FUNDAÇÃO
FRANCISCO MANUEL DOS SANTOS

ESTUDOS DA FUNDAÇÃO • 2021

Carlos Oliveira Cruz
Álvaro Costa
Joaquim Miranda Sarmento
Vítor Faria e Sousa
João Fragoso Januário

Transport systems in Portugal

Analysis of efficiency and regional impact

This study aims to provide an analytical perspective on the efficiency of the sector and contribute to the understanding of the dynamics of the efficiency levels, as well as the respective influence of political and economic variables. In this regard, the last two decades provide an interesting academic case study, given the variability of economic dynamics (contraction and growth) and the 2008 financial crisis, along with the Troika intervention. From a policy-making perspective, this was also the period when a number of organizational decisions were made (privatizations, mergers, concessions, etc.). It is an important policy analysis contribution to understanding the impact of such decisions on efficiency levels, both operational and economic. The study also addresses the impact of the transportation system on the economy, particularly on productivity. It aims to grasp the relationship between accessibility and productivity by using a spatial model that accounts for spillover effects.

Transport systems in Portugal

Analysis of efficiency and regional impact

Carlos Oliveira Cruz
Álvaro Costa
Joaquim Miranda Sarmento
Vítor Faria e Sousa
João Fragoso Januário

FUNDAÇÃO
FRANCISCO MANUEL DOS SANTOS

Largo Monterroio Mascarenhas, n.º 1, 7.º piso
1099-081 Lisboa
Tel: 21 001 58 00
ffms@ffms.pt

Director of publications: António Araújo
Director of the Foundation Studies series: Gonçalo Saraiva Matias
Title: Transport systems in Portugal: Analysis of efficiency and regional impact
Authors: Carlos Oliveira Cruz, Álvaro Costa, Joaquim Miranda Sarmento,
Vítor Faria e Sousa and João Fragoso Januário
Proofreading: Rita Matos
Design: Inês Sena
Typesetting: Guidesign

ISBN: 978-989-9064-29-4

Contents

Acknowledgements

The authors would like to thank the Francisco Manuel dos Santos Foundation (FFMS) for the support and promotion of this research work. FFMS plays an invaluable role in encouraging and disseminating science. In particular, we would like to thank Mónica Barreiros, João Gaspar and Fernando Alexandre for their constant support in the management of this project, and the three anonymous referees for their valuable input to the research.

The development of this study relied on active collaboration on the part of several entities. Firstly, we would like to acknowledge the contribution of Infraestruturas de Portugal, whose interest and availability in providing data related to the road and rail network and respective indicators were crucial to the development of this project. Special acknowledgements are due to the President of this institution, António Laranjo, and to the Director of Studies and Innovation, Eduardo Borges Pires.

We would also like to thank António Pires (CARRIS), Manuel Queiró (STCP), Helena Campos (Metropolitano de Lisboa), Cristina Dourado (Fertagus), Cristina Vasconcelos (Metro Transportes do Sul) for providing their management reports.

Finally, a note of appreciation to PhD students and researchers Diana Braga and Lígia Conceição, who supported the project and, in particular, Melissa Gama, who provided invaluable assistance in calculating efficiency indicators, and Marta Martins and Sofia Oliveira, for their assistance with the chapter on accessibility.

Chapter 1
Introduction

1.1. Overview

The transport infrastructure network is a central element of any economic system, and it can be a lever for development and competitiveness. The transport system facilitates labour mobility and employers' access to job exchanges and sources of geographically dispersed raw materials. Conversely, it also ensures the distribution of produced goods and access to geographically distant markets and consumers. The (good) functioning of this system is even more critical in a country like Portugal, whose geographical position is far from Europe's economic-financial centre of gravity and, as such, it needs an effective and efficient system to support export activities.

In addition, mobility is of particular importance as a factor of competitiveness, not only because of its impact on logistic costs, but also on the development and accessibility of populations, with direct effects on their social and economic well-being (López et al., 2008). The recent COVID-19 pandemic, which forced isolation and lockdown, was a demonstration of the impact that the absence of mobility can have on people's well-being and the maintenance of relationships, economic and otherwise, of vital importance to the contemporary way of life.

The functioning of this system is ensured by several layers, from the "hardest" systems, such as roads, railways, bridges and tunnels, which constitute the basic infrastructure systems, to "soft" systems, such as traffic management systems (air, rail or road), that enable circulation to be regulated and bring "order" to movements. In turn, these different layers can be vertically integrated, as is the case with motorways, where a concessionaire manages all services from maintenance of the pavement to assistance or traffic management services; or they can be vertically separated, as in the case of air transport in which airports, airplanes and navigation systems are managed by different companies. They can also be horizontally integrated, for instance in the case of integrated management of road and railway infrastructures; or, most commonly, horizontally separated, with each category of transportation infrastructures managed by different companies and further split by location.

For each of these different configurations of the value chain management model, there are also different models of ownership, management and markets with different natures. From public companies operating in monopolies, to private companies operating in total competition, a multiplicity of models coexist. This makes it difficult to obtain a general perspective of the system (along with a more difficult process of data availability and the collecting of such data). The resources consumed by the transportation system, and their respective outputs, are a vital topic in the discussion of economic competitiveness. An inefficient transport sector translates into higher transportation and logistics costs, and, therefore, it decreases competitiveness. The maximization of this trade-off is the responsibility of the public sector, as is the planning and regulation of the system. In Portugal, the public sector also plays a crucial role in the system operation as the main shareholder of transportation companies (directly, through the central government, as is the case of IP, the national road and railway manager, or indirectly, through the municipalities, as is the case of CARRIS, the bus transportation company owned by the city of Lisbon).

Transportation public policies and, particularly, the choices decision makers have to make (e.g., which projects to build, which lines should be closed/open, how to involve the private sector, among many others) are frequently subjected to intense public debate. This happens for several reasons: i) this sector is capital intensive, and requires significant public investment; ii) the development of transportation projects has pluriannual impacts, and often requires political consensus; iii) transportation infrastructures contribute to shaping the territory, constraining or driving the development and location of economic activities and communities; and iv) transportation systems have a direct and indirect impact on the everyday life of citizens and companies at social, economic and environmental levels.

Unfortunately, this debate often lacks substantial data and analysis that can help foster the evaluation and improvement of the decision-making process. This research project is a first step towards filling that research gap.

1.2. Objectives

The investment and development of the transport infrastructure network in Portugal has varied according to different public policies and strategies. Some examples of these strategies include decisions to increase or decrease investment; to increase or decrease the supply of the system; to grant parts of the system to the private sector or to maintain public management; among others. It is imperative to understand the effects of public policies related to the transport infrastructure sector, but, above all, to establish a culture of evaluation, transparency and reflection on decision options and their effects.

This study aims to provide an analytical perspective on the efficiency of the sector and contribute to the understanding of the dynamics of the efficiency levels, and the respective influence of political and economic variables. In this regard, the last two decades provide an interesting academic case study, given the variability of economic dynamics (contraction and growth) and the 2008 financial crisis, along with the Troika intervention. From a policy-making perspective, this was also the period when a number of organizational decisions were made (privatizations, mergers, concessions, etc.). It is an important policy analysis contribution to understanding the impact of such decisions on efficiency levels, both operational and economic.

It should be noted that this study does not intend to encompass all the aspects of analysis, which are many and varied, but rather to be a concrete step in the evaluation of policies related to transport infrastructure systems. One of the obstacles to the pursuit of this objective has been a lack of structured and transparent information. Therefore, one of our main objectives is to present and disseminate information related to companies, but also related to the impact on the territory, which will enable the development of further studies and/or set a structured information database to be complemented or extended in the future.

This report provides answers to the following research questions that will guide the proposed research:

- How has the efficiency of the various modes of transport evolved?
- What is the impact of policy decisions on the system on your efficiency scores?
- What are the effects of the system on the productivity of the regions?

1.3. Structure

The present report is structured according to seven chapters.

Chapter 1 – Contains a short introduction to the subject and establishes the report's objectives and structure (current chapter).

Chapter 2 – Provides a literature review on the different applications of efficiency analysis as well on the theoretical foundations of the research.

Chapter 3 – Presents five essays on transport infrastructure efficiency, identifying the impact of economic context and political strategies (privatization, merger, etc.) on firms' efficiency.

Chapter 4 – Presents a theoretical discussion on the relationship between government, infrastructure and productivity.

Chapter 5 – Provides an accessibility analysis and theoretical background for accessibility indicators.

Chapter 6 – Contains an essay on the productivity analysis, identifying the impact of regional accessibility on productivity.

Chapter 7 – Presents and discusses the main conclusions.

Chapter 2
Methodological approach for efficiency analysis

2.1. Introduction

There are currently two types of methods used to evaluate the efficiency of organizations with frontier methodologies (deterministic specification), namely, the parametric approach (stochastic frontier analysis), and nonparametric methods, which started with the development of FDH (free disposal hull) and later evolved into DEA (data envelopment analysis) in its several forms.

Since its launch, DEA has become the most frequently used method. The higher number of applications of DEA is mainly related to the difficulty in justifying the shape of the production function. Additionally, it is more reliable and accurate to use a methodology that compares organizations with similar characteristics in relation to what can be produced with the means that they have available without entering into a discussion on the shape of the production function. DEA is also used more often because it is frequent to encounter it in organizations that lack an explicit production function, such as infrastructures, schools, and hospitals, but still need to evaluate their performance in order to improve management decisions.

Emrouznejad and Young (2018) identified 2974 papers in 21 journals in the period of 1978-2016: for the 2015 and 2016 publications, the number of papers on transportation represented the fourth largest group. This corresponds to an extensive list of academic studies which used data envelopment analysis (DEA) to evaluate the efficiency of transportation companies in the different modes of transport and that relate to infrastructure and operators. In public transport operators, DEA has been widely used for evaluating the companies' efficiency.

Table 1, Table 2, Table 3 and Table 4 provide a summary of the existing literature on the following sectors: public transport, roads, air transport and railways.

Table 1 Summary of DEA literature on public transport [adapted from Borger et al. (2002) and Jarboui (2012)]

Author(s)	Data type	Sample size	Country	Function	Inputs	Outputs
Agarwal et al. (2011)	cross-section	35 (private) state transport undertakings (STUs); 2004–2005	India	DEA	vehicles staff fuel accidents per km	vehicle-km passenger-km load factor
Barnum et al. (2011)	panel	52 (private) transit agencies 2002-2006	USA	DEA	total operating expenses	estimated seat-hours
Boame (2004)	panel	30 transit systems 1990–1999	Canada	DEA	vehicles fuel staff	revenue vehicle-km
De Borger et al. (2008)	cross-section	154 (public/private) Norwegian, 55 French bus operators, 1991	Norway, France	DEA	fuel staff other costs	seat-km
Button and Costa (1999)	panel	nine bus companies 1985 – 93	Italy	DEA	vehicles staff	vehicle-km (Seat-km)
Chang and Kao (1992)	time series;	one bus companies 1956-88;	Taiwan;	DEA,	vehicles staff fuel;	vehicle-km vehicle-km revenue bus trips revenue
	panel	five bus companies 1970-88	Taiwan	DEA	vehicles staff fuel	vehicle-km vehicle-km revenue bus trips revenue
Chu et al. (1992)	cross-section	86 bus companies 1986	USA	DEA	vehicle operating expenses maintenance expenses general/administration expenses other expenses revenue vehicle hours population density % of households without car subsidy passenger	revenue vehicle-hours unlinked passengers trips
Costa and Markellos (1997)	time series	London Metro 1970-94	UK	DEA	vehicles staff	vehicle-km
Costa (1998)	time series	one underground company Madrid 1981-92	Spain	DEA	staff vehicles energy network route length	vehicle-km passengers

Author(s)	Data type	Sample size	Country	Function	Inputs	Outputs
Cowie (2002)	panel	58 companies (private/public) 1990–1997	Brittany	DEA	staff vehicles	vehicle-km
Cowie and Asenova (1999)	cross-section	141 urban transit systems 1995-96	UK	DEA vehicles 35 seats vehicles <35 seats	staff	operating revenue
Hirschhausen and Cullmann (2010)	panel	127 to 179 bus companies 1990-2004	Germany		staff vehicles	seat-km bus-km
Holvad et al. (2004)	cross-section	154 bus companies (public/ private) 1991	Norway	DEA, MEA	fuel driver costs other costs	seat-km
Gathon (1989)	cross-section	60 urban transit systems 1984	Europe	FDH	staff seats	seat-km
Karlaftis (2004)	panel	259 systems (private/public) 1990-94	USA	DEA	staff fuel vehicles	vehicle-miles annual ridership
Kerstens (1996, 1999)	cross-section	114 bus companies 1990	France	DEA a,b FDH a	vehicles staff energy	vehicle-km (seat-km)
Kumar (2011)	cross-section	31 (private) state road transport undertakings 2006-2007	DEA	India	vehicles staff fuel and lubricants	revenue bus-day passenger-km
Levaggi (1994)	cross-section	55 bus companies 1989	Italy	DEA	load staff costs fuel costs other variable costs route length population density vehicles same without load	passenger-km load
Loizides and Giahalis (1995)	time series (yearly)	one regional bus company 1971-89	Greece	DEA	staff capital and other services	passenger-km
Margari et al. (2007)	panel	42 public companies 1993–1999	Italy	DEA, SFA	staff fuel total operating expenditure (costs of staff and fuel)	vehicle-km seat-km

Author(s)	Data type	Sample size	Country	Function	Inputs	Outputs
Nolan (1996)	panel	25 bus companies 1989-93	USA	DEA	staff fuel vehicles	vehicle-km
Nolan et al. (2002)	panel	20 bus companies 1990-95	USA	DEA	staff fuel vehicles input efficiency score	vehicle revenue miles vehicle-miles non-diesel fuel staff safety incidents route miles
Nollet et al. (1988)	time series (monthly)	1977-98	Belgium	FDH	staff energy seats	seat-km
Obeng (1994)	cross-section	73 bus companies 1988	USA	DEA	staff fuel vehicles operational subsidies capital subsidies price of capital	vehicle-miles
Odeck (2008)	panel	27 bus companies 1995–2002	Norway	DEA	seats fuel total number of hours worked	seat-km
Odeck and Alkadi (2003)	Cross-section	47 bus companies 1994	Norway	DEA	seats effective driving hours staff fuel	seat-km
Odeck and Alkadi (2001)	cross-section	47 companies 1994	Norway	DEA	seats fuel equipment effective driving hours staff	seat-km
Barros and Peypoch (2010)	panel	11 public and private companies, 1995–2008	Portugal	DEA	Liquid assets staff fuel vehicle capacity	sales number of passengers
Pina and Torres (2001)		Public and private companies	Spain	DEA	Fuel/100 km cost/km or cost/traveller subsidy/ traveller	bus-km/employ bus-km/bus bus-km/inhabitant accident rate population

Author(s)	Data type	Sample size	Country	Function	Inputs	Outputs
Sampaio et al. (2008)	panel	19 systems 2001–2005	Brazil Spain England France Germany Holland Greece Lithuania	DEA	staff vehicles fuel	vehicles/distance travelled passengers/ distance travelled
Sanchez (2009)	cross-section	24 public and private companies 2008	Spain	DEA	staff fuel vehicles	hours seats vehicles-km passengers frequency accessibility comfort safety
Saxena P. and Saxena R. (2011)	panel	25 (public) transport undertakings 2002- -2005	India	DEA	vehicles staff fuel	passenger-km seat-km
Sheth et al. (2007)	cross-section	60 bus companies 2007	Greece	DEA	headway cost service duration number of intersections priority lanes	average travelling time vehicle-miles schedule reliability passenger-miles
Tone and Sawada (1990)	cross-section	207 bus companies 1985	Japan	DEA	vehicles staff operating expenses	vehicle-km vehicles staff operating income density of service
Tulkens et al. (1988)	time series (monthly)	three bus companies 1979-1985	Belgium	FDH	staff energy seats	seat-km
Tulkens (1993)	time series (monthly)	1977-89	Belgium	FDH	seats staff energy	seat-km
Tulkens and Vanden Eeckaut (1995)	time series (monthly)	1977-91	Belgium	FDH (benchmark)	seats staff energy	seat-km

Author(s)	Data type	Sample size	Country	Function	Inputs	Outputs
Tulkens and Wunsch (1994)	time series (monthly)	1977-92	Belgium	FDH	seats staff energy	seat-km
Venkatesh and Kushwaha (2018)	panel	23 bus operators 2004-2013	India	DEA	fleet staff fuel	vehicle-km
Viton (1997)	cross-section	217 bus motor bus (MB) or demand--responsive (DR) 1990	USA	DEA	staff fuel vehicles tyres and materials services cost utilities cost insurance cost average speed (MB/DR) average fleet age directional miles	vehicle-miles passenger-trips
Viton (1998)	panel	183 bus companies in 1988 169 bus companies in 1992 motor-bus (MB) or demand responsive (DR)	USA	DEA (Malm-quist)	staff fuel vehicles average fleet age directional miles	vehicle-miles passenger-trips vehicle-hours
Wunsch (1994)	cross-section	1988-93	Europe	DEA FDH	costs	vehicle-km seat-km
Yu and Fan (2009)	panel	23 firms (public) 2001-2002	Taiwan	DEA	staff vehicles fuel network length	vehicle-km passenger-km passengers-trips

Table 2 Summary of DEA literature on the road sector [adapted from Sarmento et al. (2017)]

Author(s)	Units	Method	Inputs	Outputs	Main conclusions
Deller and Halstead (1994)	Rural highways (New England, USA)	Stochastic frontier model	staff wages price of motorized grader price of dump trucks traffic lanes	miles of highways	Maintenance costs higher than necessary due to managerial inefficiencies
Amdal et al. (2007)	26 toll highways (Norway)	Panel data analysis	debt OBU – cars on-board units	average cost per vehicle	Very important unexploited economies of scale Competitive tendering reduces average costs Increased number of lanes, debt, and passenger charges increase average costs
Odeck (2008)	18 companies, from 2001 to 2004 Norway	DEA	operational costs payments to managers	annual traffic number of lanes	Potential for efficiency increases Economies of scales: Larger companies are more efficient than smaller ones Productivity increase due to companies using more efficient methods to collect revenue
Ozbek et al. (2010)	Highway maintenance (Virginia, USA)	DEA	19 cost maintenance inputs, such as climate, cost, traffic, accidents, or speed limit	7 outputs, such as changes in highway or bridge conditions and pollution	Theoretical background and framework for road efficiency Specific inputs and outputs for bridges
Welde and Odeck (2011)	20 companies from 2003 to 2008 (Norway)	DEA and stochastic frontier analysis	operational costs administrative costs	annual traffic number of lanes	Great potential for efficiency improvement No evidence of economies of scale, unlike in Odeck (2008)
Daito and Geiford (2014)	53 highways (USA)	DEA and stochastic frontier analysis	project costs construction duration	number of lanes length in miles	Private highway projects were not more efficient than non-private counterparts

Table 3 Summary of DEA literature on air transport [adapted from Chang and Yu (2014)]

Author(s)	Data type	Models	Sample data	Inputs	Outputs
Schefczyk (1993)	panel	DEA	15 airlines (1989–1992)	Available ton-km Operating cost Non-flight assets	Revenue passenger-km Non-passenger revenue
Charnes et al. (1978)	cross-section	DEA	5 Latin American airlines (1988)	Seat-km available Available ton-km fuel staff	Passenger-km
Tofallis (1997)	cross-section	DEA	14 major airlines (1990)	fuel staff Aircraft cost	Number of flights Seat-mile
Sengupta (1999)	panel	DEA	7 airlines (1988–1994)	Available ton-km reflects aircraft capacity Total operating cost net Total non-flight assets	Revenue passenger-km Non-passenger revenue
Fethi et al. (2000)	panel	DEA, Tobit	17 European airlines (1991–1995)	Available ton-km Operating cost Non-flight assets	Revenue passenger-km Non-passenger revenue
Scheraga (2004)	panel	DEA	38 airlines from different regions (1995/2000)	Available ton-km Operating cost Non-flight assets fuel staff Aircraft cost	Revenue passenger-km Non-passenger revenue ton-km Number of flights Seat mile Passenger-mile Embarkation Passengers
Färe et al. (2007)	panel	TFP, DEA	13 airlines (1979–1994)	fuel	Cargo and charter operations
Barbot et al. (2008)	cross-section	DEA, TFP	49 airlines (2005)	staff fleet fuel	seat-km revenue passenger-km revenue ton-km
Barros and Peypoch (2009)	panel	DEA-CCR	27 European Airlines (2000–2005)	staff operational cost fleet	Operational revenue by passenger-km EBIT
Michaelides et al. (2009)	panel	SFA, DEA	24 airlines (1991–2000)	staff fuel fleet	Passenger-km
Yu et al. (2019)	panel	DEA	13 airlines in China and India (2008-2015)	staff fleet	revenue passenger-km revenue ton-km

