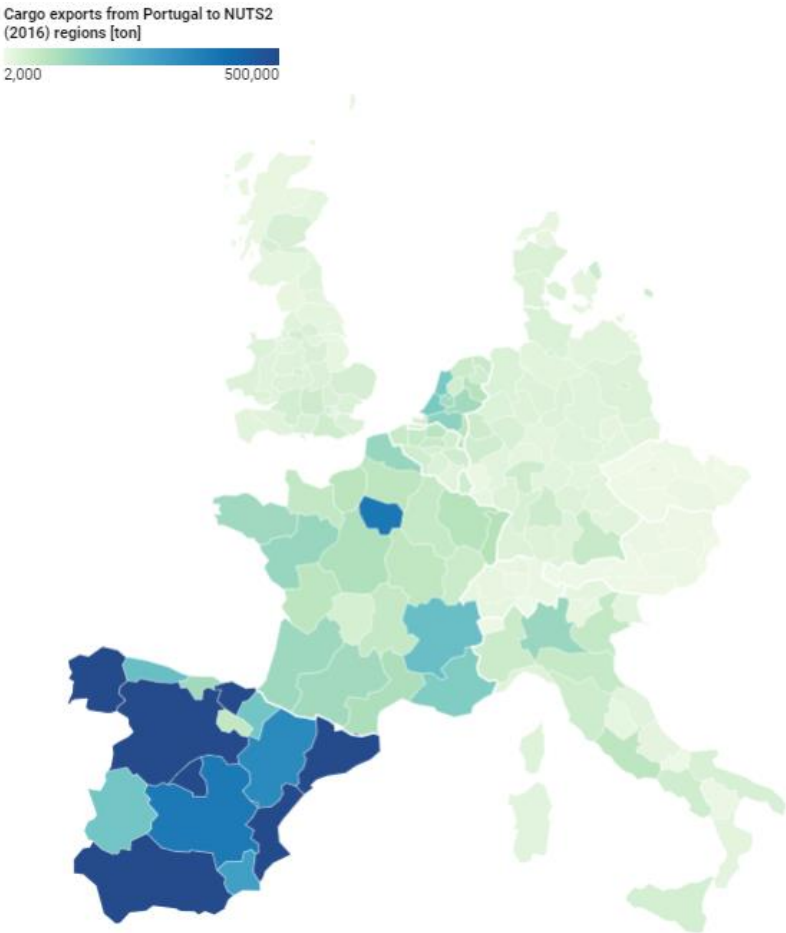

Figure 5.2.1: Cargo exports from Portugal to NUTS 2 regions.

It is interesting to indicate that the sum of the cargo demand on all the regions of a country equals the total cargo demand from that country, which is as expected and required. Moreover, a pattern can be seen regarding the distribution of cargo. Given that the criteria used to disaggregate the volume of cargo was the GDP, it is expected that the regions that represent the highest economic activity of a country are attributed with the highest portion of cargo. Although this can be noticed for all of the countries, a few examples are highlighted below:

- In Spain, most expressive cargo demands come from ES30 - Madrid and ES51 - Catalonia (Barcelona);
- In France, the highest cargo demand comes from FR10 - Paris;
- In Italy, Lombardia – ITC4 is the region that attracts the highest cargo volumes.

With the cargo demand determined for all the NUTS 2 regions covered by this thesis, the logistic regression could be used to determine the modal split for all these regions and, therefore, verify which percentage of the cargo volume is transported by road and short sea shipping.

5.3 Internal costs of transportation

With all the parameters input in the numerical tool *Intermodal Analyst,* it was possible to run the software and analyze the numerical results for scenarios 1 and 2. To every path in every set, the software calculates total transportation time and cost. With the results in hand, the path that offered the cheapest transportation was selected and attractiveness maps were generated by assigning to every set (NUTS 2 region) the type (road or maritime) of this cheapest path. The competitiveness maps here displayed regard only the total monetary cost. Results for the generalized transportation cost can be verified in Chapter 5.4. The geographical scope of competitiveness for scenario 1 is shown in Figure 5.3.1 below.

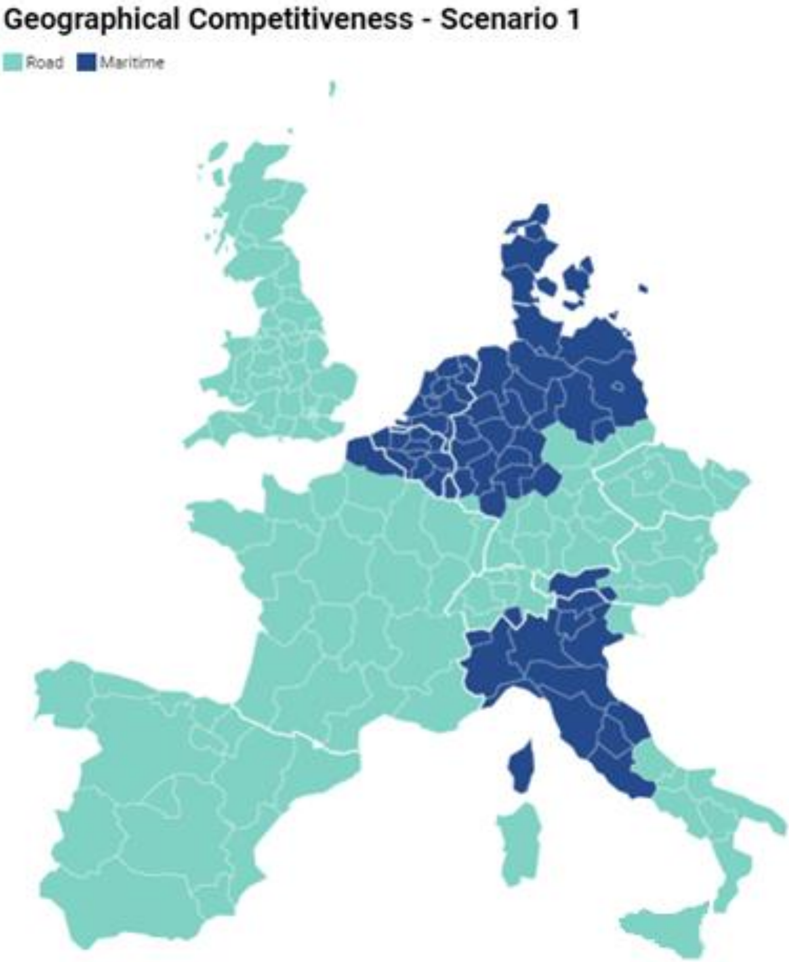

Figure 5.3.1: Competitiveness map for scenario 1.