Table 4 Summary of DEA literature on railways [adapted from Marchetti and Wanke (2017)]

Author(s)	Sample size	Country	Function	Inputs mentioned	Outputs mentioned	Contextual variables	Purpose of the study
George and Rangaraj (2008)	16	India	DEA and SDEA	operating costs tractive effort	ton-km passenger-km	-	Performance in railway zones
Hilmola (2007)	25	EU	DEA CRS	staff locomotives wagons line length	tons	-	Efficiency and productivity of European cargo railways
Yu (2008)	40	World	DEA and NDEA	staff wagons line length passenger cars passenger trains-km cargo trains-km	ton-km passenger-km passenger trains-km cargo trains-km	Income (GNI) and population density	Efficiency and efficacy of 40 railways (2002)
Yu and Lin (2008)	20	World	NDEA CRS	staff wagons line length passenger cars passenger trains-km cargo trains-km	ton-km passenger-km passenger trains-km cargo trains-km	Income (GNI) and population density	Production efficiency, service efficacy and technical efficacy of 20 selected railways (2002)
Shi et al. (2010)	42	US	DEA and Malmquist Index	staff locomotives wagons fuel consumption line length materials consumed	revenues/ ton-km	-	Productivity and technical efficiency of Class I railways (2002-2007)
Guzman and Montoya (2011)	18	Spain	DEA (VRS) and Malmquist Index	tractive effort seats available available cargo capacity distance travelled	revenues	-	Efficiency of Spanish railways between 1910 and 1922
Hilmola (2011)	43	World	DEA (CRS) and Linear Regression	population and population density (small DEA) proportion of jobs in downtown area, GDP/inhab, urban population + jobs density (large DEA)	bus-km/hec tramway-km/ hec VLT. km/hec, metro vehicle-km/hec train-km/ hec or bus-km/ inhab, tramway-km/inhab, VLT-km/inhab, metro vehicle-km/inhab, train-km/inhab	-	Assessment of public transport in major cities (railways and others)

Author(s)	Sample size	Country	Function	Inputs mentioned	Outputs mentioned	Contextual variables	Purpose of the study
Bhanot and Singh (2012)	18	India	DEA (CRS and VRS)	staff wagons cargo terminals transhipment equipment containers	ton-km net profits	-	Performance of rail container operators
Kutlar et al. (2013)	31	World	DEA (CRS and VRS) and Tobit Regression	staff locomotives wagons operating cost line length passenger cars	revenues passengers passengers/km tons ton/km	-	Performance of passenger and cargo rail companies
Bil (2013)	23	EU	DEA (CRS, VRS and SBM)	staff wagons line length passenger cars	ton-km passenger-km	-	Relevance of overestimation of efficiency
Kabasakal et al. (2015)	31	World	DEA (CRS and VRS), Panel Regression and Malmquist Index	staff locomotives wagons operating cost line length passenger cars	revenues passengers passenger-km tons ton-km	-	Efficiency in railway companies
Oum et al. (2013)	27	Japan	DODF	staff operating cost capital cost travel time	Passenger-km life-cycle CO_2	-	Social efficiency of railways and airlines on the domestic market
Wanke and Barros (2016)	90	Brazil	DFM and Tobit Regression	staff locomotives wagons fuel consumption	investment revenues ton-km	Location and cargo type	Drivers in the railway operator industry
Bogart and Chaudary (2013)	NA	India	TFP	staff fuel consumption line length capital inventory variations	ton-km passengers-km	-	TFP estimates for Indian railways between 1874 and 1912, whose growth topped that of American, British and Spanish railways
Chen (2014)	192	Taiwan	DEA, Malmquist Index and Tobit Regression	number of buses number of drivers fuel	passengers-km	GDP, Market share, bus operator diversification, outlays on sales, overhead and assets	Efficiency of the bus industry after the arrival of the Taiwan High--Speed Rail system (THSR)

Author(s)	Sample size	Country	Function	Inputs mentioned	Outputs mentioned	Contextual variables	Purpose of the study
Crafts et al. (2007)	61	UK	TFP	capital staff coal consumed	passenger trains-miles ton-miles (ores) ton-miles (other cargoes)	-	Productivity of British railways between 1852 and 1912
Couto and Graham (2008)	30	EU	SFA	mean wages costs costs of materials energy/trains-km equipment (capital inventory)	passenger-km ton-km (or passenger train-km, cargo train-km)	-	Analysis of technical (management) and allocative efficiency (sub-optimal scale)
Crafts et al. (2008)	280	UK	TFP	capital staff coal consumed	passenger trains-miles, ton-miles (ores) ton-miles (other cargoes)	-	Performance of major British railways in the beginning of the 20th century
Dodgson (2011)	100	UK	TFP	staff fuel materials capital	passenger trains-miles revenues	-	Performance of British railways in the late-19th century, disaggregating the results in different activities
Doomernik (2015)	8	Europe and Asia	two-stage Network DEA (NDEA) model	total route vehicles seats	yearly train-km of fleet yearly seat-km of fleet yearly number of passengers yearly passenger-km		To identify the best high-speed rail practices and to clarify the operational performance and efficiency
Graham (2008)	89	UK	TFP and DEA	staff fleet capacity (seats) line length (km)	passenger cars-km/year	Control systems subsidy level environmental externalities (GDP/C and population density)	Efficiency estimates comparisons between parametric (TFP) and non-parametric (DEA) models
Kumbakar et al. (2007)	391	EU	Input and output DF, LCM (mixed)	energy consumption (kcal) staff and capital (wagons capacity in tons and passenger cars capacity in seats)	tons/km passenger/km	Dummies: HSPEED (high speed train services existence), D8494 and D9194 (European directives for improvement of financial performance)	Efficiency of 17 European railways applied in Panel Data
Loizides and Tsionas (2002)	240	EU	DF and SUR	staff fuel (electricity, diesel and lubricants) capital (assets, wagons and equipment)	passenger-km tons-km		Assessment of the productivity growth of 10 European railways during 1970-1992 considering their different characteristics (heterogeneity)
Jitsuzumi and Nakamura (2010)	318	Japan	DEA and cost--based model Japan	assets staff operating costs (except wages, taxes and depreciation)	passenger-km tons-km	transport density (passengers-km/ line length)	Inefficiency causes on Japanese railways (1998-2003) and optimum subsidy level method

Author(s)	Sample size	Country	Function	Inputs mentioned	Outputs mentioned	Contextual variables	Purpose of the study
Mallikarjun (2014)	240	US	NDEA and censored Tobit Regression and GLS Regression with bootstrapping	operating costs vehicle-miles revenue-miles passenger--miles	vehicle-miles revenue-miles passenger--miles fare revenue	population density GDP/C number of stations vehicles total lines length	Relationship between subsidies and performance of US urban railways between 2001 and 2010

Notes:
DEA = Data Envelopment Analysis; DFM = Distance Friction Minimization; DODF = Directional Output Distance Function; NDEA = Network DEA; SDEA = Super efficiency DEA;
TFP = Total Factor Productivity; SFA = Stochastic Frontier Analysis; LCM = Latent Class Model; DF = Distance Function; SUR = Seemingly Unrelated Regression;
GLS ¼ Generalized Least Squares.

2.2. DEA methodology

DEA is a nonparametric method based on linear programming that evaluates the relative efficiency of decision-making units (DMUs) that use the same resources (inputs) and produce the same products (outputs).

The model chosen is the input-oriented CCR model (Charnes et al., 1978). This model is also known as constant returns to scale, since it considers that any input variation generates proportional variation in outputs. With input orientation, efficiency is achieved through the minimization of the inputs to obtain a specific level of outputs. The model proposed by Charnes et al. (1978) is as follows:

$$\max h_0 = \frac{\sum_{r \in R} u_r Y_{r0}}{\sum_{i \in I} v_i X_{i0}}$$

subject to the following:

$$\frac{\sum_{r \in R} u_r Y_{rj}}{\sum_{i \in I} v_i X_{ij}} \leq 1, \forall j \in J$$

$$u_r, v_i \geq 0, \forall r \in R, i \in I$$

where j is the set of DMUs ($j = 1,\ldots, |j|$), I is the set of inputs ($i = 1,\ldots, |I|$), R is the set of outputs ($r = 1,\ldots, |R|$), X_{ij} is input i of DMU j, Y_{rj} is output r of DMU j, v_i is the weight of input i, and u_r is the weight of output r.

The linear programming formulation of the model can be written as follows:

$$\max h'_0 = \sum_{r \in R} u_r Y_{r0}$$

subject to the following:

$$\sum_{r \in R} u_r Y_{rj} - \sum_{i \in I} v_i X_{ij} \leq 0, \forall j \in J$$

$$\sum_{i \in I} v_i X_{i0} = 1$$

$$u_r, v_i \geq 0, \forall r \in R, i \in I$$

while the formulation of the dual programme is stated as follows:

$$\min z_0$$

subject to the following:

$$\sum_{j \in J} Y_{rj} \lambda_j \geq Y_{r0}, \forall r \in R$$

$$\sum_{j \in J} X_{ij} \lambda_j \geq z_0 X_{i0}, \forall i \in I$$

$$\lambda_j \geq 0, z_0 \text{ unconstrained}$$

For each firm, efficiency is evaluated from two perspectives: i) economic and ii) technical. For both, the years are the DMUs. The inputs and outputs considered depend on the type of firm and are presented in the next section for each case.

Most of the papers applying a DEA methodology use panel or cross section data (see Table 1, Table 2, Table 3 and Table 4) because their purpose is to compare the efficiency of different companies or organizations. Additionally, because DEA is a comparative methodology, the size of the dataset affects the values of the scores; in theory, the larger the dataset, the more robust the application, because there are more DMUs to be compared.

For the purpose of this work, which is to identify external factors in the Portuguese context that have affected the efficiency of the companies, we have built a dataset with annual information for each company. Thus, there were enough DMUs to calculate reliable scores[1]. Additionally, the dataset includes information from transportation companies of various types (e.g., private, public, large, and small) and sectors (e.g., road, rail and air), enabling a comprehensive overview of the transportation sector in Portugal.

Nevertheless, the results should be analysed carefully since DEA provides a measure of relative efficiency rather than absolute efficiency. When each company is analysed individually and, therefore, each DMU is a specific year within the period of analysis, a score of 1 means that, in that specific year, the levels of efficiency were maximal compared with the other years. It does not mean, however, that the company has been efficient in that year when compared with other companies, but simply that it was more efficient than in other years. When companies are being benchmarked together, and each company is a DMU, then a score of 1 means that the company is the most efficient within that sample or pool of companies. Again, it does not mean that the company is efficient, in absolute terms, only that it is more efficient than the other companies in the sample.

The choice to use constant returns to scale (CRS) is related to the fact that the applications are using year scores for the same firm, so the scale of operations is quite similar over that period of time in most of the cases.

The choice to apply the input-oriented formulation means that organizations try to minimize the resources consumed to obtain a specific level of production. This is particularly true in the case of operators (airlines, railway operators and bus companies), as margins tend to be small and prices fixed administratively, leaving the management to control only the inputs and costs.

When encountering organizations that manage transport infrastructure, they lack the flexibility to change some of their resources. Thus, it is more common to use an output-oriented formulation when comparing the efficiency of different organizations. In this case, given the type of problem – using a long-term series of a firm for which we are comparing efficiency between different years –, the formulation should also be input-oriented because we want to relate to occurrences and short-term impacts on efficiency.

Several yearly efficiency scores were computed for each company, changing the composition of the inputs and outputs in type and number. Since DEA is a relative measure of efficiency, the variables chosen affect the values of the scores, even if these variables seem to have a similar meaning. Additionally, the purpose was to explain the subsequent impact of certain occurrences, such as mergers, government changes and privatizations, on the companies' efficiency. As seen in the literature, there is great variety of choice of the inputs and outputs considered in the different applications.

For the purpose of this study, the option was to have a greater number of and more diverse scores without discussing the right inputs and outputs for each company, because this will also depend on the purpose of the analysis. Thus, a wider view is covered, and the scores' meaning makes the analysis more robust because we can extract more information and, consequently, better explain the impact of the occurrences on the variation of efficiency. Furthermore, the scores will provide a basis for future studies aiming to respond to other research questions.

The inputs and outputs are divided by type, technical and economic, from which technical and economic DEA scores were obtained. More economic than technical scores were calculated for each firm because it was possible to create more combinations given the source of the data collected, which was the companies' annual reports. The economic scores show a wider difference because the economic data vary more greatly between different years.

When assessing economic efficiency, the inputs considered were the operating costs, assets, and liabilities as a percentage of assets, where the outputs were operating revenues, EBITDA as a percentage of operating revenue, and net profit. Different combinations of inputs and outputs were considered in the calculation of DEA economic scores.

When assessing technical efficiency, the inputs considered were the resources used in the production, such as fleet (i.e. number of buses in the case of bus operators, number of carriages in the case of metros and railways, number of planes in the case of airlines and staff). The outputs were the results of the production (i.e., the production itself in terms of vehicle.km in most cases, train.km in the case of railways, seat.km for airlines). Additionally, we also used a measure related to the utilization of production, such as the number of passengers, which is more related to the effectiveness of production.

The reason to explore different economic efficiency scores derives from the fact that it is more difficult to choose and justify which indicators should be used as inputs and outputs. However, technical efficiency is more objective and widely accepted in the literature. Costa (1998) and Doomernik (2015) explain the concepts of efficiency and effectiveness of production, which in some companies can be important because ridership creates disruptions in operations and so affects technical efficiency. In a certain way, effectiveness is more related to the social value of the company.

There is a considerable amount of academic research with efficiency scores calculated mixing inputs and outputs of different natures together, both economic and technical. For the purpose of this study, which is to explore the relationship between policies and efficiency, it makes sense to split the scores by nature in order to better isolate the impacts of the occurrences. In the transport sector, more occurrences affect technical efficiency differently than they do economic efficiency, resulting in different impacts on the scores. Therefore, it seems clearer to identify those occurrences with this kind of approach.

2.3. Economic scores

Economic scores are determined for different firms from different transportation sectors. The data necessary to assess the efficiency was collected mainly from the annual reports of each firm. The period of analysis, the inputs and outputs are described for each firm. The results (economic scores) are presented in the form of a graphic. Table 5 to Table 22 provide more detail on the economic scores. All the scores, both economic and technical, will be analysed and discussed in Chapter 3.

An economic efficiency analysis comparing different firms is also presented for the road and urban rail sector.

2.3.1. Urban road sector

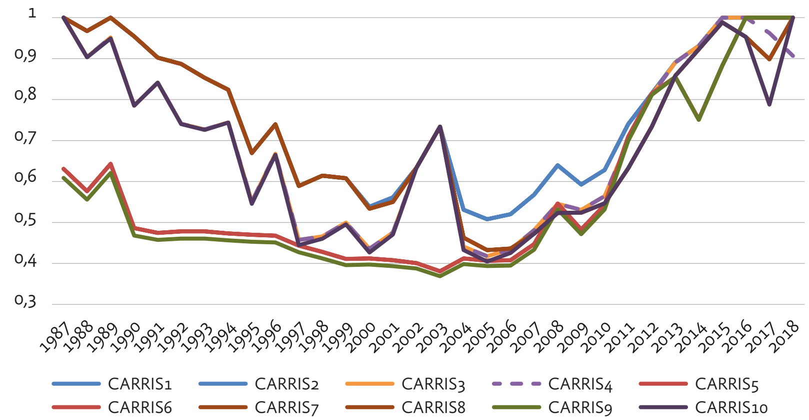
2.3.1.1. Carris

The economic scores of Carris were calculated from 1987 to 2018. Ten combinations of inputs (Operating costs, Asset, and Liabilities as percentage of asset) and outputs (Revenue and Net profit) were considered as shown in Table 5. The economic scores for each combination are presented in Figure 1.

Table 5 Economic efficiency: inputs and outputs for Carris

Analysis	Inputs	Outputs
CARRIS1	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
CARRIS2	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
CARRIS3	Operating costs (€) Asset (€)	Revenue (from tickets) (€) Net profit (€)
CARRIS4	Operating costs (€) Asset (€)	Revenue (from tickets) (€)
CARRIS5	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
CARRIS6	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
CARRIS7	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
CARRIS8	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
CARRIS9	Operating costs (€)	Revenue (from tickets) (€) Net profit (€)
CARRIS10	Asset (€)	Revenue (from tickets) (€) Net profit (€)

Figure 1 Economic efficiency for Carris



Two groups of scores patterns can be visualized: i) one with a growing trend (CARRIS 6 and 9); and ii) another with a minimum peak in the early 2000s. However, there is no common inputs and outputs distinct from the other scores justifying the difference, which highlights the difficulty in deciding the correct inputs and outputs to use.

2.3.1.2. STCP

The economic scores of STCP were calculated from 1987 to 2018. The operating costs and asset as inputs and the revenue as the output were considered as shown in Table 6. The economic scores are presented in Figure 2. There was a marked decrease in efficiency between 1987 and 1990, followed by a fluctuation around an efficiency of 0.65 since then.

Table 6 Economic efficiency: inputs and outputs for STCP

Analysis	Inputs	Outputs
STCP1	Operating costs (€) Asset (€)	Revenue (from passenger tickets) (€)

Figure 2 Economic efficiency for STCP

2.3.2. Urban rail sector

2.3.2.1. Fertagus

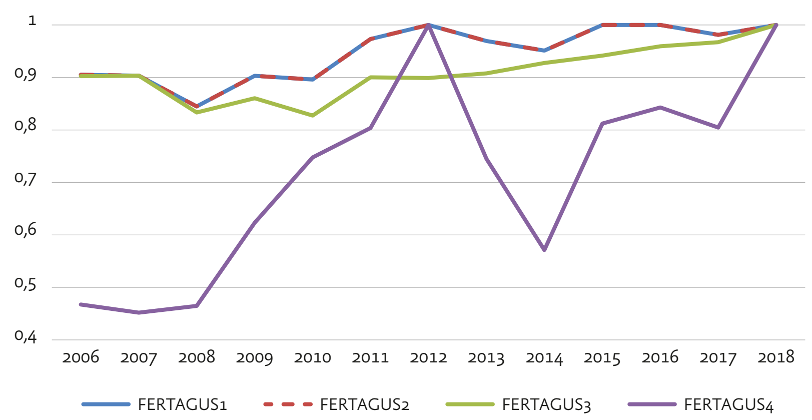
The economic scores of Fertagus were calculated from 2006 to 2018. Four combinations of inputs (Operating costs and Asset) and outputs (Revenue and Net profit) were considered as shown in Table 7. The economic scores for each combination are presented in Figure 3.

Table 7 Economic efficiency: inputs and outputs for Fertagus

Analysis	Inputs	Outputs
FERTAGUS1	Operating costs (€) Asset (€)	Revenue (from tickets) (€) Net profit (€)
FERTAGUS2	Operating costs (€) Asset (€)	Revenue (from tickets) (€)
FERTAGUS3	Operating costs (€)	Revenue (from tickets) (€) Net profit (€)
FERTAGUS4	Asset (€)	Revenue (from tickets) (€) Net profit (€)

The efficiency scores have increased over time, particularly the FERTAGUS4, which relates the asset with the revenue from tickets and net profit. This implies that there have been only small savings in operating costs, but that the assets are being more efficiently used.