Given that results regarding only internal costs of transportation are displayed, it is easier to verify some relations. The first of them is that road transportation always finds its best competitiveness in short to medium journeys (see comments about Figure 4.3.1). For the closest countries to Portugal, Spain and France, there is only one single region that has SSS as its cheapest way to haul cargo from Portugal (region Nord-Pas-de-Calais, NUTS 2 code FRE1, in Northern France). Road transportation is financially advantageous for short journeys and begin to lose competitiveness for higher distances when the economies of scale from the maritime modes of transportation begin to count positively.

It is also interesting to notice how the regions attracted to SSS are evenly distributed along areas within a certain radius from a port. The closest regions to a destination port are more easily attracted by the combination of the maritime and road transportation given the short road connection that must be done between the port and the final destination. The farthest it gets from the port - and, therefore, the largest the connection performed by trucks to get to the destination -, the less competitive it is for this combination of modals. From the list of available paths in scenario 1 (Table 4.2.2), it is clear that the maritime clusters of regions take place around the closest regions to the ports of Genova, Rotterdam and Hamburg.

Figure 5.3.2 shows the geographical scope of competitiveness for scenario 2, that is the evolution when new intermodal chains are included in the transportation network.

Figure 5.3.2: Competitiveness map for scenario 2.

The introduction of other transportation chains clearly is able to increase the competitiveness of short sea shipping in intra-European trade. From the results in scenario 2, almost the entire country of Italy with exception of one region has intermodal maritime transportation as the cheapest option for hauling cargo from Porto, with the south of the country being especially affected by the utilization of the port of Naples. Also, in Northern France, two regions are added to the attractiveness scope of SSS because of the inclusion of the port of Le Havre as a container and Ro-Ro terminal.

The use of these maps is important to verify that the calculations performed in the numerical software and the parameters input there produce realistic and reliable results, also allowing some conclusions to be taken. However, even though these maps allow the analysis of the cheapest mode of transportation per set, it does not allow the verification of the cargo distribution per mode along the paths, since not all the available cargo will be transported in the cheapest mode. That is the role of using a methodology for determining the modal split based on a logistic regression, whose results are shown in Chapter 5.4.

5.4 Estimation of the modal split

With the cargo demand determined and the numerical results generated by the software, it was possible to begin the procedure of estimating the β parameter of the model using as base Scenario 1, which had the objective of representing the current transportation chains connecting Portugal and Northern and Eastern European countries.

As in Chapter 3.3, Equation 14, the probability of transportation on the path p of the set k is calculated through a multinomial logit model:

$$P_{kp} = \frac{e^{-\beta . GTC_{kp}}}{\sum_{p=1}^{P} e^{-\beta . GTC_{kp}}}$$

Given the numerical results of the generalized transportation cost (GTC) per path available in Scenario 1 for all the sets, the estimation of the β parameter was accomplished with the help of the Solver tool from MS Excel. The procedure was to vary the value of the parameter with the objective function of obtaining the smallest average error of modal split. The error of the modal split was obtained with the comparison between the known modal split of each country – from INE data – and the calculated modal split obtained with the logistic regression. In Table 5.4.1, the values of actual modal split for each country are shown.

Table 5.4.1: Actual modal split per country studied.

Country	Road Cargo Volume [t]	Maritime Cargo Volume [t]	Road Share	Maritime Share
IT	499,000	247,593	67%	33%
NL	555,000	534,854	51%	49%
ES	10,017,000	637,773	94%	6%
FR	2,181,000	104,440	95%	5%
DE	784,000	307,431	72%	28%
BE	295,000	270,251	52%	48%
DK	124,280	19,314	87%	13%
AT	38,817	17,963	68%	32%
CH	73,323	12,943	85%	15%
UK	571,511	646,353	47%	53%
CZ	54,948	2,662	95%	5%
LU	45,267	2,072	96%	4%

As it can be seen from the table, the range of modal splits vary substantially between the countries, with maritime share reaching from 53% in the UK to as low as 4% in Luxembourg. Taking in consideration the different modal shares for the various countries under study, it was considered to be prudent to use two different values of β: one for countries with more than 70% of road share and another value for countries with less than 70% of road share. Using only one β would decrease the accuracy of the estimations as it would be considered that the modal splits in all the 12 countries are determined by the exact same exponential factor. Dividing the countries in two groups with more similar results raises the potential accuracy of the model. In fact, maximum accuracy would be reached if each one of the countries was assigned with a β value of their own. However, the numerical effort to determine the value that would represent each country the best would be higher and the proposal of producing a modular model that could be replicated in other studies would be lost.

Said so, Table 5.4.2 shows the results of the converged values of β and the average absolute error when the modal split estimated was compared with the values of the actual modal split.

Table 5.4.2: Comparison of parameters between the two VoTs.

Parameter	VoT = 6.82 EUR/h	VoT = 20.8 EUR/h
β_1 (Road Share < 70%)	0.000858	0.000383
β_2 (Road Share > 70%)	0.003308	0.001002
Average Abs. Error	7.52 %	8.28 %

These values of β were found to be the ones that produced the minimum average error between the actual modal split and the estimated one. It was chosen to use the average of the absolute differences in modal split as the variable to be minimized in order to attribute to all of the countries the same degree of importance. If, for example, the objective function was to obtain the minimum difference in volume of cargo (tons), the Solver would likely find values for β that would prioritize countries that have the highest share of cargo demand – Spain, in this case. That way, the solution would be parameters that produce good fit to the most relevant countries in volume and poor fit to the other ones, generating extreme values of difference of modal split in percentage.

Regarding the results for the two values of time, despite presenting a slightly difference in the average error, the results for the VoT = 6.82 EUR/h shows a more accurate regression (by 0.76%) when this value is considered for the calculation of the GTC. The fact that such different values of time produced such a small difference in the average error is caused by the fact that the MS Solver tool was able to level the difference in VoT by reducing the values of β for VoT=20.8 EUR/h, which ends up leading to a similar exponential distribution and, therefore, similar modal splits per country and average error. Despite these considerations, it is inevitable that the generalized transportation costs obtained with the VoT of 6.82 EUR/h produced a better fit with the actual data. As indicated in Chapter 4.3, the VoT that is able to produce the smallest average difference will be the chosen to proceed with in further calculations and, therefore, from now on only the results for VoT = 6.82 EUR/h are regarded.

With all the above considered, the results of modal split for Scenario 1 (VoT = 6.82 EUR/h) and the absolute difference of values obtained are shown in the Table 5.4.3.

Table 5.4.3: Results and comparison of modal splits obtained in Scenario 1.