Figure 3 Economic efficiency for Fertagus



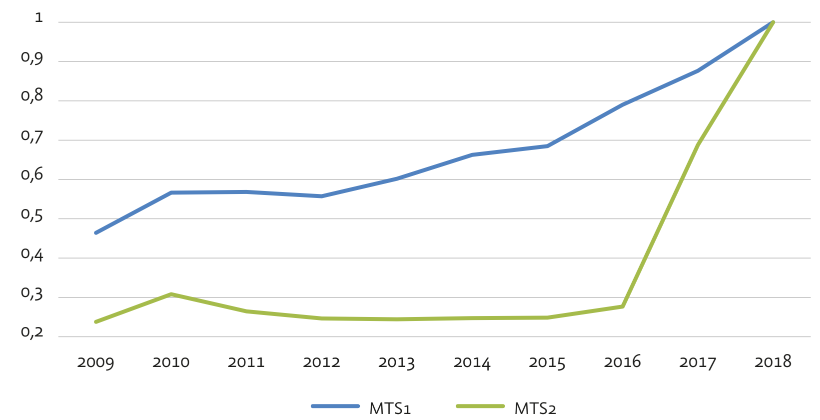
2.3.2.2. Metro Transportes do Sul

The economic scores of Metro Transportes do Sul (MTS) were calculated from 2009 to 2018. Four combinations of inputs (Operating costs and Asset) and outputs (Revenue and Net profit) were considered as shown in Table 8. The economic scores for each combination are presented in Figure 4.

Table 8 Economic efficiency: inputs and outputs for MTS

Analysis	Inputs	Outputs
MTS1	Operating costs (€) Asset (€)	Revenue (from tickets) (€) Net profit (€)
MTS2	Operating costs (€)	Revenue (from tickets) (€) Net profit (€)

Figure 4 Economic efficiency for MTS



A very significant increase in efficiency was observed for both scores. Still, while the MTS1 increase was gradual over time, MTS2 improvement was concentrated after 2016.

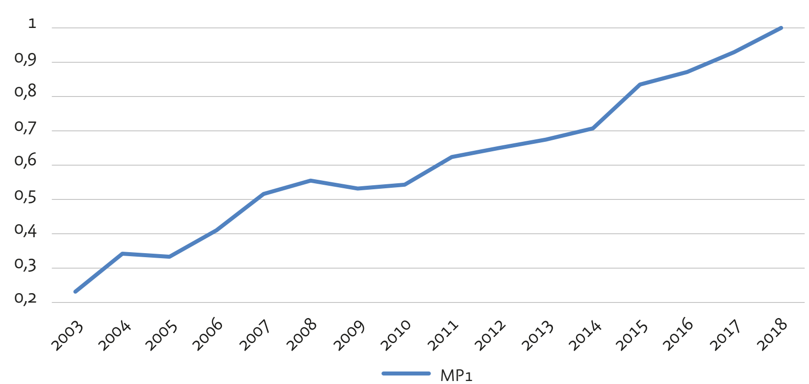
2.3.2.3. Metro do Porto

The economic scores of Metro do Porto (MP) were calculated from 2003 to 2018. The operating costs and asset as inputs and the revenue as the output were considered as shown in Table 9. The economic scores are presented in Figure 5, evidencing a gradual growth since 2003.

Table 9 Economic efficiency: inputs and outputs for MP

Analysis	Inputs	Outputs
MP1	Operating costs (€) Asset (€)	Revenue (from tickets) (€)

Figure 5 Economic efficiency for MP



2.3.2.4. Metropolitano de Lisboa

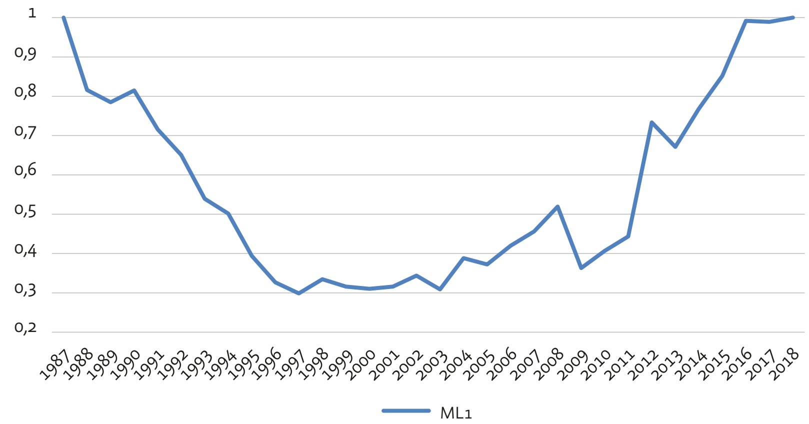
The economic scores of Metropolitano de Lisboa (ML) were calculated from 1987 to 2018. The operating costs and asset as inputs and the revenue as the output were considered as shown in Table 10. The economic scores are presented in Figure 6.

Table 10 Economic efficiency: Inputs and outputs for ML

Analysis	Inputs	Outputs
ML1	Operating costs (€)	Revenue (from tickets) (€) Net profit (€)

The efficiency score reached a minimum in the early 2000s. The trend of decrease in efficiency began to reverse after that and, except for the financial crisis (decrease between 2008-2009) and the international bailout (decrease in 2012-2013), there has been a recovery in efficiency.

Figure 6 Economic efficiency for ML



2.3.3. Railway sector

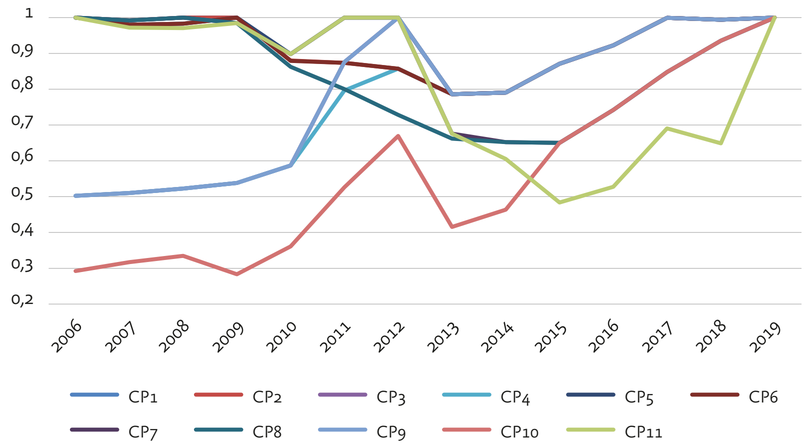
2.3.3.1. Comboios de Portugal

The economic scores of Comboios de Portugal (CP) were calculated from 2006 to 2019. Eleven combinations of inputs (Operating costs, Asset, and Liabilities as percentage of asset) and outputs (Revenue and EBITDA as percentage of revenue) were considered as shown in Table 11. The economic scores for each combination are presented in Figure 7.

Table 11 Economic efficiency: inputs and outputs for CP

Analysis	Inputs	Outputs
CP1	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
CP2	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
CP3	Operating costs (€) Asset (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
CP4	Operating costs (€) Asset (€)	Revenue (from tickets) (€)
CP5	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
CP6	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
CP7	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
CP8	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
CP9	Operating costs (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
CP10	Asset (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
CP11	Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)

Figure 7 Economic efficiency for CP



Two categories of patterns can be identified in the efficiency scores results: i) the scores that decreased during the financial crisis and international bailout years; and ii) the efficiency scores that have been improving constantly. A common factor between these groups is that the liabilities, as percentage of asset, are always an input of the former and never of the latter.

2.3.4. Air transport sector

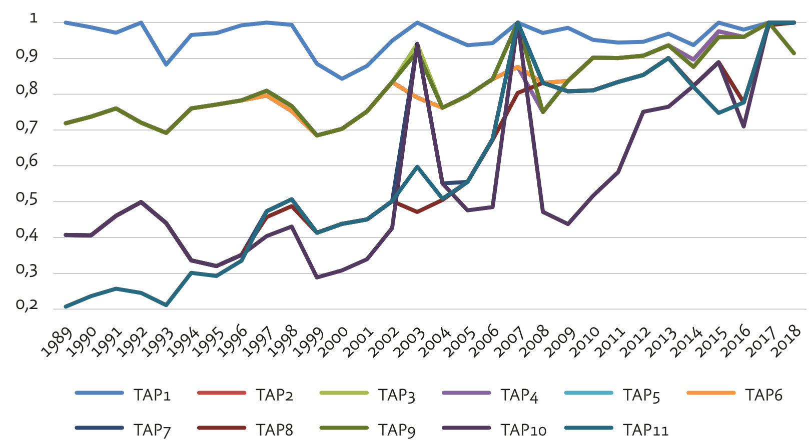
2.3.4.1. TAP

The economic scores of TAP were calculated from 1989 to 2018. Eleven combinations of inputs (Operating costs, Asset, and Liabilities as percentage of asset) and outputs (Revenue and Net profit) were considered as shown in Table 12. The economic scores for each combination are presented in Figure 8.

Table 12 Economic efficiency: inputs and outputs for TAP

Analysis	Inputs	Outputs
TAP1	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
TAP2	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
TAP3	Operating costs (€) Asset (€)	Revenue (from tickets) (€) Net profit (€)
TAP4	Operating costs (€) Asset (€)	Revenue (from tickets) (€)
TAP5	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
TAP6	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
TAP7	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
TAP8	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
TAP9	Operating costs (€)	Revenue (from tickets) (€) Net profit (€)
TAP10	Asset (€)	Revenue (from tickets) (€) Net profit (€)
TAP11	Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)

Figure 8 Economic efficiency for TAP



Three distinct patterns can be devised in the efficiency scores: i) an almost constant efficiency is found when combining all possible inputs with all possible outputs; ii) a very significant increase in efficiency is observed when the asset (asset and/or liabilities as percentage of asset) is the only input; and iii) a slight increase in efficiency can be observed when the operating costs are used as an input.

2.3.5. Road sector

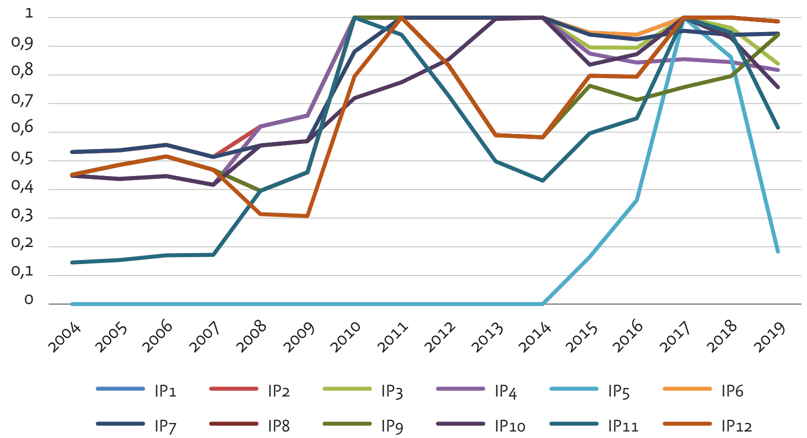
2.3.5.1. EP, Refer and IP

EP (roads) and Refer (railways) are two infrastructure firms that merged into a single firm (IP) in 2015. The economic scores were calculated from 2004 to 2014, summing up the indicator values for EP and Refer, and from 2015 to 2019 for IP. Twelve combinations of inputs (Operating costs, Asset, and Liabilities as percentage of asset) and outputs (Revenue and Net profit) were considered as shown in Table 13. The economic scores for each combination are presented in Figure 9.

Table 13 Economic efficiency: inputs and outputs for EP, Refer and IP

Analysis	Inputs	Outputs
IP1	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
IP2	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
IP3	Operating costs (€) Asset (€)	Revenue (from tickets) (€) Net profit (€)
IP4	Operating costs (€) Asset (€)	Revenue (from tickets) (€)
IP5	Operating costs (€) Asset (€)	Net profit (€)
IP6	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
IP7	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
IP8	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
IP9	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
IP10	Operating costs (€)	Revenue (from tickets) (€) Net profit (€)
IP11	Asset (€)	Revenue (from tickets) (€) Net profit (€)
IP12	Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)

Figure 9 Economic efficiency for EP, Refer and IP



With the exception of the efficiency score IP5, which is zero until 2014, the remaining scores show a growth in efficiency until 2010--2011, followed by a decrease during the international bailout years on the scores using the asset (asset and/or liabilities as percentage of asset) or the operating costs alone as inputs.

2.4. Technical scores

Technical scores are determined for different firms from different transportation sectors. The necessary data to assess the efficiency was collected mainly from each firm's annual reports. The period of analysis, inputs and outputs are described for each firm. The results, i.e., the technical scores, are presented in the form of a graphic. Table 14 to Table 19 provide more detail on the technical scores.

2.4.1. Urban road sector

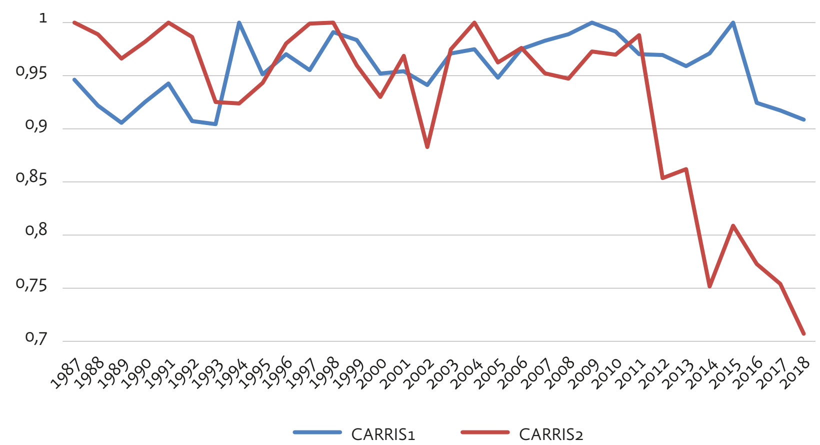
2.4.1.1. Carris

The technical scores of Carris were calculated from 1987 to 2018. Considering the same inputs (fleet and staff), the outputs differ for the efficiency and effectiveness assessments. For the efficiency assessment, the output is the production in terms of vehicles.km, whereas for the effectiveness assessment, the output corresponds to the number of passengers, as shown in Table 14. The technical scores are presented in Figure 10.

Table 14 Technical efficiency: inputs and outputs for Carris

Analysis	DMU	Inputs	Outputs
CARRIS1	1987-2018	Fleet Staff	Vehicles.km
CARRIS2	1987-2018	Fleet Staff	Passengers

Figure 10 Technical efficiency for Carris



In terms of passengers, Carris's efficiency has decreased over the last few years. This coincided with some of latest underground expansions and the launch of a public rental service for electrical bicycles and scooters.

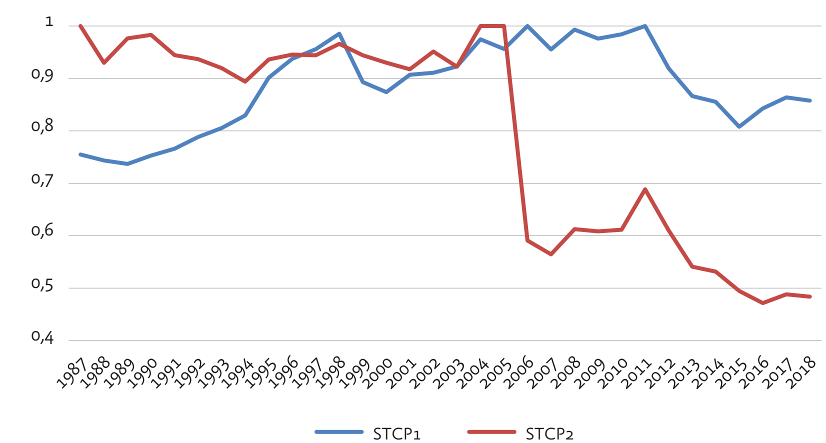
2.4.1.2. STCP

The technical scores of STCP were calculated from 1987 to 2018. Considering the same inputs (fleet and staff), the outputs differ for the efficiency and effectiveness assessments. For the efficiency assessment, the output is the production in terms of vehicles.km, whereas for the effectiveness assessment, the output corresponds to the number of passengers, as shown in Table 15. The technical scores are presented in Figure 11, with a marked decrease in efficiency between 2005-2006, when using the number of passengers as output; the most significant event during this period was the opening of the yellow line in Porto's underground.

Table 15 Technical efficiency: inputs and outputs for STCP

Analysis	Inputs	Outputs
STCP1	Fleet Staff	Vehicles.km
STCP2	Fleet Staff	Passengers

Figure 11 Technical efficiency for STCP



2.4.2. Urban rail sector

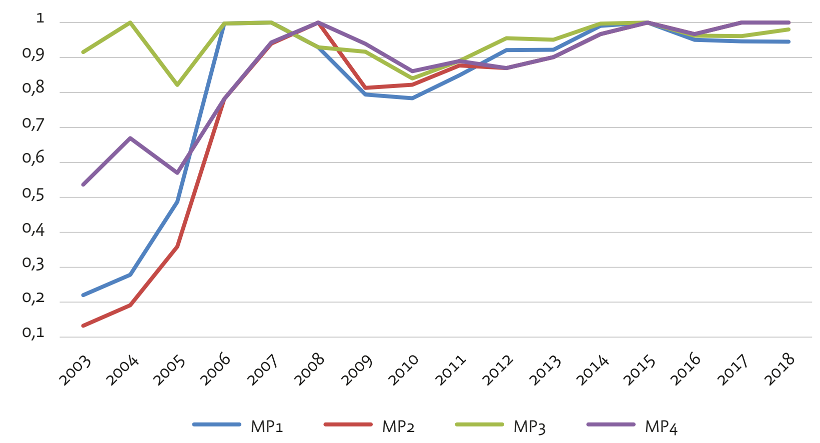
2.4.2.1. Metro do Porto

The technical scores of Metro do Porto (MP) were calculated from 2003 to 2018. Four analyses were carried out. The first two have the same inputs (fleet and staff) but the outputs differ for the efficiency and effectiveness assessments. For the efficiency assessment, the output is the production in terms of vehicles.km, whereas for the effectiveness assessment, the output corresponds to the number of passengers. The last two analyses include the length of the network in the input set as shown in Table 16. The technical scores are presented in Figure 12.

Table 16 Technical efficiency: inputs and outputs for MP

Analysis	Inputs	Outputs
MP1	Fleet Staff	Vehicles.km
MP2	Fleet Staff	Passengers
MP3	Fleet Staff Length	Vehicles.km
MP4	Fleet Staff Length	Passengers

Figure 12 Technical efficiency for MP



The efficiency scores have globally improved over the years, with most of this improvement occurring during the early years, when the network was still being expanded.

2.4.2.2. Metropolitano de Lisboa

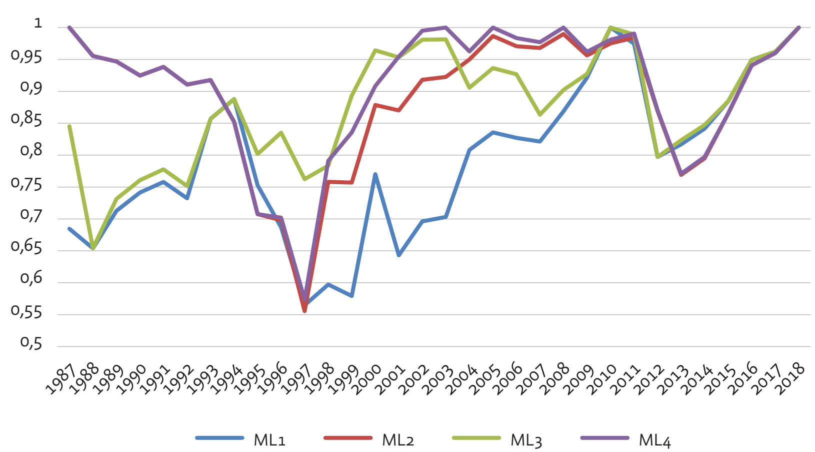
The technical scores of Metropolitano de Lisboa (ML) were calculated from 1987 to 2018. Two analyses were carried out. The first two have the same inputs (fleet and staff) but the outputs differ for the efficiency and effectiveness assessments. For the efficiency assessment, the output is the production in terms of vehicles.km, whereas for the effectiveness assessment, the output corresponds to the number of passengers. The last two analyses include the length of the network in the input set as shown in Table 17. The technical scores are presented in Figure 13.