Country	Actual Cargo Volume			Calculated Cargo Volume			Comparison
	Road [t]	Maritime [t]	Road Share	Road [t]	Maritime [t]	Road Share	Difference
IT	499,000	247,593	66.8%	524,532	222,062	70.3%	3.4%
NL	555,000	534,854	50.9%	496,239	593,615	45.5%	5.4%
ES	10,017,000	637,773	94.0%	10,478,075	176,698	98.3%	4.3%
FR	2,181,000	104,440	95.4%	2,201,927	83,516	96.3%	0.9%
DE	784,000	307,431	71.8%	876,215	215,217	80.3%	8.4%
BE	295,000	270,251	52.2%	291,367	273,883	51.5%	0.6%
DK	124,280	19,314	86.5%	113,254	30,340	78.9%	7.7%
AT	38,817	17,963	68.4%	28,628	28,151	50.4%	17.9%
CH	73,323	12,943	85.0%	84,107	2,160	97.5%	12.5%
UK	571,511	646,353	46.9%	631,989	341,390	64.9%	18.0%
CZ	54,948	2,662	95.4%	53,629	3,981	93.1%	2.3%
LU	45,267	2,072	95.6%	41,139	6,200	86.9%	8.7%

From the data shown in Table 5.4.3, it can be seen that for some countries the road share of the modal split is overestimated (Italy, Spain, France, Germany, Switzerland and UK), while it is underestimated for the others. The average difference of obtained was 7.52%, with maximum difference of 18% in the UK (and 17.9% in Austria) and minimum difference of 0.6% in Belgium. The bar charts below provide a visual perspective of the accuracy of the model by comparing the road and maritime shares estimated in Scenario 1 with the actual share. It is reminded here that Road % + Maritime % = 100%, therefore the difference in percentage seen in Figure 5.4.1 is the same as in Figure 5.4.2.

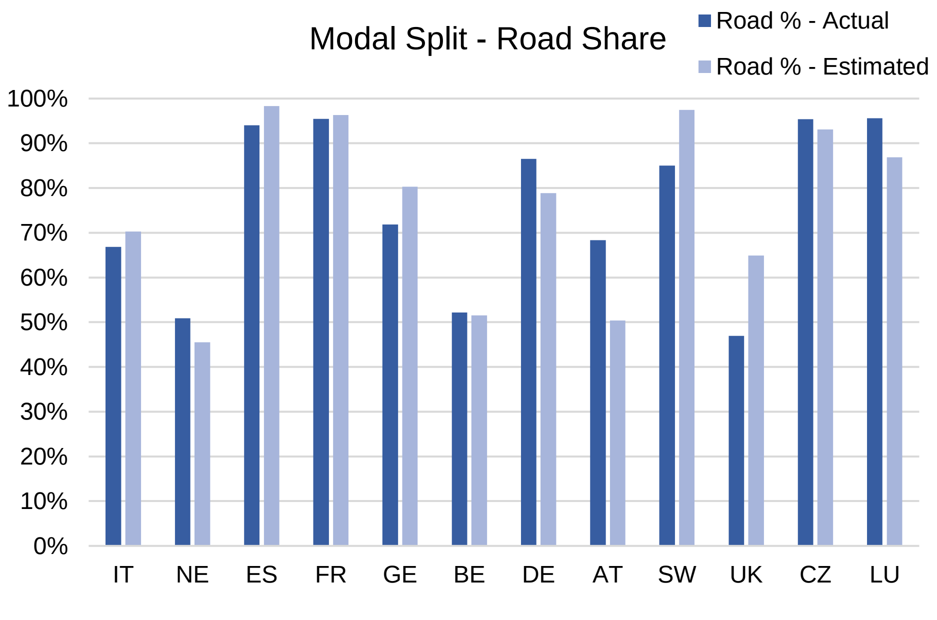

Figure 5.4.1: Comparison between actual road share and estimated in scenario 1.

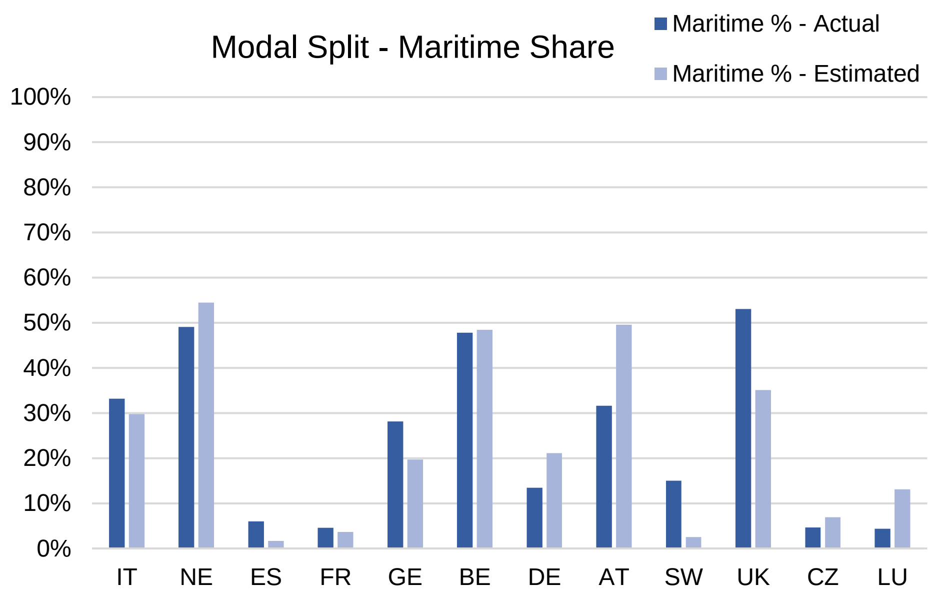

Figure 5.4.2: Comparison between actual maritime share and estimated in scenario 1.

It is important to mention at this point that the fact that UK, Austria and Switzerland were the countries with the highest differences between the estimations in Scenario 1 and the actual values does not mean that the transportation network for these countries in Scenario 1 does not represent them as accurately as for the other countries. Actually, the fact that the MS Solver pursuits values for β that can represent the behavior of several countries - which is, by principle, impossible -, it becomes inevitable that some will be assigned with highest errors than others, which only means that those countries are not as close to be represented by this value of β as the other ones are. Yet, the most appropriate way to calibrate the multinomial logit model still is to use as objective function the minimization of the average error, making it necessary to deal with higher differences for a few countries.