Table 17 Technical efficiency: input and outputs for ML

Analysis	Inputs	Outputs
ML1	Fleet Staff	Vehicles.km
ML2	Fleet Staff	Passengers
ML3	Fleet Staff Length	Vehicles.km
ML4	Fleet Staff Length	Passengers

The technical efficiency scores of ML are marked by low spikes in 1997 and 2012-2013, coinciding with the financial crisis and the international bailout program, respectively.

Figure 13 Technical efficiency for ML



2.4.3. Railway sector

2.4.3.1. Comboios de Portugal

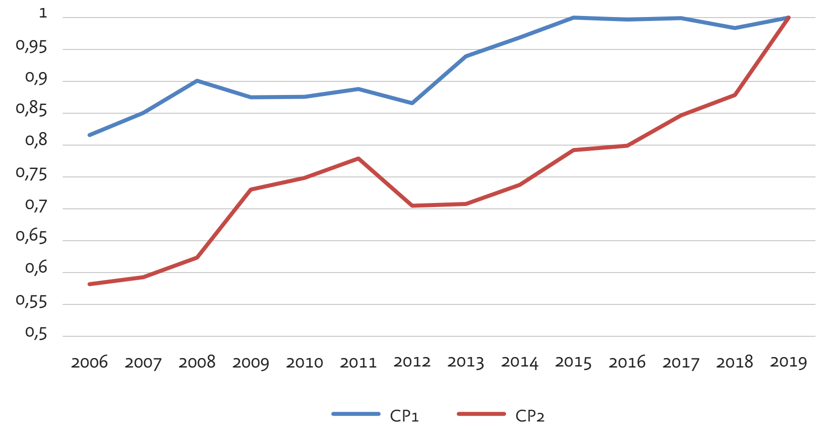
The technical scores of Comboios de Portugal (CP) were calculated from 2006 to 2019. Considering the same inputs (rolling stock and staff), the outputs differ for the efficiency and effectiveness assessments. For the efficiency assessment, the output is the production in terms of trains.km, whereas for the effectiveness assessment, the output corresponds to the number of passengers, as shown in Table 18. The technical scores are presented in Figure 14.

Table 18 Technical efficiency: inputs and outputs for CP

Analysis	Inputs	Outputs
CP1	Rolling stock Staff	Trains.km
CP2	Rolling stock Staff	Passengers

Both scores show increasing efficiency over time, with only a slight disruption at the start of the international bailout programme.

Figure 14 Technical efficiency for CP



2.4.4. Air transport sector

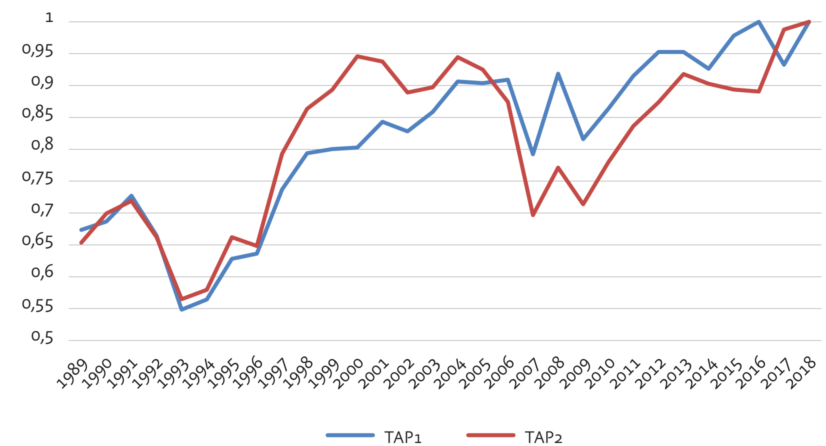
2.4.4.1. TAP

The technical scores of TAP were calculated from 1989 to 2018. Considering the same inputs (fleet and staff), the outputs differ for the efficiency and effectiveness assessments. For the efficiency assessment, the output is the production in terms of seats.km, whereas for the effectiveness assessment, the output corresponds to the number of passengers, as shown in Table 19. The technical scores are presented in Figure 15, with TAP's growing technical efficiency being clearly affected by the 2008 financial crisis.

Table 19 Technical efficiency: inputs and outputs for TAP

Analysis	Inputs	Outputs
TAP1	Fleet Staff	Seats.km
TAP2	Fleet Staff	Passengers

Figure 15 Technical efficiency for TAP



Chapter 3
Efficiency analysis

3.1. Introduction

The purpose of this chapter is to analyse the relationship and impact of external or exogenous factors on efficiency scores, particularly economic shocks and policy decisions. Hence, a total of five analyses was developed taking into account the following main aspects: sector specificity (air transport, roads and urban transit) and policy decisions (privatizations and mergers).

The following essays are:

- Analysis 1: Effects of external shocks on efficiency scores.
- Analysis 2: Airline privatization and efficiency: An analysis of TAP Air Portugal.
- Analysis 3: Effects of ownership models on efficiency scores: The case of urban rail transit transport.
- Analysis 4: Effects of concessions models on efficiency scores: The case of road concessions (availability vs real tolls).
- Analysis 5: Effects of governance changes on efficiency: EP-Refer merger.

3.2. Analysis 1: Effects of external shocks on efficiency scores

3.2.1. Introduction

Economic cycles are the natural trend of fluctuation between periods of expansion (growth) and periods of contraction (recession). Economic cycles are usually measured as the growth of GDP, but they can impact unemployment, income, profits and several other economic measures (Brunner et al., 1980). There are several triggers that can lead to a slow-down and contraction of GDP, with economic shocks being one of the most common causes of recession. In recent decades, recessions have been to the result of oil shocks (1973) (Aguiar-Conraria and Wen, 2007), and, more recently, in 1991, provoked by the first Gulf War (which led to a recession in 92-93), and by a strong increase in German interest rates following German reunification (Bishop et al., 2001). Later, in 2001, the 9/11 events and the dot.com bubble also led to a recession (2001--2003) (Nordhaus, 2002). The last recession, in 2008-2010, has been called “the great recession” (similar, in some ways, to the great depression of 1929) and was mainly motivated by a financial bubble (Borio, 2018). US subprime loans for real estate led to the bailout of several banks, but the Lehman Brothers collapse accelerated the crisis (De Haas and Van Horen, 2012). Following that crisis, Europe faced a sovereign debt crisis after the 2010 Greek scandal in public accounts (Mink and De Haan, 2013). This European sovereign debt crisis led to a major crisis in the eurozone (2010-2013) (Reis, 2017; Sarmento, 2018).

Since economic cycles and shocks impact strongly on transportation, particularly in terms of demand, this essay aims to assess the impact of specific economic shocks on the efficiency of transport firms. We used the Portuguese urban transport firms of Lisbon and Oporto in our study, covering bus and rail systems. Our database covers six firms: two bus companies and four rail/underground companies. The sample covers the period from 1987 to 2019. The economic shocks that have been considered were the 2008-2009 financial crisis and the 2010-2014 sovereign debt crisis, which, in Portugal, led to a bailout by the Troika (IMF, EC and ECB). In the latter crisis, Portugal was obliged to implement a memorandum of understanding (MoU) and a strong reform and fiscal consolidation programme (Simões do Paço and Vareal, 2015). We control for the type of sector, firm and year effects, along with election periods and GDP growth.

The results show that both the financial crisis and the Troika bailout had little or no impact in the short term, but have had a positive long--term impact on both technical and operational efficiency.

This essay is organized as follows: section 2 presents the literature review. Section 3 addresses the research methods and data used, with results and discussion provided in section 4. Conclusions are presented in section 5.

3.2.2. Literature review

Economic cycles usually follow a trend of GDP growth (output fluctuations, also called business cycles), yet they are marked by periods of expansion with positive real GDP growth, followed by periods of recession with negative real GDP growth. Recessions can occur for multiple reasons, such as a crisis in the financial markets (as in 2008), an increase in prices of a very relevant input such as oil (as in 1973), the end of a bubble in investments (such as the dot.com bubble of 2000) or political events (such as the first Gulf War which, along with German reunification, led to an increase in interest rates and oil prices, which in turn led to the 1992 recession) (Samuelson, 2010). Economic fluctuations are therefore the result of shocks in aggregate supply or demand and the dynamic effects of each shock (Blanchard, 2017). Recessions are associated with lower incomes, higher rates of unemployment and poverty, lower firm profits and more bankruptcies, along with other effects. Recessions tend to be relatively short in time and GDP drop. However, some recessions are longer and deeper. Such recessions are usually referred to as economic shocks (Blanchard, 2017). The 2008 financial crisis is an example of a recession that lasted much longer and was much more profound than the previous 2001 recession. The latter lasted only eight months, whereas the former lasted more than twice as long.

There is a biunivocal correlation between economic growth and transportation. On the one hand, investment in transport infrastructures and services can boost economic growth and development (Banister and Berechman, 2001). One of the main benefits of transport investment lies in the positive externalities of reducing time and accidents, leading to higher transport efficiency and therefore promoting private sector investment, growth and employment (Gherghina et al., 2018). On the other hand, on already-established transport modes, economic growth can also have a strong impact, particularly on transport infrastructures, but also on firms providing transport services (Buehler and Pucher, 2011). Economic growth implies a higher demand for transport of persons and freight (Nasreen et al., 2018). This higher demand can drive transport services to be more efficient (Banister and Stead, 2002; De Borger et al., 2002; Mendiluce and Schipper, 2011).

Economic growth has durable impacts on transport service efficiency. The efficiency of transport firms providing urban transports such as bus, rail or underground is strongly impacted by the economic cycle (Winston and Shirley, 2010). Recessions and, particularly, economic shocks have a significant effect on these firms' efficiency, both technical and financial, and impact overall firm efficiency (Jarboui et al., 2015). An economic shock can impact demand – either by reducing it, because unemployment increases, making people travel less for work or leisure (as their income is reduced); or by increasing demand, because people shift from private cars to public transport for affordability reasons (Redman et al., 2013; Efthymiou and Antoniou, 2017). A reduction in demand tends to make these firms less efficient (both technically and financially) due to scale effects, as the use of infrastructure and operation is not maximized and revenues drop but costs remain equal (Cordera et al., 2015). A public transport service operating at full capacity or at a very low capacity basically has similar costs, as the operational costs are mainly fixed costs (staff, depreciation, energy, services, along with others) (Avenali et al., 2016; Daraio et al., 2016). An economic shock can also impact financial efficiency due to an increase in interest rates. Because most public transport firms are highly indebted, such a shock can lead to an increase in financial costs.

The efficiency of transport firms such as rail or bus lines can also be impacted by several other factors. Firstly, the efficiency of such a firm is highly correlated with scale, returns to scale and economies of scope (Farsi et al., 2007). Larger firms can find it easier to reduce total and unit fixed costs (Mohring, 1972). Additionally, there is evidence that significant scope economies can provide a basis in favour of integrated multimode operation as opposed to unbundling (Jara-Diaz and Basso, 2003). Secondly, competition and management can also impact efficiency. Boitani et al. (2013) found evidence, for many local public transport firms across Europe, that fully or partially state-owned enterprises (SOE) have lower levels of efficiency. They also found that firms selected through competitive tendering display higher efficiency levels. Similar results were also found by Roy and Yvrande-Billon (2007) and Ottoz et al. (2009). Thirdly, the type of incentives is also relevant. For instance, firms operating under a high-powered incentive scheme, such as a fixed-price contract, are more efficient than those firms operating under a low-powered incentive scheme, such as cost-plus contracts (Gagnepain and Ivaldi, 2002; Piacenza, 2006; Boitani et al., 2013).

3.2.3. Research methods and data

In this essay, we intend to analyse how economic shocks impact the performance of transport firms. We used the Portuguese bus and rail/underground firms in Lisbon and Oporto as the basis for our study. We have considered two bus firms, one from Lisbon and one from Oporto, two rail firms and two underground firms (Lisbon and Oporto). Our data covers the period from 1987 to 2019, but for some of the companies the length of the dataset is shorter, either because of a lack of data or because the companies are more recent. Public transport firm efficiency has been a major topic in the literature and in policy decisions (see, for instance, Pina and Torres, 2001; Odeck, 2003; Holvad et al., 2004; Barros and Peypoch, 2010; Cavaignac and Petiot, 2017). Chapter 2 also provides a more detailed literature review on the distinct transport modes.

To evaluate these firms' performance, we used technical (*effic_tecn*) and financial (*effic_fin*) efficiency scores as dependent variables.

The normality of the residuals of the dependent variables was assessed graphically and analytically. Figure 16 and Figure 17 present the kernel density and the p-norm graphs for the dependent variables.

Figure 16 Kernel density and p-norm graphs for the variable effic_tecn

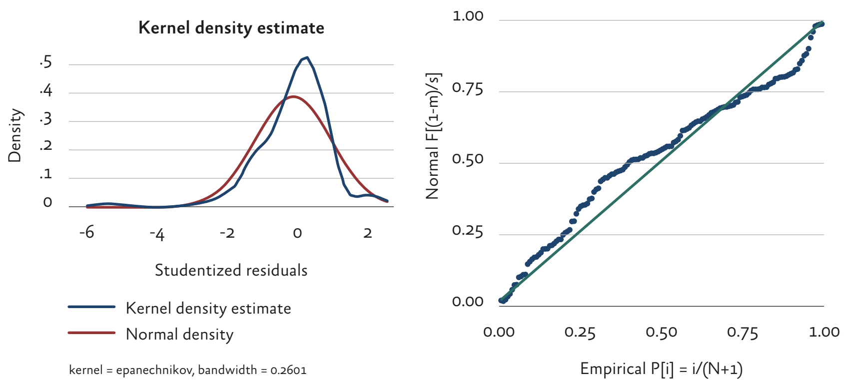
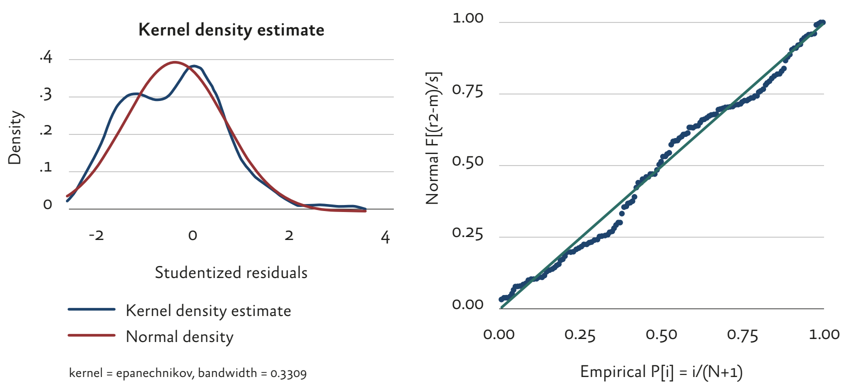


Figure 17 Kernel density and p-norm graphs for the variable effic_fin



We used several explanatory variables for the impacts of economic shocks. Firstly, the variable *fincrisis* represents the 2008 financial crisis impact. The 2008 crisis had a strong impact worldwide, so much so that it was referred to as "the great recession" (Drezner, 2014). Portugal was substantially affected, with a decline in GDP of 4% and a strong increase in public deficit and debt (Carreira and Teixeira, 2016). This variable assumes the value 1 for the years 2008 and 2009, and 0 otherwise. This variable is intended to capture the effect of those two years on these firms' performance. To capture the effect of the financial crisis, we also used another variable called *fincrisis_perm*. This variable aims to examine whether the effects of the crisis were not felt solely in 2008-2009, but instead have persisted over time. The variable assumes the value 1 for the years 2008 and beyond, and 0 for the previous years.

After the financial crisis, Portugal requested a financial bailout from a Troika programme (IMF, EC and ECB) in 2011, due to the sovereign debt crisis that hit the eurozone. Portugal, Greece and Ireland had requested bailouts previously (Hardiman et al., 2019). The Portuguese government signed a memorandum of understanding (MoU) with the Troika, leading to reforms and fiscal consolidation measures (Pereira and Wemans, 2015). These measures included the need to reduce public spending (representing a cut in public servants' salaries and the overall number of workers) and the privatization of public companies, among others.

In the case of the firms analysed in this essay, those that are SOE were substantially affected, not just in terms of salary cuts, but also of other measures, such as an overall decrease in outsourcing and spending on infrastructure maintenance, among others. These measures were mainly intended to ensure the companies' financial rebalance, as historically they operated with large losses. As the programme was applied between May 2011 and May 2014, we used the variable *troika*, assuming the value 1 for the years 2011, 2012, 2013 and 2014, and 0 otherwise. We also used the variable *troika_perm*, assuming the value 1 for the years 2011 and beyond, and 0 for the previous years. As the Troika MoU was implemented during those years, we assumed a lag effect on the measures. For that lag, we also used the variable *troika_lag1*, assuming the value 1 only for 2012 and beyond, and 0 otherwise; and *troika_lag2*, assuming the value 1 only for 2013 and beyond, and 0 otherwise. We can thus observe whether the Troika economic shock effect produced some lag between the start of the programme and the impact of the measures.

There were two reasons for using only these two economic shocks: firstly, these are the two main recessions in our sample period – the other recessions (such as 1992-1993 and 2001-2003) are relatively much shorter in terms of time and GDP reduction. Secondly, as described below, we control for the economic cycle by using the GDP growth as a control variable.

We control our results for several factors that can impact transport firm performance. We used Portugal's national elections, with the variable *ely* assuming the value 1 in years with elections and 0 otherwise. We also used the variable *elylag* for the year before the election and the variable *elylead* for the year after the election. We also control for the economic growth of GDP (*gdgp*). As a transport firm's performance can also be affected by endogenous factors (Bhattacharyya et al., 1995), we control for the type of management. The variable *priv_firm* assumes the value 1 if the firm is managed by a private company through a concession, and 0 if the concession is run by a public entity or SOE. We also control for the firm transport mode. The variable *rodo* assumes the value 1 if the firm is running a bus service and 0 if the firm is running a rail/underground service.

Our analysis of the explanatory and control variables shows multicollinearity (using the correlation matrix and the VIF test) between several variables – between the financial crisis variables and between the Troika variables. Therefore, each explanatory variable must be used in isolation with the control variables. There is evidence (Shapiro--Wilk and Breusch-Pagan tests) of heteroscedasticity, but we used robust standard errors. The Wald test shows all variables in the model are significant. The Hausmann test shows evidence of random effects. Descriptive statistics of the variables are presented in Table 20.

Table 20 Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
effic_tecn	146	0,86	0,14	0,22	1,00
effic_fin	158	0,59	0,32	0,00	1,00
dif_scoree~c	151	0,01	0,09	-0,41	0,43
fincrisis1	158	0,09	0,29	0	1
fincrisis_perm	158	0,49	0,50	0	1
troika	158	0,18	0,38	0	1
troika_perm	158	0,36	0,48	0	1
troika_lag1	158	0,32	0,47	0	1
troika_lag2	158	0,27	0,45	0	1
elylag	158	0,25	0,43	0	1
ely	158	0,27	0,45	0	1

Variable	Obs	Mean	Std. Dev.	Min	Max
elylead	158	0,28	0,45	0	1
gdpg	158	1,55	2,59	-4	7,9
priv_firm	158	0,30	0,46	0	1
rodo	158	0,41	0,49	0	1

3.2.4. Results and discussion

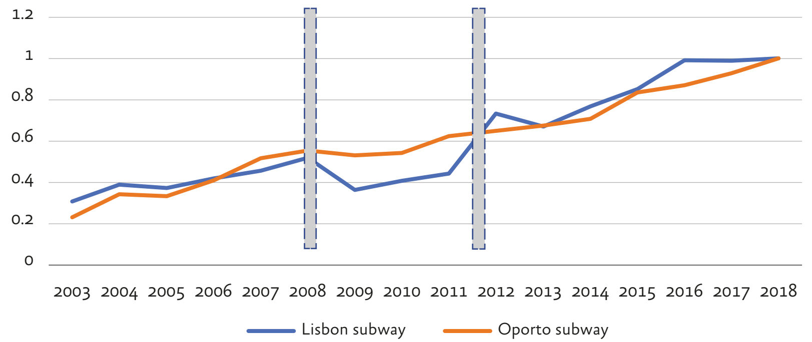
We measured efficiency for each firm from two different perspectives: i) technical; and ii) financial. Efficiency scores do not identify the causes of efficiency in the sense that the results only show an increase or decrease in efficiency, but they identify the inefficient units in terms of either change in technical efficiency or technological change (Cooper et al., 2007, 2011). With that information, we can compare the evolution of either inputs or outputs and how they affect the changes in efficiency. We can compare, for each firm and then globally, what the changes were in efficiency over time and, in particular, after the 2008 financial crisis and after the Troika programme.

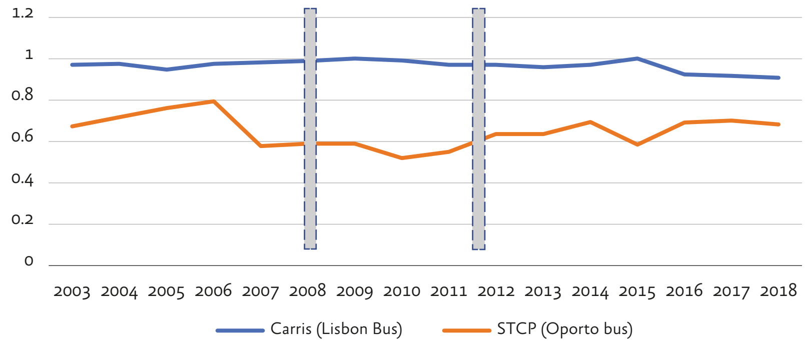
The evolution of the *effic_tecn* for the firms between 2003 and 2018 is presented in Figure 18.

Figure 18 Effic_tech evolution 2003-2018

The evolution of technical efficiency between the underground firms of Lisbon and Oporto, between the two bus firms and between the two rail firms is compared. There was some increase in efficiency for the two underground and railway operators, but not among the bus firms. The evolution of the *effic_fin* is also shown in Figure 19 – Effic_fin evolution 2003-2018, displaying a similar pattern.

Figure 19 Effic_fin evolution 2003-2018





Note: In the case of Fertagus and the railway company (third graph in Figure 18), there were several years of data missing, which prevented the presentation the corresponding graph.

We can see a substantial improvement in the financial efficiency of both underground operators but also, and to a lesser extent, of the two bus firms. Using this linear programming analysis results in an efficiency frontier – the best-practice benchmark – against which we gauge the efficiency of each operator in each transport sub-mode. This analysis shows that the average productivity of these firms increased over time. In general, this increase is mainly caused by an increase in financial efficiency and, to a lesser extent, an increase in technical efficiency.

The results of our econometric model for the *effic_tecn* are presented in Table 21. We can observe that both financial crisis and the Troika seem to have had no impact if we only consider the specific period of each shock (2008-2009 and 2011-2014). However, if we consider the variables *fincrisis_perm* and *troika_perm,* we can see that these two shocks did produce long-term effects. Additionally, in the case of the Troika programme, we can see a positive impact on the technical efficiency of these operators when we considered a lag period of one or two years.

Table 21 Results of technical efficiency

This table presents the results for the dependent variable *effic_tecn*, measuring the technical efficiency. Random effects were used due to results on the Hausmann test. Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	**effic_tecn**	**effic_tecn**	**effic_tecn**	**effic_tecn**	**effic_tecn**	**effic_tecn**
Explanatory variables						
fincrisis1	0.0161					
	(0.0410)					
fincrisis_perm		0.0921***				
		(0.0224)				
troika			0.0037			
			(0.0323)			
troika_perm				0.0760***		
				(0.0231)		
troika_lag1					0.0723***	
					(0.0239)	
troika_lag2						0.0853***
						(0.0244)
Control Variables						
gdpg	-0.0091**	-0.0015	-0.0094*	-0.0056	-0.0070*	-0.0095**
	(0.0044)	(0.0043)	(0.0048)	(0.0041)	(0.0040)	(0.0039)
rodo	0.0771	0.0920*	0.0769	0.0861*	0.0849*	0.0869*
	(0.0499)	(0.0499)	(0.0499)	(0.0499)	(0.0499)	(0.0499)
ely	-0.0410	-0.0300	-0.0392	-0.0161	-0.0078	-0.0072
	(0.0278)	(0.0262)	(0.0280)	(0.0275)	(0.0287)	(0.0280)
elylag	-0.0073	-0.0098	-0.0047	0.0214	0.0202	0.0213
	(0.0269)	(0.0247)	(0.0262)	(0.0264)	(0.0267)	(0.0262)
elylead	-0.0252	-0.0148	-0.0260	-0.0058	-0.0081	0.0034
	(0.0259)	(0.0244)	(0.0260)	(0.0255)	(0.0256)	(0.0260)
priv_firm	-0.0529	-0.0522	-0.0531	-0.0538	-0.0543	-0.0561
	(0.0517)	(0.0514)	(0.0517)	(0.0515)	(0.0515)	(0.0515)
Constant	0.8821***	0.8152***	0.8826***	0.8282***	0.8342***	0.8336***
	(0.0406)	(0.0432)	(0.0423)	(0.0434)	(0.0433)	(0.0424)
Observations	146	146	146	146	146	146
Wald Test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The results for the effic_fin are presented in Table 22. As with previous results, the immediate impacts of the financial crisis and the Troika do not show any impact on financial efficiency. Again, the positive impact of these shocks is only perceived in the long term. Additionally, the Troika impact only appears with a lag period of one or two years.

Table 22 **Results of financial efficiency**

This table presents the results for the dependent variable *effic_fin*, measuring the financial efficiency. Random effects were used due to results on the Hausmann test. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	**effic_fin**	**effic_fin**	**effic_fin**	**effic_fin**	**effic_fin**	**effic_fin**
Explanatory variables						
fincrisis1	0.1504*					
	(0.0818)					
fincrisis_perm		0.1783***				
		(0.0462)				
troika			0.0366			
			(0.0655)			
troika_perm				0.1221**		
				(0.0475)		
troika_lag1					0.1301***	
					(0.0489)	
troika_lag2						0.1189**
						(0.0504)
Control Variables						
gdpg	0.0188**	0.0290***	0.0157	0.0192**	0.0173**	0.0125
	(0.0090)	(0.0090)	(0.0101)	(0.0087)	(0.0084)	(0.0083)
rodo	0.0466	0.0630	0.0454	0.0555	0.0553	0.0551
	(0.0497)	(0.0494)	(0.0502)	(0.0494)	(0.0493)	(0.0496)
ely	-0.0846	-0.0508	-0.0660	-0.0324	-0.0116	-0.0248
	(0.0567)	(0.0542)	(0.0577)	(0.0578)	(0.0600)	(0.0593)
elylag	-0.1122**	-0.0974*	-0.0868	-0.0435	-0.0405	-0.0500
	(0.0548)	(0.0510)	(0.0537)	(0.0553)	(0.0554)	(0.0551)
elylead	-0.0263	-0.0177	-0.0352	-0.0074	-0.0077	0.0019
	(0.0528)	(0.0504)	(0.0535)	(0.0532)	(0.0530)	(0.0549)
priv_firm	-0.3485***	-0.3692***	-0.3490***	-0.3596***	-0.3604***	-0.3614***
	(0.0535)	(0.0526)	(0.0541)	(0.0531)	(0.0530)	(0.0534)
Constant	0.6945***	0.5891***	0.6980***	0.6263***	0.6261***	0.6460***
	(0.0542)	(0.0611)	(0.0599)	(0.0626)	(0.0619)	(0.0600)
Observations	158	158	158	158	158	158
Wald Test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Regarding the control variables, we found evidence that economic growth also has an impact on technical and economic efficiency. However, economic growth tends to reduce technical efficiency. On the other hand, GDP growth tends to improve financial efficiency. Considering both efficiencies in the overall efficiency, economic growth tends to increase the global efficiency score of these firms. There is a higher level of technical efficiency (but not of financial efficiency) in the bus operators. Apparently, election periods do not impact either efficiency.

3.2.5. Conclusions

In recent decades, overall efficiency (technical and economic) in transport projects, particularly in rail-based companies, has seen average growth. This growth is interesting because these companies have larger sunk investments and lower levels of flexibility, whereas one would expect bus companies to be more efficient. The results also showed that, although there was neither a short-term impact from the financial crisis nor from the austerity measures brought by the Troika, there has been a larger impact when considering a two-year period.

One explanation for this lag is the fact that the managerial decisions on adjusting supply, that is, increasing or decreasing supply, are relatively rigid in these types of firm. The tendering of vehicles is a slow process that can last for two years (if not more, given the bottlenecks in public procurement); thus, the process of selling and/or scrapping vehicles can help to explain this lag.

The results also show that the economic environment affects the efficiency scores. On the one hand, GDP growth improves economic efficiency, which might be linked to growth in revenues and revenue per passenger. For example, the growth in tourism increases the use of single-journey or single-day tickets, which tend to provide a higher average revenue than the one provided by regular commuters who use monthly passes. On the other hand, we see a negative effect on technical efficiency. In periods of economic growth, companies tend to increase their staff and fleets, which might reduce technical efficiency overall. Note that most transport companies are public and, as such, they are vulnerable to austerity when growth is negative. As soon as the restrictions are alleviated, companies engage in renewal strategies that can have a negative short-term impact on technical efficiency.

Finally, there is no evidence of any type of political bias, in the sense that the existence of elections does not appear to affect company efficiency. One might expect that, around election time, companies might be pressured into increasing supply or the overall quality of service, thereby affecting their efficiency scores, but there is no evidence of such an effect.

3.3. Analysis 2: Airline privatization and efficiency: An analysis of TAP Air Portugal

3.3.1. Introduction

The privatization of airlines has been a recurrent topic in the air transport literature. Some of the early studies, such as Forsyth (1984), have questioned the motivation for governments to privatize. Frequently, the reasons behind privatizations have focused on introducing greater efficiency (Kay and Thompson, 1986), on fostering investment (Zhang and Round, 2008), or on more political strategies to decrease the role of the government in the direct provision of transport services and deregulation strategies (Sjögren and Söderberg, 2011).

Most studies focus on comparing the efficiency levels of airlines based on their type of service, for example, comparing the efficiency levels of low-cost and full-service airlines (e.g., Yu et al., 2019; Dobruszkes and Wang, 2019), comparing public vs private ownership models (e.g., Backx et al., 2002; Mhlanga et al., 2018), or the membership to strategic alliances (Kottas and Madas, 2018). However, the scope of studies on airline efficiency is much broader (e.g., see Li et al., 2016).

This essay adopts a different approach. We focus our analysis on a single airline providing a longitudinal analysis of several efficiency scores, both technical and economic.

Based on this, the research question we pose is: “Did the privatization of the Portuguese national airline lead to higher operational and economic efficiencies?”

TAP – *Transportes Aéreos Portugueses* (Portuguese Air Transportations) is the Portuguese flag carrier airline. Established in 1945, it began offering commercial services in 1946. Since the privatization topic was first brought up in 1991, it became a dominant point of discussion throughout the following governments and the company was eventually privatized at the end of 2015. A DEA model assessed the firm's operational and economic efficiency scores before and after the conversion. Those scores have been used here as the dependent variable. Our explanatory variable is a dummy privatization, assuming the value 0 until 2015 and 1 thereafter.

In our results, we control for several factors that could also impact efficiency: i) the financial crisis between 2008 and 2010; ii) the period of the Portuguese bailout programme (Troika) between 2011 and 2014, as a consequence of the financial crisis; iii) GDP growth; and iv) the unemployment rate. Election years were also controlled, and we used a one-year lead and lag for the election year. The acquisition of the airline Portugália by TAP in 2006 was also controlled through the inclusion of a dummy variable representing the acquisition, assuming the value 1 after 2006 and 0 before. The regional nature of the service provided by Portugália complemented the long-distance service offered by TAP. Until 2006, Portugália was owned by a private Portuguese group (Espírito Santo International), and the acquisition value was 140 million euros. This event enables us to explore an additional research question: "Does an acquisition complementing an airline's service increase its efficiency?" This question is particularly important since the main motivation behind such an acquisition was, in fact, the creation of synergies.

This essay is organized as follows: section 2 provides an overview of the merger process and objectives; the research methods and data used are explained in section 3; the results and discussion are presented in section 4; and conclusions are provided in section 5.

3.3.2. Literature review and research questions

As mentioned earlier, literature has been addressing the ownership models and their potential impact on efficiency. Overall, this literature has provided evidence of a positive correlation between private ownership and better performance. One of the early studies focusing on this issue was Gillen (1989), who examined Air Canada in 1964--1981. The author concluded that, during this period, public ownership caused a reduction in productive efficiency of 23% of the carrier costs; therefore, the author urged that the company should be privatized.

The same conclusion was drawn by Eckel et al. (1997), who analysed the effect of privatization on the performance of British Airways, looking at airfares and competitors' stock prices. The results suggest that private ownership improved economic efficiency. Al-Jazzaf (1999) examines the impact of privatization on airline performance in ten countries. This study considered several KPIs, including sales, net income, total assets, number of employees, and capital expenditure, and provided empirical evidence that suggests overall positive evidence of performance.

Backx et al. (2002) studied 50 companies over a period of five years (1993-97) and the results indicate that public-sector airlines underperform comparable private sector ones. Chow's (2010) study on performance differences based on airline ownership in China showed that nonstate-owned enterprises perform better than state-owned enterprises, which the author has largely attributed to efficiency improvements. Ochieng and Ahmed (2014) showed that privatization had a positive impact on Kenya Airways.

In many of these studies, the authors used efficiency analysis based on a set of methodologies, such as data envelopment analysis (DEA), total factor productivity (TFP) or even simple empirical KPI analysis. The studies on efficiency have analysed a set of efficiency determinants, among which are privatizations and ownership models. The most common methodology is clearly DEA, using distinct sets of inputs and outputs. However, there are some frequent variables, such as operating costs, revenues, passengers, and staff, etc. The mix of inputs and outputs measures different types of efficiency – technical and economic – although, in most studies, there is not an explicit distinction between the two.

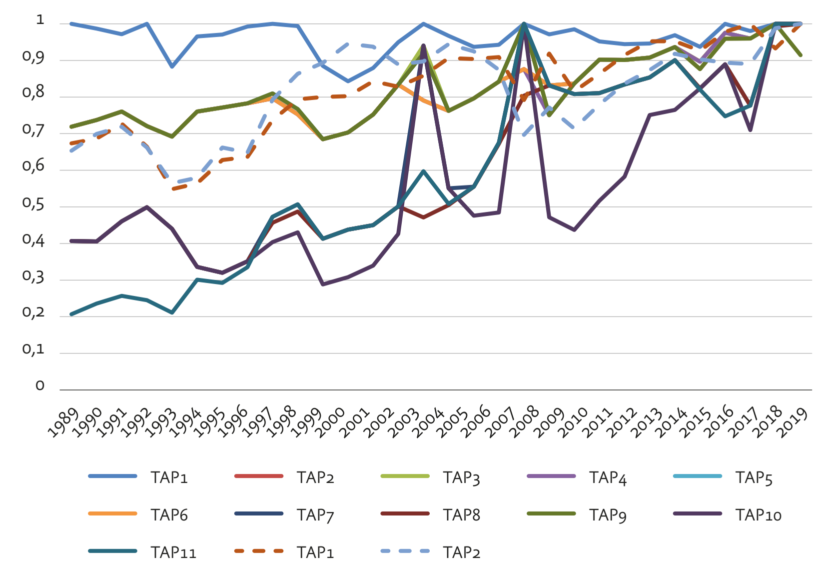
The aim of our research is to evaluate the impact of the privatization of TAP Air Portugal on efficiency, both technical and economic, while controlling for a set of external economic factors (economic, social, managerial and political) that could also affect efficiency scores. To the authors' knowledge, this paper is the first to employ such an approach.

3.3.3. Research methods and data

The data collection underlying the determination of the efficiency scores was done using annual reports with operational and financial results between 1989 and 2018 (Chapter 2 presents all variables collected). Complementarily, the dataset considered the following potential exogenous drivers in addition to privatization: i) the acquisition of Portugália (*acpo*); ii) election years (*elye*); iii) the financial crisis (*ficr*); iv) Troika (*troi*); vi) unemployment rate (*unra*); and vii) gross domestic product growth (*gdpg*). For the election years, a lead (*elyelead*) and lag (*elyelag*) of one year were considered. Between 2008 and 2010, Portugal was severely affected by the 2008 economic crisis, culminating in an international bailout programme from the European Commission, the European Central Bank and the International Monetary Fund between 2011 and 2014, a period during which the country was under Troika supervision.

The annual operational and financial data were used to estimate efficiency scores using data envelopment analysis (DEA). Two technical and two financial efficiency scores were obtained for each year (Figure 20).

Figure 20 Economic (full lines) and technical (dashed lines) scores for TAP



The technical scores and exogenous variables were subjected to a preliminary data analysis. Scatter and box plots, along with descriptive statistics, were computed, but for the purpose of the remaining analysis, the most relevant test was examining the normality of the data of each efficiency score alone and for the public and private ownership periods using the Shapiro-Wilk test. The option to use this test instead of Kolmogorov-Smirnov was chosen due to the small sample size under consideration.

Comparison of means tests and correlation analysis were used to evaluate the relationship between each exogenous variable alone and each efficiency score. Both parametric (t-test) and nonparametric (Mann-Whitney U test) comparisons of means tests were used for the categorical exogenous variables. For the exogenous scale variables, the parametric (Pearson) and nonparametric (Kendall's tau) correlation was used.

The evaluation of the influence of privatization on the efficiency scores while controlling for the effect of all other significant predictors was done using ordinary least squares (OLS) regression to build the following econometric model:

$$Yi = \beta_0 + \beta_1 \, priv + \beta_2 \, acqpo + \beta_3 \, troi + \beta_4 \, fincrisis + \beta_5 \, \mathrm{gdpg} + \beta_6 \, \mathrm{unemp} + \beta_7 \, \mathrm{ely} + \mu i$$

where

priv is a dummy variable, taking the value 0 for the years before the privatization and 1 thereafter. This approach allows us to assess the specific impact of the privatization on firm efficiency.

acpo is a dummy variable to account for the acquisition of Portugália. It takes the value 0 until 2007 and 1 thereafter, and enables assessing the specific impact of privatization on firm efficiency, along with controlling for this impact on privatization.

troi is a dummy variable assuming the value 1 in the years that Portugal was subject to a bailout programme with the IMF/ECB/EU (between 2011 and 2014) and 0 otherwise. Portugal asked for a financial bailout in 2011 due to a steady increase in public and external debt (Pereira and Wemans, 2015; Reis, 2015). There are several reasons why the Troika period may have impacted on the efficiency of these infrastructures. Firstly, there were substantial financial restrictions, which can lead to a reduction in investment and maintenance, thus decreasing efficiency. Additionally, there was a recession during the Troika programme period, leading to less demand, which can also reduce infrastructure efficiency (De Borger et al., 2002; Sarmento et al., 2017). Furthermore, the programme included several measures concerning the transport sector, aiming to increase the sector's efficiency (Sarmento and Reis, 2019).

fincrisis is a variable assuming the value 1 between 2008 and 2010, and 0 otherwise. This variable is intended to capture the effect of the 2008 financial crisis that culminated in the bailout programme in 2011.

gdpg is GDP growth as a percentage. Better economic times mean more demand for travelling, which can increase infrastructure efficiency *per se*.

unra is the unemployment rate as a percentage. More unemployment leads to less demand for transport, creating pressure on the efficiency of the infrastructures. We also tested with the log of this variable.

elye is a dummy variable assuming the value 1 if there was a national Parliament election (which elects the government) on that year, and 0 otherwise. It is intended to capture whether an election and a potential change in policies led to more or less efficiency. It was also used to test the option of considering a lead or a lag of one year in relation to the election year.