With the considerations made and the appropriate values of β determined, the software performed the calculations of GTC for Scenario 2 and, again, the multinomial logit was used to calculate the modal split, now with the updated transportation chains of the new scenario. As per Chapter 4.2, the objective of Scenario 2 is to study an expanded range of intermodal chains that are not present in the current transportation chains. By comparing the results of modal split from Scenario 2 with Scenario 1, it is possible to evaluate the potential of modal shift from road to SSS.

Table 5.4.4 shows the comparison of the modal split between scenarios 1 and 2. The difference between modal splits is the modal shift.

Table 5.4.4: Potential modal shift from scenario 1 to scenario 2.

Country	Scenario 1 - Cargo Volume			Scenario 2 - Cargo Volume			Modal Shift
	Road [t]	Maritime [t]	Road Share	Road [t]	Maritime [t]	Road Share	
IT	524,532	222,062	70.3%	237,153	509,441	31.8%	38.5%
NL	496,239	593,615	45.5%	294,930	794,924	27.1%	18.5%
ES	10,478,075	176,698	98.3%	10,478,075	176,698	98.3%	0.0%
FR	2,201,927	83,516	96.3%	1,994,899	290,544	87.3%	9.1%
DE	876,215	215,217	80.3%	720,211	371,221	66.0%	14.3%
BE	291,367	273,883	51.5%	154,062	411,188	27.3%	24.3%
DK	113,254	30,340	78.9%	102,207	41,387	71.2%	7.7%
AT	28,628	28,151	50.4%	32,230	24,549	56.8%	-6.3%
CH	84,107	2,160	97.5%	80,452	5,815	93.3%	4.2%
UK	631,989	341,390	64.9%	499,368	474,011	51.3%	13.6%
CZ	53,629	3,981	93.1%	51,202	6,408	88.9%	4.2%
LU	41,139	6,200	86.9%	34,829	12,510	73.6%	13.3%

Before engaging in the analysis of the results, an observation must be done regarding the case of Spain. As it can be seen in Table 5.4.4, the numerical results regarding the scenarios are identical for this country. The reason for this is that Spain is the only country for which the transportation chains are the same for both scenarios 1 and 2 (see Table 4.2.2), given that, besides the conventional road transportation, the existence of a liner service that connect Leixões to southern and northern destinations in Spain is already considered in scenario 1 and no additional connection would be as relevant to be included in the second scenario.

The results displayed in Table 5.4.4 allow several conclusions to be highlighted regarding the potential of a modal shift from road to SSS. At first, it can be seen that the range of percentages of the market that can be converted to maritime transportation varies a lot between the countries, going through as high as 38.5% in Italy to -6.3% in Austria. The bar charts in Figures 5.4.3 and 5.4.4 show how substantial the increase of the maritime can be considering these data.

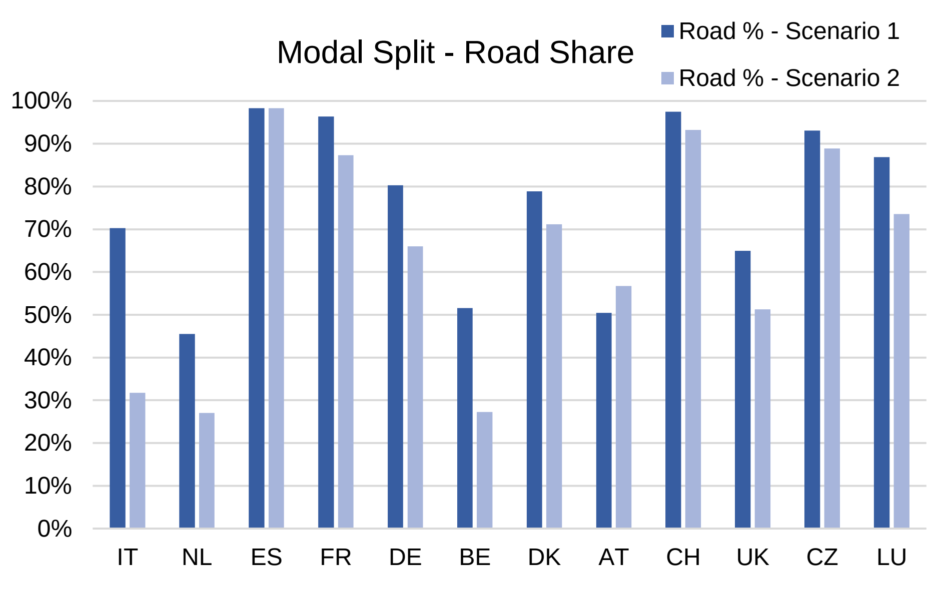

Figure 5.4.3: Comparison between road shares estimated in scenario 1 and 2.

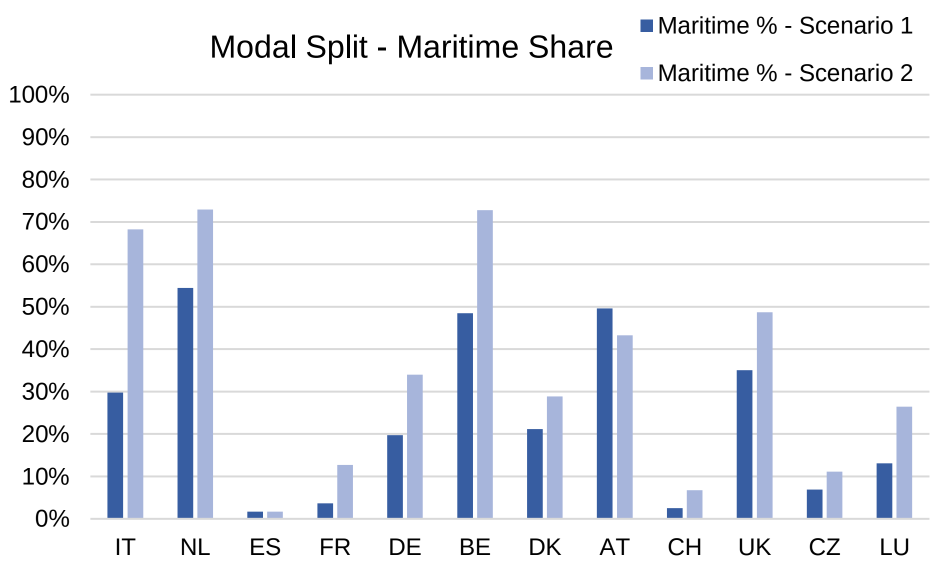

Figure 5.4.4: Comparison between maritime shares estimated in scenario 1 and 2.

The Italian case is a promising example where the relation between competitivity of SSS and offer of SSS services can be verified. The additional four paths that are included in scenario 2 increase the market share of maritime transportation from 29.7% to 68.2%, which is more than doubling the role that short sea shipping plays in the exportation market from Portugal to this country. In the second scenario, Italy becomes well provided with new competitive chains that connect Leixões to both northern and southern regions in the country.

The Italian case represents a combination of two factors that together can increase substantially the participation of maritime transportation. The first of them is a current underused potential of the modal, which, in the Italian case, currently holds only 33.2% of the cargo analyzed in this thesis (Table 5.4.3), even though the country is a peninsula in the center of the Mediterranean Sea. The second factor is the dispersion and availability of ports connected in the intra-European transportation network, which, in scenario 2, covers the northern regions of Italy with the ports of Genova and Livorno and southern regions with the ports of Napoli and Salerno. This availability of ports reduces the potential road connection that must be performed from the port until the final destination, which can reduce a relevant portion of costs and time.

In fact, a geographical pattern can be noticed regarding the potential of modal shifts for the countries analyzed. Figure 5.4.5 below allows visualizing this pattern. In the image, a color map of the modal shift potential is presented for the countries studied. As a general pattern, it is possible to see that, the more continental in the European continent a country is, the smallest the potential for modal shift to maritime transportation. That is because, in these countries, even though additional transportation chains can slightly increase the competitiveness of the intermodality, the obligation to connect by road a port considerably distant from the destination is still substantially relevant in the final composition of the GTC, which will account for the additional cost with the road connection to the destination and the time that it will take. Therefore, it is not expectable to verify outstanding numbers pointing to a tendence of movement towards short sea shipping in these countries.

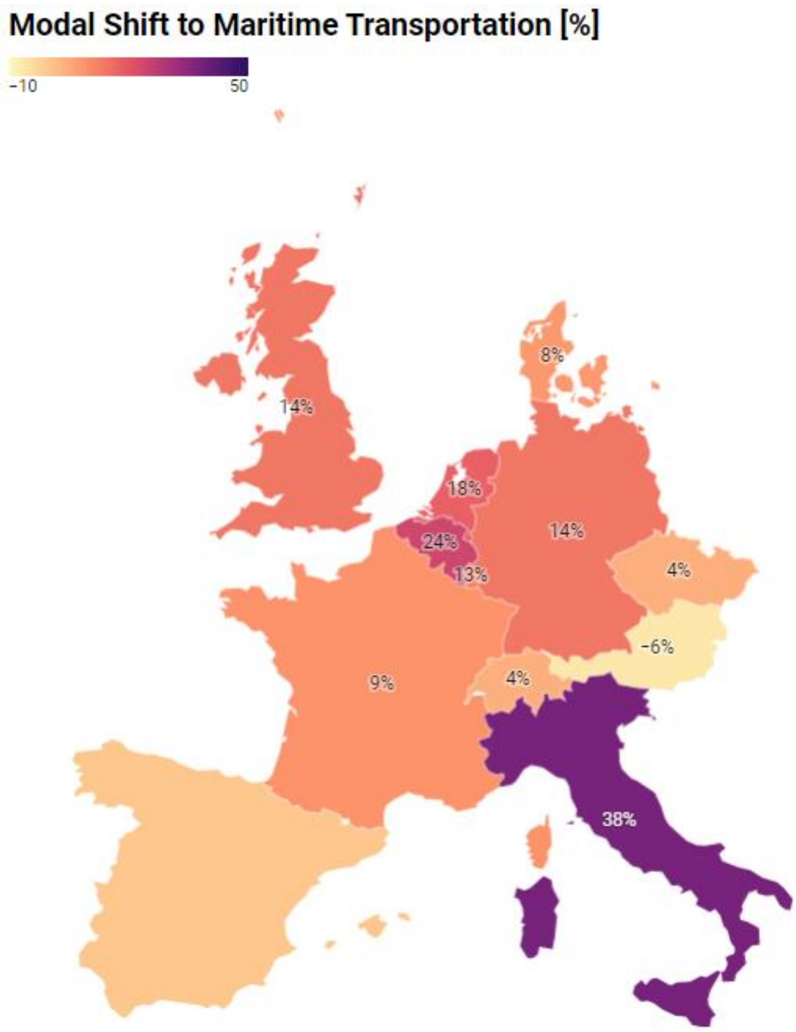

Figure 5.4.5: Map representing the potential for modal shift to maritime transportation.

That is part of the reason why, in Austria, there is actually a modal shift from SSS to road transportation. In the Austrian case, from scenario 1 to scenario 2 there is an addition of an intermodal road-rail chain (path 07) and three intermodal maritime chain (paths 24, 25 and 26). The fact is that the new SSS chains end up not being cost and time competitive because of the long maritime links and long road connections until the destination, while the new road path provides cost and time effective transportation, therefore accounting with a more competitive generalized transportation cost leading to an expansion of the road share of transportation from Portugal to Austria.

On the other hand, the countries with coastlines, which are already more likely to trade using higher portions of maritime transportation, become even more encouraged to do so with the availability of additional liner services connecting them to Portugal. Besides the Italian case, Belgium, the Netherlands and the UK present promising potential for increasing their market share of transportation to SSS, not only because of the cost competitiveness of the new services, but also because of the short distance between port and destinations that must be performed by road. Even Luxembourg, which does not have an exit to the sea itself, benefits from its short distance to countries that do have such exit (port), especially the Netherlands with the port of Rotterdam and Germany with Hamburg.

Another factor to take into account is the distance between Porto and the final destination. The arguments exposed in Chapter 4.3 regarding the specific costs of transportation and the advantage of road transportation over other alternatives for short distances are always relevant and they limit, for example, the potential of modal shift in France to 9%, i.e., even though additional transportation chains can slightly increase the competitiveness of intermodality, the relative lower cost and higher speed of road transportation for such distance is still relevant, which benefits the generalized transportation cost for road transportation.

Finally, it becomes clear from the results here presented that, even though short sea shipping is already one of the main transport modes to haul cargo in intra-European trade, there is clearly room for raising its market share presence. Despite obtaining an average of 12.9% for modal shifts between scenarios, some countries are privileged by their geographical conditioning and their possibility to be more easily integrated in intermodal transportation chains. The potential of each country is, however, determined by factors that are subjected to changes over time, such as specific cost of transportation - which depends on a series of factors, such as fuel price -, time dwells in intermodal terminals, as well as handling charges. That is the reason why this thesis models the problem in a parametric way and constantly subjected to updates according with market variations.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Concluding remarks

This thesis has presented a literature review covering the role of short sea shipping in the European continent and applications of gravity models and logistic regression in maritime transportation problems. Methodologies were presented for estimating demand for cargo transport to NUTS 2 regions of Western Europe countries and for determining the modal split in two different scenarios with the assistance of a numerical tool used to determine the generalized transportation cost in the transportation network. The final objective was to analyze the potential of modal shift from road transportation to short sea shipping (SSS) in a scenario where new supply chains are considered.