The selection of the variables to be included in the regression models was done using a best subsets approach and tested the difference between using the Akaike information criterion or the adjusted R2 as the criterion for entry or removal of the predictors in the process of selecting the best subsets. Multicollinearity and heteroscedasticity were assessed through the volume of inflation factor and the Breusch--Pagan test, respectively.

The combined effect of the predictors was evaluated by building a generalized linear model (GLM) with an interaction term, but only for the OLS models determined in the previous step with highest fit (based on the R-squared). All variables were statistically significant, and at least one continuous variable was included.

3.3.4. Results and discussion

The scores obtained were presented in Chapter 2 along with the exogenous variables considered. Based on a visual observation of the data, higher efficiency scores seem to exist, both at the technical and financial levels, after the privatization, despite the fewer number of years as a private company. The only exception is the case of economic efficiency 1, which presents similar scores.

The continuous variables have normal distributions, with the exception of the technical efficiency 1 scores and gross domestic product growth. Almost all efficiency scores evidenced nonnormal distributions for at least one of the groups of the categorical predictors. The few exceptions were economic efficiency 1 in the case of the lead up to an election year and of the privatization. Therefore, nonparametric tests were given preference to evaluate the uncontrolled effect of the predictors.

The Mann-Whitney U test results (Table 23) disclose the privatization as the predictor with more cases with statistically significant differences (p-value<0.05). Only for the *ECON1* was there no statistically significant different efficiency score before and after the privatization. The uncontrolled effect of the acquisition of Portugália was statistically significant for *TECH1* and *ECON2*. The statistically significant cases for both the privatization and the acquisition of Portugália led to an efficiency increase. The only other predictor with statistically significant results was the Troika, which showed a positive effect on technical efficiency score 1.

Table 23 Results of the effect of the privatization and the acquisition of Portugália

Variable	TECH1	TECH2	ECON1	ECON2
Privatization				
Mann-Whitney U	78.000	72.000	65.000	78.000
Standard Error	14.462	14.465	14.330	14.459
Standardized Test Statistic	2.593	2.178	1.710	2.594
Asymptotic Sig.(2-sided test)	0.010	0.029	0.087	0.009
Exact Sig.(2-sided test)	0.003	0.026	0.100	0.003
Acquisition of Portugália				
Mann-Whitney U	198.000	137.000	129.000	197.000
Standard Error	23.617	23.622	23.400	23.612
Standardized Test Statistic	3.811	1.228	0.897	3.769
Asymptotic Sig.(2-sided test)	0.000	0.220	0.369	0.000
Exact Sig.(2-sided test)	0.000	0.232	0.391	0.000

The unemployment rate revealed a statistically significant correlation between technical efficiency 1 and economic efficiency 2, while the only statistically significant correlation in terms of gross domestic product growth was with economic efficiency 1 (Table 24). All three statistically significant correlations were positive. For the cases related to economic efficiency, possible explanations include the following: i) the contribution of the tourism sector for gross domestic product growth, particularly in recent years, has been particularly significant; and ii) higher unemployment rates tend to foster lower wages, decreasing both internal and external costs. Note that the unemployment rate was only used to evaluate the existence of a linear correlation. No variable transformation was carried out to assess nonlinear situations.

Table 24 Correlations between efficiency scores and continuous predictors

	Pearson		Kendall's tau	
Variable	gdpg	unra	gdpg	unra
TECH1	-0.356	,576**	-0.240	0.426**
TECH2	-0.132	0.255	-0.023	0.092
ECON1	0.169	0.151	0.262*	0.038
ECON2	-0.342	0.666**	-0.196	0.536**

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed).

The comparison of means and correlation analysis point to the following: i) the economic efficiency score appears to be the independent variable least explained by this set of predictors; ii) privatization appears to be the most consistent predictor for efficiency scores; iii) the unemployment rate and the acquisition of Portugália evidence the strongest and most positive relations; and iv) the influence of the election and Troika years shows limited relation with both the operation and financial efficiency of TAP.

The multiple linear regression model shows signs of multicollinearity between *acqportugalia* and *unemp* (the VIF test result, not formally reported, for both variables is greater than 5 for all efficiency scores). Therefore, two separate sets of models were developed, one considering the *acqportugalia* and the other the *unemp*. From the eight possible models (one for each efficiency score and considering *acqportugalia* or *unemp*), only one showed signs of heteroscedasticity (Breusch-Pagan test) and other nonnormal distribution of the residuals (Shapiro-Wilk test). Nevertheless, robust standard errors were used in all models. There is no evidence of specification problems (linktest), the functional forms seem appropriate (Ramsey test), and there are no influential observations based on the Cook's distance.

Table 25 and Table 26 depict the results of the evaluation of the privatization, controlling for exogenous variables considering the unemployment rate or the acquisition of Portugal, respectively. Using the unemployment rate (Table 25), the privatization is a statistically significant variable for most models, except in one model for economic efficiency 1. Replacing the unemployment rate with the acquisition of Portugália in the list of potential variables (Table 26) weakens the statistical significance of the privatization. Only one model is presented for the technical efficiency 2 score because the remaining models are equal to those presented in Table 25.

Table 25 **Results of the controlled effect of the privatization without the acquisition of Portugália**
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

	Regressions				
Variables	**1**	**2**	**3**	**4**	**5**
			TECH1		
priv	0.1507***	0.1596***	0.1489***	0.1557***	0.1603***
	(0.0329)	(0.0363)	(0.0265)	(0.0344)	(0.0317)
unra	0.0199***	0.0198***	0.0203***	0.0194***	0.0171**
	(0.0030)	(0.0029)	(0.0031)	(0.0031)	(0.0065)
elye		0.0296			
		(0.0395)			
elyelag			0.0329		
			(0.0426)		
fincrisis				0.0390	
				(0.0429)	
gdpg					-0.0062
					(0.0091)
Constant	0.6477***	0.6397***	0.6348***	0.6475***	0.6807***
	(0.0389)	(0.0435)	(0.0408)	(0.0396)	(0.0778)
Observations	30	30	30	30	30
R-squared	0.4570	0.4672	0.4710	0.4652	0.4664
			TECH2		
priv	0.1765***	0.1857***	0.1723***	0.1775***	0.1785***
	(0.0400)	(0.0447)	(0.0434)	(0.0410)	(0.0424)
troi	0.0999***	0.1015***	0.0957**	0.0904*	0.1064
	(0.0313)	(0.0360)	(0.0352)	(0.0521)	(0.0786)
elye		0.0301			
		(0.0476)			
fincrisis			-0.0322		
			(0.0359)		
gdpg				-0.0025	
				(0.0093)	
unra					-0.0008
					(0.0096)
Constant	0.7829***	0.7738***	0.7871***	0.7887***	0.7882***
	(0.0266)	(0.0327)	(0.0309)	(0.0380)	(0.0734)
Observations	30	30	30	30	30
R-squared	0.2311	0.2423	0.2371	0.2330	0.2313
			ECON1		
priv	0.0333***	0.0336***	0.0330***	0.0366***	0.0175
	(0.0098)	(0.0114)	(0.0107)	(0.0110)	(0.0138)

Variables	Regressions 1	2	3	4	5
unra	0.0015				0.0064*
	(0.0022)				(0.0037)
troi		-0.0106			-0.0626**
		(0.0117)			(0.0249)
gdpg			0.0023		
			(0.0026)		
fincrisis				0.0126	
				(0.0126)	
Constant	0.9468***	0.9598***	0.9542***	0.9569***	0.9179***
	(0.0231)	(0.0099)	(0.0082)	(0.0095)	(0.0313)
Observations	30	30	30	30	30
R-squared	0.0808	0.0731	0.0856	0.0740	0.1752
ECON2					
priv	0.1305***	0.1163**	0.1197**	0.1190**	0.1197**
	(0.0395)	(0.0451)	(0.0453)	(0.0490)	(0.0455)
unra	0.0242***	0.0274***	0.0262***	0.0262***	0.0263***
	(0.0041)	(0.0049)	(0.0056)	(0.0058)	(0.0058)
troi	-0.0807*	-0.1125**	-0.1194**	-0.1201*	-0.1205**
	(0.0407)	(0.0520)	(0.0551)	(0.0623)	(0.0559)
fincrisis		-0.0478	-0.0565	-0.0568	-0.0567
		(0.0302)	(0.0386)	(0.0417)	(0.0401)
gdpg			-0.0040	-0.0041	-0.0041
			(0.0067)	(0.0076)	(0.0067)
elye				-0.0020	
				(0.0281)	
elyelead					-0.0035
					(0.0266)

Variables	Regressions 1	2	3	4	5
Constant	0.6382***	0.6239***	0.6421***	0.6429***	0.6427***
	(0.0274)	(0.0290)	(0.0496)	(0.0540)	(0.0505)
Observations	30	30	30	30	30
R-squared	0.6751	0.6909	0.6968	0.6969	0.6970

Table 26 Results of the controlled effect of the privatization without the unemployment rate

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Variables	Regressions 1	2	3	4	5
TECH1					
priv	0.0759**	0.0841**	0.0759**	0.0606**	0.1006**
	(0.0287)	(0.0318)	(0.0284)	(0.0283)	(0.0387)
elye		0.0246		0.0890*	
		(0.0408)		(0.0493)	
elyelag			0.0107	0.0800	
			(0.0401)	(0.0493)	
fincrisis				-0.1073**	
				(0.0488)	
gdpg					-0.0082
					(0.0090)
acpo	0.1510***	0.1497***	0.1504***	0.1820***	0.1256**
	(0.0351)	(0.0354)	(0.0363)	(0.0347)	(0.0552)
elyelead				0.0828*	
				(0.0451)	

	Regressions				
Variables	1	2	3	4	5
Constant	0.7507***	0.7438***	0.7477***	0.6807***	0.7737***
	(0.0280)	(0.0322)	(0.0296)	(0.0386)	(0.0481)
Observations	30	30	30	30	30
R-squared	0.4558	0.4628	0.4572	0.5420	0.4742
TECH2					
priv	0.1884***				
	(0.0450)				
troi	0.1118***				
	(0.0372)				
acpo	-0.0152				
	(0.0471)				
Constant	0.7862***				
	(0.0333)				
Observations	30				
R-squared	0.2331				
ECON1					
priv		0.0027	0.0262**	0.0105	
		(0.0130)	(0.0097)	(0.0134)	
troi	-0.0239	-0.0231			-0.0237*
	(0.0145)	(0.0150)			(0.0134)
gdpg	0.0045	0.0044		0.0052	0.0049
	(0.0032)	(0.0035)		(0.0032)	(0.0035)
fincrisis					
acpo	0.0385**	0.0374**	0.0135	0.0297	0.0400***
	(0.0140)	(0.0173)	(0.0143)	(0.0176)	(0.0137)
elyelag					-0.0089
					(0.0156)

	Regressions				
Variables	1	2	3	4	5
Constant	0.9412***	0.9414***	0.9537***	0.9391***	0.9425***
	(0.0150)	(0.0156)	(0.0120)	(0.0151)	(0.0155)
Observations	30	30	30	30	30
R-squared	0.1793	0.1795	0.0873	0.1579	0.1885
ECON2					
priv	0.0936**	-0.0011	0.0037	-0.0021	-0.0062
	(0.0455)	(0.0152)	(0.0197)	(0.0199)	(0.0272)
acpo	0.1243**	0.2191***	0.2136***	0.2159***	0.2220***
	(0.0465)	(0.0182)	(0.0214)	(0.0176)	(0.0201)
troi	0.0175	-0.0773***	-0.1076***	-0.1131***	-0.1110***
	(0.0447)	(0.0127)	(0.0296)	(0.0350)	(0.0299)
fincrisis		-0.1579***	-0.1789***	-0.1826***	-0.1857***
		(0.0404)	(0.0520)	(0.0525)	(0.0442)
gdpg			-0.0084	-0.0090	-0.0074
			(0.0069)	(0.0078)	(0.0063)
elye				-0.0123	
				(0.0251)	
elyelead					0.0279
					(0.0288)
Constant	0.7687***	0.7687***	0.7922***	0.7975***	0.7817***
	(0.0153)	(0.0156)	(0.0306)	(0.0388)	(0.0272)
Observations	30	30	30	30	30
R-squared	0.6314	0.7325	0.7598	0.7624	0.7744

The weak relationship between *ECON1* and the explanatory variables is consistent in both uncontrolled and controlled analyses. The masking effect of the acquisition of Portugália with regard to the privatization may be due to the fact that the highest unemployment rate coincides with the former. The coincidence of this acquisition within a very peculiar economic period (financial crisis followed by Troika) may require a longer post-privatization period to understand the true correlation between the two variables. In fact, the apparent domination of the acquisition of Portugália over the privatization is not reflected in the models containing only these two variables.

The existence of interactions between variables was explored for models using the unemployment rate for the technical efficiency 1 and economic efficiency 2 scores. The interaction between the unemployment rate and the privatization is statistically significant and has a negative sign in both models (Table 27). Analysing both models shows that, in the context of a high unemployment rate (above 12% for *TECH1* and above 16% for *ECON2*), the efficiency gains from the privatization are lost.

Table 27 **Results of the controlled effect of the merger considering interaction**
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

	Regressions	
Variables	TECH1	ECON2
priv	0.326***	0.454***
	(0.083)	(0.031)
unra	0.020***	0.027***
	(0.003)	(0.003)
troi		-0.101**
		(0.036)
priv*unra	-0.020**	-0.037***
	(0.008)	(0.004)
Constant	0.644***	0.622***
	(0.037)	(0.023)
Observations	30	30
R-squared	0.464	0.711

An interesting result from the interaction is that the increase in efficiency with the unemployment rate is less pronounced after the privatization. This result may imply that the gains obtained due to private management in both technical and economic efficiency make the company less sensitive to the unemployment rate.

3.3.5. Conclusions

The results point towards an increased efficiency caused by the privatization, which was expected, based on evidence from the literature review. However, this indication must be considered with caution since only been a few years have elapsed since the privatization took place (only three), and since the privatization coincided with a particularly favourable context. Since 2015-2016, Portugal has witnessed record numbers in the number of tourists visiting the country, and it was elected best tourist destination between 2017 and 2019 at the World Travel Awards. This award, combined with the discrepancy between the country's purchasing power and that of the wealthiest countries, a discrepancy which was exacerbated by the 2008 economic crisis and the Troika years, has made Portugal a very attractive destination.

The results also show evidence of the importance that the acquisition of Portugália has had on improving the company's efficiency. Portugália, with a fleet of smaller aircrafts, provided more efficient short-distance, domestic and international flights, and allowed TAP to reap the benefits of an efficient feeder service, allocating the larger aircrafts to medium-distance connections. Disentangling the effects of the privatization and the acquisition of Portugália will probably require a larger data set, considering a higher number of years after the privatization took place. In the meantime, the Portuguese left-wing government has decided to partially revert the privatization, which took effect in 2020. As of 2020, the company is once again controlled by the government, owning 72.5% of total shares, and one of the initial investors holds the remaining shares. It will certainly be of interest to evaluate the effect that this decision will have on efficiency in the years to come, although the pandemic has had such a disruptive impact on the industry that efficiency analyses based on longitudinal data will be strongly affect for a very significant period.

3.4. Analysis 3: Effects of ownership models on efficiency scores – The case of urban rail transit transport

3.4.1. Introduction

The involvement of the private sector in utilities in general, and in transportation in particular, is not recent, but the expansion of that involvement is reported to have occurred in the 1980s and 1990s, driven by an agenda of devolution of public services to the private sector and a recentring of the role of government in planning, regulation and financing. In Europe, the procurement directives introduced in 1993 and subsequent rulings by the European Court of Justice put pressure on public authorities to put services out to tender, while directives on the liberalization of electricity, gas and other network services have forced the breakup of integrated public sector energy companies.

Two major motivations underpin the use of PPP and concessions (e.g., Hall 2012, Cruz and Marques 2013): i) overcoming public budget constraints, by using private sector funding, even if at a higher interest rate; and ii) improving service at reduced costs for the final users by bringing management, know-how and expertise to the private sector, in addition to competition that would boost efficiency and encourage innovation.

However, currently, Hall (2012) claims that there is a clear trend of municipalities shifting from privatization to "*remunicipalization*". In several countries in Europe, including Germany, France and the UK, there are various cases of services being brought under public control in sectors such as water, energy, public transport and waste management. In many cases, the end of contract maturity is an important enabling factor, but bases for the decisions on nonrenewal of contracts and changes in the model include cost reduction, higher service effectiveness, better control, private failure and more flexibility to adjust the service to meet public objectives.

Within this context, this paper aims to contribute to the discussion by comparing the economic efficiency of privately and publicly managed urban rail transportation firms in Portugal. This comparison was done through econometric models with a dummy variable identifying the groups of publicly (0) and privately (1) managed firms. The economic efficiency was obtained on a yearly basis with a DEA model developed from the firms' financial report data.

The influence of the type of management on economic efficiency was assessed by controlling for the potential effect of the following exogenous factors: i) the financial crisis between 2008 and 2010; ii) the period of the Portuguese bailout programme (Troika) between 2011 and 2014; iii) GDP growth; and iv) the unemployment rate. Additionally, the creation of a regulator for the transportation sector in 2014 and the political cycles identified by the election years were considered. A one-year lead and lag of the election year was also considered.

3.4.2. Literature review and research questions

The discussion of the merits and pitfalls of private management of transportation companies has distant roots in economic and management theory (Vickers and Yarrow, 1988; Dnes, 1996). The underlying rationale of the discussion and research has been to identify the optimal ownership models or, in other words, the organizational and ownership models that enable a more efficient use of resources (Wang and Chen, 2010). In fact, the search for the optimal system configuration (in terms of ownership and regulation) should focus on achieving the most efficient solutions.

In the specific field of rail services and rail urban transit, the discussion in the literature began with the study of the UK case. The UK has had a leading role in fostering private sector participation in rail systems with the Railways Act 1993 (Shires et al., 1994). The first evidence, confirmed by Pollitt and Smith (2005), was that it was possible to achieve higher efficiency and lower government subsidies, all without decreasing the quality of service. Cowie (2009) claims that the British passenger rail privatization stimulated an increase in efficiency while decreasing government subsidies, although at the expense of some forms of the winner's curse phenomenon.

However, the British case has been quite controversial, as discussed by MacCartney and Stittle (2008) and Smith (2006). Mathiew (2003) claims that efficiency gains have been achieved at the expense of a lower quality to price ratio and, therefore, the conclusions on the increase in social welfare were unclear.

Other geographies have evidenced similar patterns, as discussed by Boardman et al. (2013). These authors analysed the privatization of the Canadian National Railway and found a long-term increase in productivity and profitability, among other financial indicators.

Many authors have found evidence that increasing the role of the private sector can increase productivity and social welfare (e.g., Boardman et al., 2002, Boardman and Vinning, 1989, Megginson and Netter, 2001). The Japanese experience also seems to support the thesis of a superior performance of private management over purely public management, as extensively discussed by Mizutani and Nakamura (1996) or Thompson (2003).

This discussion was mostly centred on traditional forms of privatization, which has changed over the last 20 to 30 years, with an increase in the use of PPPs and concessions. Although many scholars still use the term "privatization", in many cases the ownership model is, in fact, a PPP or a concession (for more on the distinction between PPP and concession, see Cruz and Sarmento, 2017).