Regarding the freight disaggregation, the gravity model based on the GDP of the NUTS 2 regions presented itself as a reliable tool to predict the demand for cargo transportation in the intra-European level of NUTS 2 regions, showing statistically reasonable results. Therefore, the positive results obtained in this thesis can serve as an additional confirmation of the reliability of using the GDP model to disaggregate cargo, which is already a consolidated methodology in the literature to predict trade between bodies with economic activity.

Moreover, even though the focus of this thesis is to present the cargo distribution over different modes of transportation using the generalized transportation costs (GTC), the results for the geographical scopes of competitiveness based on the internal costs of transportation already show how the introduction of new intermodal chains reduces costs of maritime transportation of cargo. In the second scenario, it was possible to see that the geographical scope of attractiveness of SSS increased with the inclusion of ports that were not available in the first scenario and with the improvement of performance of those chains linked with ports that were already present in scenario 1.

The modal split fit that resulted from the application of logistic regression in scenario 1 is very promising. A 7.52% difference between the actual modal split and the estimated one shows not only that the cost and time parameters input in the numerical software in order to calculate the GTC for every path were well estimated, but also that the cargo disaggregation was adequately performed. Based in this fact, it can be stated that the sequence of procedures here executed provides fair results for estimating splits of cargo over transport chains by performing logistic regression, and could potentially be replicated in other studies.

Furthermore, increasing the available transport chains with intermodal chains that are currently not available as regular services was shown to be especially advantageous regarding modal shifts to SSS for coastal, farthest from Portugal countries, with Italy reaching up to 38% potential modal shift and countries in the Northern Sea reaching from 8 to 24%. These countries benefit from the geographical factors that generally make maritime transportation more competitive when compared to road haulage. Extensive travel and dwell times, increases in cargo handling costs and long final road connections make maritime intermodal chains less attractive for continental countries if the generalized transportation cost is the only factor to be considered as decision parameter. Overall, new intermodal transport chains based on short sea shipping show a good potential to support Portuguese foreign trade as they contribute to lower generalized transport costs, making exports more competitive.

It is interesting to verify that a proper allocation of resources dedicated to introducing some new intermodal chains using the transportation network could produce relevant results for this industry in Europe. However, introducing new regular services demands time, planning and investment, and upgrading the transportation network in the magnitude required under scenario 2 can be unrealistic in a short period of time. It would be possible, however, to prioritize the intermodal chains that would produce the most promising results for modal shift. In other words, investing time and resources on new chains covering Switzerland would not lead to the same benefits as doing such for Italy and, therefore, in a context of limited resources, should be put behind in the line of priority.

With that considered, a reasonable line of thought would be, for the competent bodies such as the European Commission, to promote funding projects – a variation of the Marco Polo Program, for example – that would support the development of appropriate updates in the transportation network. Such program would have the potential of increasing trade competitiveness, alleviating congestion in links of land transportation and reducing emissions of greenhouse gases and air pollutants. In fact, this last point is what has kept public bodies interested in developing policies to support the development of short sea shipping. The results presented in this thesis provide additional motivation to keep on doing so.

6.2 Recommendations for further work

There are a few suggestions that can be done for extensions of the research presented in this thesis as further work. First, it would be interesting to consider the rail mode of transportation as a separate mode to be evaluated beyond the scope of the road and maritime modes. Regarding the rail as a separate mode could lead to relevant results, expanding the work to an assessment of the potential of rail and short sea shipping on promoting modal shifts from road transportation by applying a multinomial logistic regression. Also, as it was presented, the modal split is defined by the calculation of probabilities of usage of available paths in the transportation network by performing a logistic regression. The decision variable – or attribute in the utility – used in this thesis was the generalized transportation count because of its capability of merging internal costs and time results in a single variable. It would be interesting to study more extensively, though, how the consideration of external costs of transportation would modify the results presented in the case of internalization. With demands for internalization of external costs arising in discussions around transportation, the accountability of externalities in the methodology of this research can allow further conclusions to be taken.

Besides that, the main subject of this thesis was to analyze how the introduction of new intermodal chains would increase the market share of short sea shipping in the intra-European transportation industry. It was not in the scope of this thesis, however, the task of estimating financially the investment that would be required to introduce each one of the intermodal paths. A further analysis on the financial feasibility of transport chains would allow conclusions to be drawn regarding the financial viability of adding a new regular service, how advantageous it would be to add it, if the investment would be worth it and which ports and ships should be used.

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ANNEX 1

Table A1.1: Data used in the calibration of the gravity models.

NUTS 2 Region	GDP (2010)	Population (2010)	Road Distance from Porto	Cargo Demand (2010)
	[Mill. EUR]	[Habitants]	[km]	%
ES	**1,001,309**	**43,716,339**	**-**	**100%**
ES11	56,767	2,702,592	231	11%
ES12	22,734	1,018,899	525	3%
ES13	12,837	582,388	640	1%
ES21	64,681	2,189,138	709	5%
ES22	17,934	656,509	761	1%
ES23	7,998	315,931	684	0%
ES24	33,829	1,330,333	850	2%
ES30	197,145	6,747,068	563	17%
ES41	54,970	2,401,307	405	8%
ES42	38,706	2,045,554	629	5%
ES43	18,136	1,061,979	418	5%
ES51	201,706	7,652,348	1,150	13%
ES52	101,201	5,029,341	913	7%
ES61	144,752	8,478,083	581	20%
ES62	27,913	1,504,869	961	2%
FR	**2,585,232**	**82,185,561**	**-**	**100%**
FR10	605,403	12,291,557	1,581	16%
FRB0	66,237	2,565,726	1,456	5%
FRC1	41,986	1,618,321	1,637	3%
FRC2	28,539	1,176,196	1,697	2%
FRD1	36,533	1,463,606	1,603	2%
FRD2	50,408	1,849,826	1,666	3%
FRE1	100,514	4,061,166	1,806	4%
FRE2	45,198	1,926,629	1,718	3%
FRF1	52,691	1,908,494	1,942	3%
FRF2	35,481	1,311,830	1,773	3%
FRF3	54,957	2,315,678	1,925	4%
FRG0	95,642	3,818,421	1,364	7%
FRH0	80,679	3,358,524	1,471	5%
FRI1	88,213	3,478,538	996	6%
FRI2	16,833	726,253	1,228	2%
FRI3	43,231	1,813,633	1,253	4%
FRJ1	63,157	2,864,782	1,339	3%
FRJ2	77,062	3,087,068	1,108	5%
FRK1	32,013	1,371,820	1,375	2%
FRK2	192,360	6,692,326	1,550	10%
FRL0	143,052	5,077,582	1,507	5%

NL	**635,043**	**17,407,585**	**-**	**100%**
NL11	25,095	585,866	2,229	5%
NL12	17,573	649,957	2,198	10%
NL13	13,538	493,682	2,207	4%
NL21	35,609	1,162,406	2,127	8%
NL22	64,062	2,085,952	2,089	11%
NL23	11,488	423,021	2,103	3%
NL31	59,306	1,319,231	2,050	9%
NL32	129,225	2,879,527	2,097	14%
NL33	140,675	3,744,299	2,051	15%
NL34	11,505	383,488	1,939	4%
NL41	91,266	2,562,955	2,024	12%
NL42	35,701	1,117,201	1,977	7%
DE	**2,564,400**	**83,166,711**	**-**	**100%**
DE11	160,271	4,154,223	2,070	6%
DE12	97,379	2,810,854	2,005	3%
DE13	65,611	2,271,351	1,882	3%
DE14	59,635	1,863,966	2,042	4%
DE21	195,130	4,710,865	2,288	4%
DE22	36,652	1,244,169	2,337	2%
DE23	34,602	1,112,102	2,339	2%
DE24	30,812	1,065,371	2,323	2%
DE25	58,315	1,775,169	2,331	2%
DE26	41,373	1,317,619	2,189	2%
DE27	55,243	1,899,442	2,224	3%
DE30	103,052	3,669,491	2,626	2%
DE40	55,770	2,521,893	2,596	4%
DE50	26,358	681,202	2,369	1%
DE60	93,643	1,847,253	2,486	3%
DE71	162,968	4,019,961	2,131	4%
DE72	28,420	1,048,646	2,200	2%
DE73	35,315	1,219,473	2,331	2%
DE80	34,651	1,608,138	2,588	2%
DE91	56,338	1,594,929	2,407	2%
DE92	65,460	2,148,238	2,345	3%
DE93	35,995	1,716,448	2,463	2%
DE94	67,967	2,533,993	2,356	2%
DEA1	176,391	5,207,457	2,071	5%
DEA2	146,643	4,478,847	2,073	4%
DEA3	70,469	2,624,625	2,203	3%
DEA4	59,844	2,055,724	2,247	2%
DEA5	100,866	3,580,568	2,148	4%
DEB1	38,776	1,498,223	2,115	2%
DEB2	12,623	533,113	1,991	1%
DEB3	61,075	2,062,567	2,107	3%

DEC0	30,049	986,887	1,966	2%
DED2	37,722	1,596,566	2,598	1%
DED4	33,039	1,426,380	2,532	1%
DED5	24,057	1,049,025	2,529	1%
DEE0	51,120	2,194,782	2,515	3%
DEF0	72,935	2,903,773	2,627	3%
DEG0	47,829	2,133,378	2,395	2%
IT	**1,939,982**	**69,552,307**	**68,714**	**100%**
ITC1	124,551	4,311,217	1,873	6%
ITC2	4,738	125,034	1,841	0%
ITC3	46,095	1,524,826	1,860	3%
ITC4	349,558	10,027,602	2,010	18%
ITH1	20,012	532,644	2,240	3%
ITH2	18,381	545,425	2,190	2%
ITH3	143,257	4,879,133	2,229	8%
ITH4	34,916	1,206,216	2,379	4%
ITH5	137,950	4,464,119	2,135	7%
ITI1	105,270	3,692,555	2,086	8%
ITI2	22,180	870,165	2,237	2%
ITI3	39,430	1,512,672	2,349	3%
ITI4	187,670	5,755,700	2,367	7%
ITF1	30,811	1,293,941	2,433	3%
ITF2	6,688	300,516	3,334	1%
ITF3	102,910	5,712,143	2,548	7%
ITF4	70,182	3,953,305	2,756	5%
ITF5	11,193	553,254	2,692	1%
ITF6	33,038	1,894,110	2,945	3%
ITG1	88,256	4,875,290	3,257	5%
BE	**362,896**	**11,522,440**	**20,953**	**100%**
BE10	69,086	1,223,364	1,888	11%
BE21	68,035	1,873,095	1,937	14%
BE22	22,464	880,602	1,961	10%
BE23	43,036	1,526,486	1,895	10%
BE24	38,075	1,156,470	1,911	12%
BE25	36,532	1,202,352	1,876	10%
BE31	14,601	406,794	1,891	5%
BE32	28,122	1,350,295	1,834	10%
BE33	25,943	1,113,943	1,953	9%
BE34	5,873	289,606	1,912	4%
BE35	11,129	499,433	1,895	5%

Table A1.2: GDP data from 2020 applied in the gravity model and disaggregation results.

NUTS	GDP (2020) [Mill. EUR]	Cargo Share %	Cargo Volume [t]	NUTS	GDP (2020) [Mill. EUR]	Cargo Share %	Cargo Volume [t]
ES	**1,051,728**	**100%**	**10,654,773**	**DE**	**3,367,560**	**100%**	**1,091,431**
ES11	59,106	5%	572,981	DE11	215,437	5%	51,012
ES12	21,474	2%	193,220	DE12	123,717	3%	36,705
ES13	12,867	1%	111,487	DE13	86,682	3%	29,719
ES21	66,558	6%	650,898	DE14	80,708	3%	28,486
ES22	19,265	2%	171,958	DE21	273,501	5%	58,773
ES23	8,129	1%	68,091	DE22	48,482	2%	21,051
ES24	35,290	3%	329,360	DE23	46,407	2%	20,512
ES30	216,528	22%	2,309,670	DE24	40,737	2%	18,986
ES41	55,402	5%	534,521	DE25	79,555	3%	28,244
ES42	39,572	3%	372,455	DE26	53,067	2%	22,211
ES43	19,385	2%	173,113	DE27	74,763	2%	27,222
ES51	212,931	21%	2,268,505	DE30	155,172	4%	41,986
ES52	104,724	10%	1,058,894	DE40	74,917	2%	27,255
ES61	150,557	15%	1,563,559	DE50	31,928	2%	16,430
ES62	29,940	3%	276,061	DE60	119,142	3%	35,893
FR	**2,257,375**	**100%**	**2,285,440**	DE71	203,858	5%	49,367
FR10	710,091	17%	377,734	DE72	36,122	2%	17,678
FRB0	71,573	4%	94,048	DE73	44,269	2%	19,946
FRC1	45,362	3%	71,342	DE80	46,585	2%	20,559
FRC2	30,195	2%	55,750	DE91	75,522	3%	27,385
FRD1	38,746	3%	64,842	DE92	84,487	3%	29,270
FRD2	51,353	3%	76,910	DE93	49,233	2%	21,245
FRE1	113,778	5%	124,545	DE94	90,853	3%	30,560
FRE2	47,852	3%	73,689	DEA1	217,053	5%	51,239
FRF1	59,579	4%	84,156	DEA2	193,315	4%	47,836
FRF2	36,659	3%	62,703	DEA3	89,380	3%	30,265
FRF3	56,552	4%	81,538	DEA4	78,673	3%	28,058
FRG0	116,153	6%	126,114	DEA5	125,486	3%	37,015
FRH0	99,654	5%	114,934	DEB1	50,571	2%	21,585
FRI1	103,979	5%	117,930	DEB2	16,304	1%	11,026
FRI2	18,085	2%	40,865	DEB3	76,692	3%	27,636
FRI3	50,039	3%	75,712	DEC0	33,949	2%	17,039
FRJ1	74,008	4%	95,974	DED2	50,634	2%	21,601
FRJ2	94,727	5%	111,457	DED4	41,277	2%	19,135
FRK1	37,176	3%	63,238	DED5	34,966	2%	17,340
FRK2	231,701	8%	191,635	DEE0	63,539	2%	24,717