However, the literature has provided evidence, albeit weak, on the influence of external economic factors, on the efficiency of the companies, or taking into account their ownership model. Our study intends to analyse the Portuguese case and the effects of private sector involvement in terms of increased efficiency. Is private management a driver of efficiency for urban transit? How are private and public companies affected by external factors? Are there statistically significant differences? These are the main research questions we pose.

3.4.3. Research methods and data

The information needed for evaluating economic efficiency was retrieved from the 2008-2018 annual reports of the four urban rail firms in Portugal. The results of the three privately-managed firms were aggregated to obtain the average efficiency instead of the individual efficiency of each firm. In addition to the type of contract, statistical data was obtained for the unemployment rate (*unra*) and gross domestic product growth (*gdpg*). The other potential explanatory variables considered were: i) election years (*elye*); ii) the financial crisis (*ficr*) period; and iii) the Troika (*troi*) supervision period. For the election years, a lead (*elyelead*) and lag (*elyelag*) of one year were also considered. Portugal was severely affected by the 2008 economic crisis until 2010, resulting in the request for an international bailout programme from the European Commission, the European Central Bank and the International Monetary Fund between 2011 and 2014.

A four-step methodology was used in this research: i) efficiency estimation; ii) assessment of the uncontrolled effect of the type of management; iii) assessment of the controlled effect of the type of management; and iv) evaluation of potential interactions between the type of management and the continuous variables.

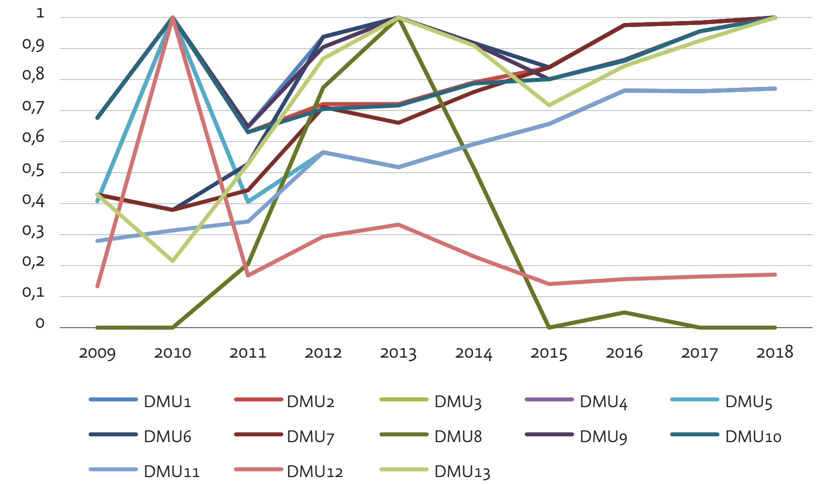
The first step consisted of estimating efficiency scores for each group of firms (publicly and privately managed), which was accomplished through data envelopment analysis (DEA). A yearly timescale was used, and a total of five financial efficiency scores were obtained. The scores are presented in Table 28. From a total of 15 scores, we have used five: 2, 4, 5, 13 and 15.

Four urban rail firms are analysed to assess the influence of the type of management on their economic efficiency. The Metropolitano de Lisboa is the only urban rail firm under public management, while Metro Transportes do Sul, Fertagus and Metro do Porto are privately managed. The economic scores are analysed from 2009 to 2018, and the data of the three privately managed firms were aggregated as one firm. Fifteen combinations of inputs (Operating costs, Assets, and Liabilities as percentage of assets) and outputs (Revenue and EBITDA as percentage of revenue) were considered, as shown in Table 28. The economic scores for each combination are presented in Figure 21 for public management and in Figure 22 for private management.

Table 28 Efficiency scores for publicly and privately managed firms

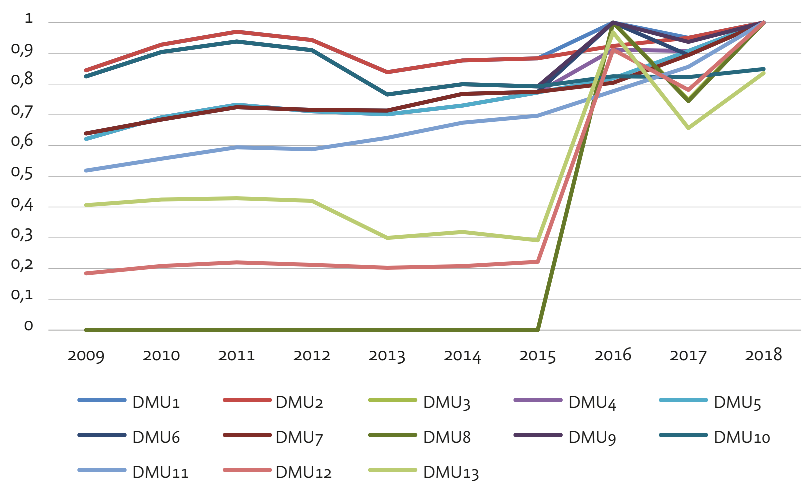
Analysis	Inputs	Outputs
DMU1	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU2	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
DMU3	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%)
DMU4	Operating costs (€) Asset (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU5	Operating costs (€) Asset (€)	Revenue (from tickets) (€)
DMU6	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU7	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
DMU8	Operating costs (€) Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%)
DMU9	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU10	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
DMU11	Operating costs (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU12	Asset (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU13	Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)

Figure 21 Economic efficiency for publicly managed firms



The uncontrolled assessment of the effect produced by the type of management was done by testing whether there is a statistically significant difference between the means of the efficiency of privately and publicly managed firms. Parametric (t-test) and nonparametric (Mann-Whitney U) tests were used depending on the normality of the efficiency scores distribution in each group. The Shapiro-Wilk test was chosen to assess the normality of the data distribution. Complementary uncontrolled analysis of the dataset was done using the same approach with the remaining categorical variables (financial crisis, Troika, election years and regulator), but only the main relevant results are reported. Regarding the continuous predictors (unemployment rate and GDP growth), correlations with efficiency scores were evaluated globally and for each group. Parametric (Pearson) and nonparametric (Kendall's tau and Spearman rho) correlations were used depending on whether the variables evidenced normal or nonnormal distribution, respectively. Despite not being reported herein, visual assessment of the data was also carried out with box plots and scatter plots.

Figure 22 Economic efficiency for privately managed firms



Ordinary least squares (OLS) multiple linear regression was used to evaluate the influence of the contract type on efficiency scores while controlling for the effect of all other significant predictors. The baseline for the controlled evaluation of the effect of the contract type on the economic efficiency of road concessions was the following econometric model:

$$Yi = \beta_0 + \beta_1\, troi + \beta_2\, ficr + \beta_3\, \mathrm{gdpg} + \beta_4\, \mathrm{unra} + \beta_5\, \mathrm{elye} + \beta_6\, mana + \beta_7\, regu + \mu i$$

where

troi is a dummy variable assuming the value 1 in the years that Portugal was subject to a bailout programme with the IMF/ECB/EU (between 2011 and 2014) and 0 otherwise. Portugal asked for a financial bailout in 2011 due to a steady increase in public and external debt (Pereira and Wemans, 2015; Reis, 2015). There are several reasons why the Troika period may have impacted on the efficiency of these infrastructures. Firstly, there were substantial financial restrictions, which can lead to a reduction in investment and maintenance, thus decreasing efficiency. Additionally, there was a recession during the Troika programme period, leading to less demand, which can also reduce infrastructure efficiency (De Borger et al., 2002; Sarmento et al., 2017). Furthermore, the programme included several measures concerning the transport sector, aiming to increase the sector's efficiency (Sarmento and Reis, 2019).*ficr* is a variable assuming the value 1 between 2008 and 2010 and 0 otherwise. This variable is intended to capture the effect of the 2008 financial crisis that culminated in the bailout programme of 2011.

gdpg is GDP growth as a percentage. Better economic times mean more demand for travelling, which can increase infrastructure efficiency *per se*.

unra is the unemployment rate as a percentage. More unemployment leads to less demand for transport, creating pressure in the efficiency of the infrastructures. We also tested with the log of this variable.

elye is a dummy variable assuming the value 1 if there was a national Parliament election (which elects the government) on that year, and 0 otherwise. It is intended to capture whether an election and a potential change in policies led to more or less efficiency. It was also used to test the option of considering a lead or a lag of one year in relation to the election year.

mana is a dummy variable, taking the value 0 for the publicly managed urban rail firm and 1 for the group of three privately managed urban rail firms. This approach allows us to assess the specific impact of the type of management on the firms' efficiency overall, but not that of each individual privately managed firm.

regu is a dummy variable representing the creation of the public transport regulator in 2014. It takes the value 0 before 2014 and 1 thereafter, controlling for any effect of this change in the sector on the firm's efficiency.

The selection of the variables to be included in the regression models was done using a best subsets approach and tested the difference between using the Akaike information criterion or the adjusted R2 as the criterion for entry or removal of the predictors in the process of selecting the best subsets. Multicollinearity and heteroscedasticity were assessed through the volume of inflation factor (VIF) and the Breusch-Pagan test, respectively. The normality of the residuals (Shapiro-Wilk test), specification (Linktest), functional form (Ramsey test) and outliers (Cook's distance) was also assessed.

The combined effect of the predictors was evaluated by building a generalized linear model (GLM) with an interaction term, but only for the OLS models determined in the previous step; with the highest fit (based on the R-squared), all were variables statistically significant and at least one continuous variable was included.

3.4.4. Results and discussion

Table 29 presents the scores obtained, along with the exogenous variables considered. From the visual observation of the data, higher efficiency scores seem to exist for most DMUs on the privately managed firms.

Table 29 Results of the effect of the type of management

Company	Year	ECON2	ECON4	ECON5	ECON13	ECON15
ML	2009	0,67682	0,40831	0,40831	0,27989	0,42881
ML	2010	1	1	1	0,31354	0,21498
ML	2011	0,63039	0,40597	0,40597	0,34195	0,52797
ML	2012	0,72113	0,56543	0,56543	0,56543	0,86762
ML	2013	0,72094	0,51744	0,51744	0,51744	1
ML	2014	0,79112	0,59195	0,59195	0,59195	0,90998
ML	2015	0,83936	0,65675	0,65675	0,65675	0,71742
ML	2016	0,97585	0,76467	0,76467	0,76467	0,84411
ML	2017	0,98356	0,76243	0,76243	0,76243	0,92519
ML	2018	1	0,77094	0,77094	0,77094	1
MTS+Fertagus+MP	2009	0,84484	0,62145	0,62145	0,51866	0,40616
MTS+Fertagus+MP	2010	0,92813	0,69163	0,69163	0,55727	0,42432
MTS+Fertagus+MP	2011	0,97036	0,73276	0,73276	0,59419	0,42865
MTS+Fertagus+MP	2012	0,94316	0,71152	0,71152	0,58787	0,42031
MTS+Fertagus+MP	2013	0,83866	0,70183	0,70183	0,62507	0,29975
MTS+Fertagus+MP	2014	0,87676	0,73012	0,73012	0,67423	0,319
MTS+Fertagus+MP	2015	0,88371	0,7727	0,7727	0,69715	0,29177
MTS+Fertagus+MP	2016	0,92391	0,91195	0,81846	0,77671	0,96838
MTS+Fertagus+MP	2017	0,95059	0,90757	0,90757	0,856	0,65705
MTS+Fertagus+MP	2018	1	1	1	1	0,83572

Except for the privately managed firms of DMU15, the distributions are normal based on the Shapiro-Wilk test results (not presented). Coincidently, DMU15 was the only economic efficiency score evidencing a noncontrolled statistically significant difference between privately and publicly managed companies. The statistical significance is confirmed by both the t-test results (Table 30) and the Mann--Whitney U test (not presented here) for a significance level of 0.05.

Table 30 **Results of the noncontrolled effect of the type of management**

Variables		Levene's Test F	Levene's Test Sig.	t-test t	t-test df	t-test Sig. (2-tailed)
DMU2	Equal variances assumed	15.365	0.001	-1.672	18	0.112
	Equal variances not assumed			-1.672	11.384	0.122
DMU4	Equal variances assumed	1.696	0.209	-1.915	18	0.072
	Equal variances not assumed			-1.915	15.458	0.074
DMU5	Equal variances assumed	2.541	0.128	-1.817	18	0.086
	Equal variances not assumed			-1.817	14.827	0.090
DMU13	Equal variances assumed	0.900	0.355	-1.725	18	0.102
	Equal variances not assumed			-1.725	17.061	0.103
DMU15	Equal variances assumed	0.224	0.642	2.117	18	0.048
	Equal variances not assumed			2.117	17.716	0.049

Regarding the remaining categorical variables, Troika, election years and the introduction of the regulator have a statistically significant effect on most efficiency scores. The financial crisis is only statistically significant on DMU13 and 15.

Except for DMU15, there is a statistically significant correlation with GDP growth. In contrast, the unemployment rate only has a statistically significant correlation with DMU2 (Table 31). Regardless of the statistical significance, the sign of the correlations is consistent for all DMUs, with a positive correlation with GDP growth and a negative correlation with the unemployment rate. The former may be due to the relationship between wealth and leisure, with an increase in wealth promoting more leisure activities that may require using more public transportation. The latter is probably related to the fact that with an increase in unemployed individuals, the demand for commuting between residence and work decreases. Furthermore, since unemployment tends to affect less-skilled and low-wage jobs more profoundly, it directly impacts those more likely to use public transportation over personal transportation. A similar pattern is observed when analysing the privately and publicly managed firms separately.

Table 31 **Correlations between efficiency scores and the continuous predictors**

	Pearson		Kendall's tau		Spearman's rho	
Variable	gdpg	unra	gdpg	unra	gdpg	unra
DMU2	0.604*	-0.473*	0.480**	-0.480**	0.632**	-0.596**
DMU4	0.654**	-0.419	0.493**	-0.385*	0.708**	-0.494*
DMU5	0.652**	-0.424	0.504**	-0.396*	0.714**	-0.503*
DMU13	0.613**	-0.341	0.595**	-0.292	0.773**	-0.368
DMU15	0.302	-0.170	0.211	-0.125	0.340	-0.146

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

The comparison of means and correlation analysis reveal the following: i) without controlling for other variables, the effect of the type of management is weak; ii) DMU15 seems to be the less explained factor based on the explanatory variables considered; and iii) GDP growth has the strongest correlation with economic efficiency.

With the exceptions of *elye* and *mana*, all other variables have a VIF above 5, and *troi* is even above 10, revealing strong multicollinearity between several of the categorical variables. There are no signs of heteroscedasticity (Breusch-Pagan test), but for DMU4 and 15, the residual distributions are nonnormal (Shapiro-Wilk test), and an influential observation exists for DMU4 (Cook's distance). However, the models built by combining subsets of the potential set of predictors to solve the multicollinearity issue do not suffer from these issues, with the exception of the influential observation in some DMU4 models. Since robust standard errors were used in all models, the influence of the influential observation on the regression coefficients values is mitigated. There is also no evidence of specification problems (linktest).

From the total of ten regression models that were developed for each DMU using the best subsets method to select the variables to include, the five with the highest adjusted R-squared of each DMU are presented in Table 32. The results reveal the existence of a statistically significant effect of management type on the economic efficiency of urban rail firms in all combinations of exogenous variables selected to control for. However, the effect of the management type on DMU15 is the opposite of the effect on the other efficiency scores. The other influential variables in various models are GDP growth, the election year, the unemployment rate, the Troika and the financial crisis.

The results of the controlled and uncontrolled analysis are consistent, including the signal inversion on the management type dummy variable in the DMU15 regression model. Note that, except for GDP growth and the election year (not the lead or lag), all other variables have a negative effect on economic efficiency.

Table 32 Result of the controlled effect of management type on the urban rail firms' economic efficiency
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

	Regression Models				
Variables	1	2	3	4	5
	DMU2				
mana	0.0821**	0.0821**	0.0821**	0.0821**	0.0821**
	(0.0350)	(0.0353)	(0.0353)	(0.0353)	(0.0360)
gdpg	0.0228**	0.0254***	0.0254***	0.0187**	0.0291***
	(0.0082)	(0.0073)	(0.0073)	(0.0082)	(0.0075)
unra	-0.0104*	-0.0185*	-0.0185*	-0.0124**	
	(0.0050)	(0.0099)	(0.0099)	(0.0053)	
elyelead	0.0798*	0.0949**	0.0949**	0.0621	0.0730*
	(0.0412)	(0.0392)	(0.0392)	(0.0407)	(0.0407)
troi		0.0620	0.0620		
		(0.0690)	(0.0690)		
elye				-0.0406	
				(0.0444)	
Constant	0.9266***	0.9923***	0.9923***	0.9681***	0.8042***
	(0.0791)	(0.1116)	(0.1116)	(0.0825)	(0.0299)
Observations	20	20	20	20	20
R-squared	0.6342	0.6528	0.6528	0.6510	0.5873

	Regression Models				
Variables	1	2	3	4	5
			DMU4		
mana	0.1338**	0.1338**	0.1338**	0.1338**	0.1338**
	(0.0500)	(0.0512)	(0.0473)	(0.0528)	(0.0478)
gdpg	0.0436***	0.0402***	0.0290***	0.0400*	0.0378***
	(0.0094)	(0.0111)	(0.0083)	(0.0196)	(0.0068)
unra		-0.0056	-0.0121*	-0.0059	
		(0.0073)	(0.0067)	(0.0134)	
elye			-0.1114**		-0.0904**
			(0.0455)		(0.0405)
ficr				-0.0031	
				(0.1435)	
Constant	0.6327***	0.6995***	0.8126***	0.7033***	0.6613***
	(0.0414)	(0.1024)	(0.0987)	(0.1702)	(0.0437)
Observations	20	20	20	20	20
R-squared	0.5974	0.6040	0.6821	0.6040	0.6547
			DMU5		
mana	0.1244**	0.1244**	0.1244**	0.1244**	0.1244**
	(0.0497)	(0.0507)	(0.0473)	(0.0478)	(0.0469)
gdpg	0.0423***	0.0386***	0.0279***	0.0367***	0.0255**
	(0.0094)	(0.0112)	(0.0086)	(0.0069)	(0.0096)
unra		-0.0059	-0.0122		
		(0.0076)	(0.0070)		
elye			-0.1068**	-0.0857*	-0.1139*
			(0.0470)	(0.0412)	(0.0570)
troi					-0.0805
					(0.0651)
Constant	0.6330***	0.7038***	0.8122***	0.6602***	0.7039***
	(0.0416)	(0.1064)	(0.1029)	(0.0439)	(0.0654)

	Regression Models				
Variables	1	2	3	4	5
Observations	20	20	20	20	20
R-squared	0.5801	0.5878	0.6638	0.6345	0.6696
			DMU13		
mana	0.1322***	0.1322***	0.1322***	0.1322***	0.1322***
	(0.0282)	(0.0283)	(0.0275)	(0.0359)	(0.0284)
gdpg			-0.0195	0.0123	
			(0.0134)	(0.0115)	
elye	-0.1107***	-0.1299***	-0.1421***	-0.1024	-0.1049**
	(0.0353)	(0.0383)	(0.0451)	(0.0675)	(0.0352)
ficr	-0.3364***	-0.3231***	-0.3953***	-0.2745***	-0.2925***
	(0.0429)	(0.0459)	(0.0611)	(0.0639)	(0.0560)
troi	-0.1450**	-0.1654**	-0.3006***		-0.1165**
	(0.0580)	(0.0609)	(0.0605)		(0.0520)
elyelead		-0.0385	-0.0684	0.0052	
		(0.0397)	(0.0407)	(0.0406)	
elyelag			0.0706*	-0.0295	
			(0.0341)	(0.0380)	
unra	-0.0166*	-0.0123		-0.0304***	-0.0154
	(0.0089)	(0.0095)		(0.0076)	(0.0095)
regu					0.0456
					(0.0366)
Constant	0.9105***	0.8824***	0.8030***	1.0048***	0.8515***
	(0.0869)	(0.0915)	(0.0496)	(0.1030)	(0.1138)
Observations	20	20	20	20	20
R-squared	0.9099	0.9156	0.9264	0.8746	0.9147
			DMU15		
mana	-0.2385**	-0.2385**	-0.2385**	-0.2385**	-0.2385**
	(0.0841)	(0.0838)	(0.0848)	(0.0848)	(0.0857)

Variables	Regression Models 1	2	3	4	5
unra	-0.0344**	-0.0391**	-0.0469**	-0.0312	-0.0479**
	(0.0133)	(0.0157)	(0.0197)	(0.0214)	(0.0204)
elye	-0.1728*	-0.2318**	-0.2096**	-0.2371**	-0.2503**
	(0.0844)	(0.0936)	(0.0733)	(0.0803)	(0.0915)
ficr	-0.3492**	-0.3150**	-0.3926**	-0.4661**	-0.3530**
	(0.1353)	(0.1270)	(0.1516)	(0.1839)	(0.1499)
elyelag		-0.1178			-0.0997
		(0.1153)			(0.1175)
gdpg			-0.0218	-0.0383	-0.0164
			(0.0216)	(0.0306)	(0.0219)
troi				-0.1878	
				(0.1771)	
Constant	1.2706***	1.3729***	1.4442***	1.3608***	1.4878***
	(0.1268)	(0.1883)	(0.2125)	(0.2117)	(0.2363)
Observations	20	20	20	20	20
R-squared	0.6284	0.6553	0.6471	0.6724	0.6653

The interaction between the management type and the unemployment rate or GDP growth was confirmed to be statistically significant for DMU2, 13 and 15 (Table 33).