FRL0	161,290	7%	153,870	DEF0	98,358	3%	32,034
FRM0	8,825	1%	26,457	DEG0	62,220	2%	24,411
UK	**2,170,288**	**100%**	**1,217,864**	**IT**	**1,652,677**	**100%**	**746,593**
UKC1	26,732	2%	19,676	ITC1	126,199	7%	55,218
UKC2	37,528	2%	24,744	ITC2	4,519	1%	4,672
UKD1	13,963	1%	12,688	ITC3	46,093	4%	26,160
UKD3	84,103	4%	42,679	ITC4	365,515	16%	121,519
UKD4	39,385	2%	25,564	ITH1	23,722	2%	15,983
UKD6	36,658	2%	24,355	ITH2	20,042	2%	14,104
UKD7	38,734	2%	25,278	ITH3	151,910	8%	63,359
UKE1	24,380	2%	18,489	ITH4	36,880	3%	22,172
UKE2	24,533	2%	18,568	ITH5	149,361	8%	62,569
UKE3	32,372	2%	22,393	ITI1	111,307	7%	50,307
UKE4	65,462	3%	36,033	ITI2	21,448	2%	14,832
UKF1	58,110	3%	33,247	ITI3	39,664	3%	23,401
UKF2	53,560	3%	31,465	ITI4	186,298	10%	73,713
UKF3	18,185	1%	15,167	ITF1	30,891	3%	19,441
UKG1	43,885	2%	27,503	ITF2	6,088	1%	5,828
UKG2	41,226	2%	26,366	ITF3	102,834	6%	47,438
UKG3	78,513	3%	40,741	ITF4	71,643	5%	36,283
UKH1	74,490	3%	39,319	ITF5	11,644	1%	9,428
UKH2	65,749	3%	36,139	ITF6	30,903	3%	19,446
UKH3	50,724	2%	30,329	ITG1	83,335	5%	40,588
UKI3	214,064	7%	80,223	ITG2	32,382	3%	20,133
UKI4	120,756	4%	54,492	**BE**	**456,587**	**100%**	**565,251**
UKI5	46,346	2%	28,535	BE10	83,847	14%	76,710
UKI6	38,910	2%	25,356	BE21	88,189	14%	78,661
UKI7	83,577	3%	42,498	BE22	28,073	8%	44,519
UKJ1	109,054	4%	50,867	BE23	54,758	11%	62,064
UKJ2	98,947	4%	47,632	BE24	49,710	10%	59,149
UKJ3	67,189	3%	36,672	BE25	45,611	10%	56,671
UKJ4	51,912	3%	30,808	BE31	22,200	7%	39,614
UKK1	85,259	4%	43,074	BE32	33,109	9%	48,326
UKK2	35,078	2%	23,641	BE33	30,964	8%	46,742
ULK3	13,314	1%	12,287	BE34	6,946	4%	22,228
UKK4	30,289	2%	21,409	BE35	13,179	5%	30,566
UKL1	43,550	2%	27,361	**DK**	**310,104**	**100%**	**143,594**
UKL2	33,966	2%	23,132	DK01	128,903	36%	51,432
UKM5	19,186	1%	15,727	DK02	31,535	12%	17,754
UKM6	13,602	1%	12,466	DK03	58,012	20%	28,138
UKM7	64,644	3%	35,728	DK04	65,330	21%	30,780
UKM8	69,525	3%	37,529	DK05	26,325	11%	15,490
UKM9	22,828	1%	17,686	**CH**	**622,746**	**100%**	**86,267**
NL	**798,992**	**100%**	**1,089,854**	CH01	115,391	17%	14,941

NL11	23,243	5%	57,466	CH02	122,651	18%	15,548
NL12	20,995	5%	54,494	CH03	90,378	15%	12,738
NL13	15,584	4%	46,642	CH04	136,791	19%	16,696
NL21	45,698	8%	81,789	CH05	73,705	13%	11,151
NL22	82,044	10%	111,015	CH06	57,037	11%	9,433
NL23	14,631	4%	45,130	CH07	26,793	7%	5,760
NL31	76,838	10%	107,280	**AT**	**379,177**	**100%**	**56,780**
NL32	171,053	15%	162,918	AT11	8,922	4%	2,398
NL33	168,986	15%	161,887	AT12	59,525	15%	8,278
NL34	13,995	4%	44,094	AT13	96,594	20%	11,354
NL41	120,733	12%	135,824	AT21	20,697	7%	4,154
NL42	45,192	7%	81,315	AT22	48,593	13%	7,251
				AT31	65,240	15%	8,788
				AT32	27,945	9%	5,053
				AT33	33,455	10%	5,683
				AT34	18,206	7%	3,820
				CZ	**215,248**	**100%**	**57,610**
				CZ01	58,038	40%	23,088
				CZ02	25,049	10%	5,752
				CZ03	20,977	7%	4,290
				CZ04	15,197	4%	2,517
				CZ05	25,458	10%	5,909
				CZ06	31,789	15%	8,531
				CZ07	19,961	7%	3,951
				CZ08	18,779	6%	3,572
				LU	**64,221**	**100%**	**47,339**
				LU00	64,221	100%	47,339