Table 33 Results of the controlled effect of the management type considering interaction

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Variables	Regressions Models DMU2	DMU4	DMU5	DMU13	DMU15
mana	0.069	0.250*	0.130**	0.316***	0.527**
	(0.092)	(0.133)	(0.040)	(0.068)	(0.229)
elyelead	0.080**				
	(0.022)				
elye		-0.111**	-0.086**	-0.111**	-0.173**
		(0.037)	(0.034)	(0.028)	(0.065)
troi				-0.145**	
				(0.048)	
ficr				-0.336***	-0.349**
				(0.031)	(0.105)
gdpg	0.043***	0.042**	0.048**		
	(0.005)	(0.011)	(0.011)		
unra	-0.011**	-0.007		-0.009	-0.002
	(0.003)	(0.008)		(0.006)	(0.013)
mana*gdpg	-0.041**	-0.025	-0.022		
	(0.10)	(0.014)	(0.014		
mana*unra	0.002	-0.009		-0.016**	-0.065**
	(0.007)	(0.011)		(0.005)	(0.017)
Constant	0.933***	0.755***	0.657***	0.819***	0.888***
	(0.037)	(0.100)	(0.039)	(0.054)	(0.158)
Observations	20	20	20	20	20
R-squared	0.850	0.708	0.664	0.925	0.743

The most interesting results can be found in DMU2 and DMU15. Regarding the former, the negative sign of the interaction between GDP growth and the management type implies that the privately managed firms are less efficient for positive GDP growths, losing their higher efficiency (coefficient of 0.069 for the management type dummy variable) for GDP growth of more than 1%. On the other hand, they become increasingly more efficient for negative GDP growth values, which may be related to the higher management flexibility enjoyed by privately managed firms, particularly regarding their workforce. Considering the financial crisis and Troika supervision context of a significant portion of the timeframe under analysis, this advantage may explain the higher efficiency displayed by the privately managed firms. When compared with the model without interaction (Table 32), the model with interaction for DMU15 changes the sign of the management type dummy variable from negative to positive. Combining this change with the regression coefficient of the interaction variable, privately managed firms were more efficient when the unemployment rate was below 8%. Between 2009 and 2018, the unemployment rate was only under that threshold (7%) in the last year. Therefore, the publicly managed firm was more efficient based on the metrics underlying the DMU15 efficiency scores.

3.4.5. Conclusions

Some relevant limitations of the study must be noted: i) there is only one publicly managed firm against three privately managed firms; ii) each firm operates under a specific context that cannot accurately be accounted for; and iii) the financial data of each privately managed firm was aggregated to estimate the overall efficiency of the group. These limitations complicate the interpretation of results and limit the overall conclusion. Linking the DEA models with the econometric models, a clear pattern emerges, whereby when measuring efficiency with the operational costs as an input, the privately managed firms are more efficient, regardless of the other financial metrics used on inputs and outputs. However, this pattern may simply be a consequence of the fact that the publicly managed firm runs an underground system, while the privately managed firms all deal with surface rail systems.

3.5. Analysis 4: Effects of concession models on efficiency scores – the case of road concessions (availability vs real tolls)

3.5.1. Introduction

Private public partnerships have been and still are extensively used by governments worldwide to provide public infrastructures with the participation of the private sector. One option frequently used in the road sector is resorting to a concession. Among the diversity of aspects and possible options when drawing a concession contract, one key aspect is the model used for reimbursing the private partner, namely, based on availability oron toll revenues. The goal of this research effort is to assess whether the contract type influences the economic efficiency of the concession and which of the contract types leads to more or less efficiency.

To answer the research question, a DEA model assessing the economic efficiency scores of the Portuguese road concessions was developed. Those scores were used as the dependent variable, and the explanatory variable is a dummy identifying the group of concessions with availability--based contracts (1) and the group with toll-based contracts (0).
To minimize the influence of other concession-specific issues, the yearly

economic efficiency was obtained for the concessions of each type of contract as a group and not for each concession separately.

Complementarily to the type of contract, the following factors that can also impact efficiency were accounted for: i) the financial crisis between 2008 and 2010; ii) the period of the Portuguese bailout programme (Troika) between 2011 and 2014; iii) GDP growth; and iv) the unemployment rate. Catalão et al. (2019a,b; 2020) found that election years are significant variables when explaining cost deviations of public construction projects. Considering that construction projects can represent a significant portion of road costs, including the operation and maintenance intervention, these variables have been included. Considering that construction projects may have long time lapses, a one-year lead and lag of the election year was also considered following the approach used by Catalão et al. (2019a,b; 2020).

This essay is organized as follows: section 2 provides an overview of the merger process and objectives; the research methods and data are explained in section 3; the results and discussion are presented in section 4; and conclusions are provided in section 5.

3.5.2. Literature review and research questions

The literature identifies two main principles to justify road development made through concessions (Cruz and Marques, 2013; Fernandes et al., 2015): i) the limitations of governments in financing road building directly; and ii) achieving value-for-money by using private sector management, i.e., increasing efficiency in the construction and O&M of road infrastructure. Therefore, efficiency and the ability to achieve higher levels of efficiency is intrinsically correlated with the genesis of road concessions and with their ex-post analyses.

Notwithstanding, the methodology and perspectives on what is efficiency and/or which aspects of efficiency should be measured have found different configurations in past research. For example, Rouse and Chiu (2009) and Wang and Tsai (2009) analysed efficiency from the perspective of road maintenance. The authors used a DEA-based methodology to identify which road operators are more efficient in maintenance operations. Other authors have focussed the analysis of road efficiency on the subject of safety evaluation (Ahmadvand et al. (2011), Odeck (2006), Egilmez and McAvoy (2013)). Moreover, other authors reduce the issue of efficiency to energy consumption (e.g., Chen et al., 2018).

The literature also provides broader perspectives of efficiency. Jiang et al. (2011) adopted a slightly different perspective and analysed road efficiency through the lens of traffic. Sarmento et al. (2017) analysed the technical and technological efficiency of Portuguese highways over time and concluded that there was a reduction in both types of efficiency, mainly due to an increase in operation and maintenance costs and a decline in traffic. López and Cacheda (2018) analysed the Spanish toll roads and concluded that the great majority of toll roads are not fully effective. Also in Spain, Albalate and Rosell (2019) found that regional governments grant more efficient road projects than central government, but there are no significant differences between public/private ownership share.

The literature on privately managed highway efficiency has not taken into consideration the differences in concession regimes. Different concession regimes represent distinct risk allocation mechanisms and, consequently, distinct incentives for road operators.

Road concessions can be organized into three categories that represent alternative remuneration mechanisms: i) real toll; ii) shadow toll; and iii) availability payments. In real toll mechanisms, concession users pay a toll for using the road. These concessions apply the user-payer principle. The tolls are typically a source of revenue for the operator; they can be the only source of revenue or include an additional subsidy component in the form of a lump sum or monthly payments. These subsidies are implemented when the toll revenue does not ensure the financial and economic balance of concessions. In shadow tolls, users do not pay tolls. The number and type of vehicles are identified, and the corresponding tolls (toll level multiplied by the type of vehicle) is paid for by the government (Tillman, 1997).

In both real and shadow tolls, the level of traffic is the underlying variable for revenue generation. This situation does not occur in availability payments, where payment is linked to the availability of the infrastructure in a "rental"-type arrangement. The government makes managerial decisions on how and when to charge tolls, the amount charged, and the potential adoption of dynamic management toll systems that determine the toll charge according to congestion (Tillman, 1997).

3.5.3. Research methods and data

The contracts of 23 road concessions and their respective annual reports between 2004 and 2016 were used to extract the data for evaluating economic efficiency. The results of each individual concession were aggregated based on the type of contract, resulting in a group of 16 availability-based contracts and another of 7 toll-based contracts. The number of concessions of each group in each year is not constant throughout the period of analysis.

In addition to the type of contract, statistical data was obtained for the unemployment rate (*unra*) and gross domestic product growth (*gdpg*). The other potential explanatory variables considered were: i) election years (*elye*); ii) the financial crisis (*ficr*) period; and iii) the Troika (*troi*) supervision period. For the election years, it was also considered a lead (*elyelead*) and lag (*elyelag*) of one year. Portugal was severely affected by the 2008 economic crisis until 2010, resulting in the request for an international bailout programme from the European Commission, the European Central Bank and the International Monetary Fund between 2011 and 2014.

Table 34 Road concessions and period of analysis per type of contract

Availability-based contract		Toll-based contract	
Road Concession	**Period**	**Road Concession**	**Period**
AE Baixo Alentejo	2011-2013	AE Atlântico	2003-2017
AE Baixo Tejo	2011-2016	AE Douro Litoral	2011-2015
AE Litoral Oeste	2011-2014	AE Marão	2008-2012
AE Transmontana	2011-2016	Brisa	2004-2009
Ascendi Douro Interior	2008-2016	Brisa Concessão Rodoviária	2010-2016
Ascendi Norte	2004-2016	Brisal	2004-2015
Euroscut Algarve	2004-2016	Lusoponte	2002-2016
Euroscut Norte Litoral	2008-2016		
Luso Grande Lisboa	2007-2016		
Lusoscut Beira Alta	2004-2016		
Lusoscut Costa	2004-2016		

Availability-based contract		Toll-based contract	
Road Concession	**Period**	**Road Concession**	**Period**
Lusoscut Grande Porto	2004-2016		
NorScut	2004-2015		
Pinhal do interior	2010-2016		
Rotas do Algarve Litoral	2011-2014		
SCUT Beira Interior	2004-2016		

Table 35 shows 40 combinations of inputs (Operating costs, Assets and Liabilities as percentage of assets) and outputs (Revenue, EBITDA as percentage of revenue and Net profit). The economic scores for each combination are presented in Figure 23, for toll-based contracts, and Figure 24, for availability-based contracts.

Table 35 Economic efficiency: inputs and outputs for road concessions

Analysis	Inputs	Outputs	Analysis	Inputs	Outputs
DMU1	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%) Net profit (€)	DMU21	Operating costs (€) Liabilities as percentage of asset (%)	Net profit (€)
DMU2	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)	DMU22	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%) Net profit (€)
DMU3	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)	DMU23	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU4	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%) Net profit (€)	DMU24	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
DMU5	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)	DMU25	Asset (€) Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%) Net profit (€)
DMU6	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%)	DMU26	Asset (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)
DMU7	Operating costs (€) Asset (€) Liabilities as percentage of asset (%)	Net profit (€)	DMU27	Asset (€) Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%)
DMU8	Operating costs (€) Asset (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%) Net profit (€)	DMU28	Asset (€) Liabilities as percentage of asset (%)	Net profit (€)
DMU9	Operating costs (€) Asset (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)	DMU29	Operating costs (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%) Net profit (€)

Analysis	Inputs	Outputs	Analysis	Inputs	Outputs
DMU10	Operating costs (€) Asset (€)	Revenue (from tickets) (€) Net profit (€)	DMU30	Operating costs (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU11	Operating costs (€) Asset (€)	EBITDA as percentage of revenue (%) Net profit (€)	DMU31	Operating costs (€)	Revenue (from tickets) (€) Net profit (€)
DMU12	Operating costs (€) Asset (€)	Revenue (from tickets) (€)	DMU32	Operating costs (€)	EBITDA as percentage of revenue (%) Net profit (€)
DMU13	Operating costs (€) Asset (€)	EBITDA as percentage of revenue (%)	DMU33	Asset (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%) Net profit (€)
DMU14	Operating costs (€) Asset (€)	Net profit (€)	DMU34	Asset (€)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU15	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%) Net profit (€)	DMU35	Asset (€)	Revenue (from tickets) (€) Net profit (€)
DMU16	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)	DMU36	Asset (€)	EBITDA as percentage of revenue (%) Net profit (€)
DMU17	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)	DMU37	Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%) Net profit (€)
DMU18	Operating costs (€) Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%) Net profit (€)	DMU38	Liabilities as percentage of asset (%)	Revenue (from tickets) (€) EBITDA as percentage of revenue (%)
DMU19	Operating costs (€) Liabilities as percentage of asset (%)	Revenue (from tickets) (€)	DMU39	Liabilities as percentage of asset (%)	Revenue (from tickets) (€) Net profit (€)
DMU20	Operating costs (€) Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%)	DMU40	Liabilities as percentage of asset (%)	EBITDA as percentage of revenue (%) Net profit (€)

The preliminary analysis consisted of the traditional plotting of scatter and box plots, along with descriptive statistics of the continuous variables and crosstabs of the categorical variables. The normality of efficiency scores was also evaluated globally and by each group of the categorical variables, along with unemployment rate and gross domestic product growth, using the Shapiro-Wilk test.

Comparison of means tests and correlation analysis were used to evaluate the relationship between each exogenous variable and each variable's efficiency score. Both parametric (t-test) and nonparametric (Mann-Whitney U test) comparisons of means tests were used for the categorical exogenous variables. For the exogenous scale variables, parametric (Pearson) and nonparametric (Kendall's tau) correlations were used.

Figure 23 Economic efficiency for toll-based contracts

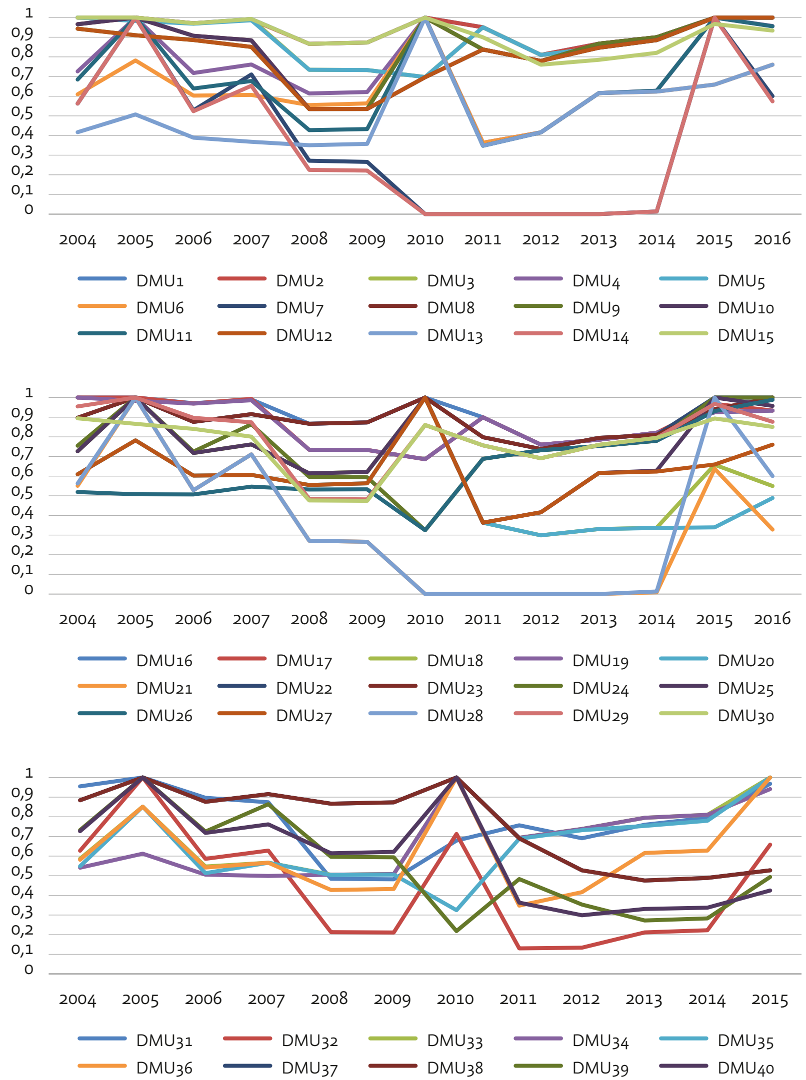
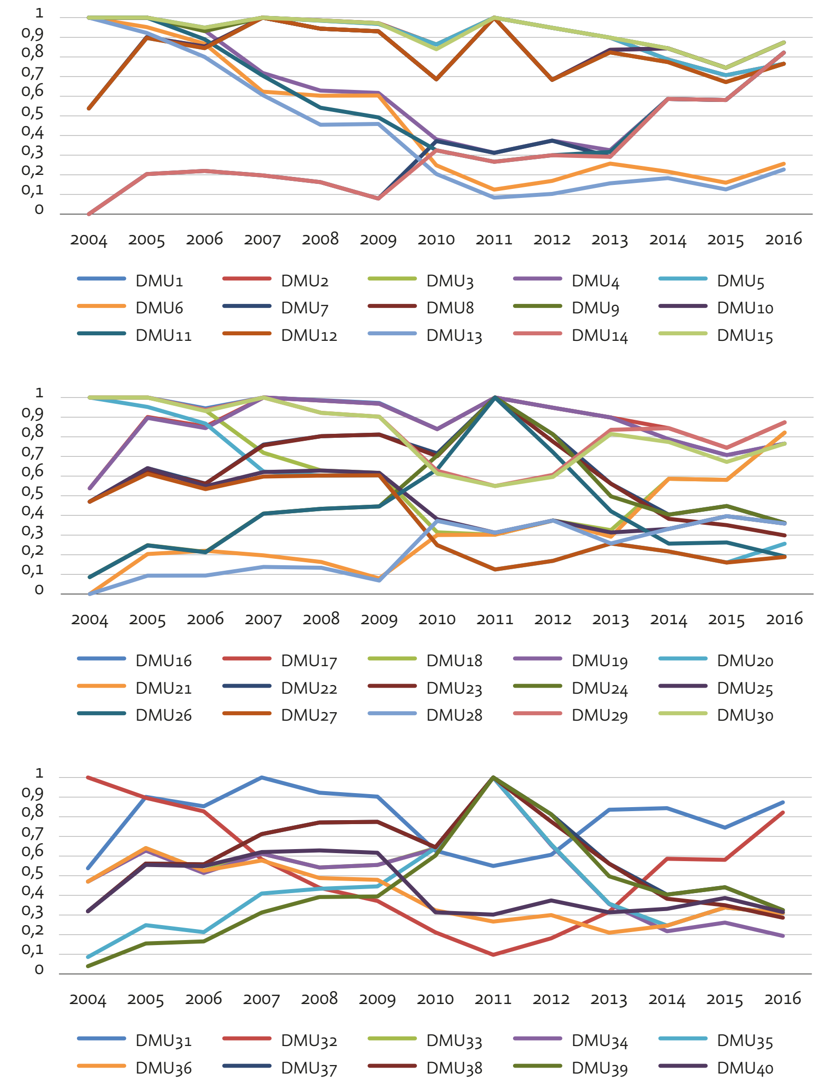


Figure 24 Economic efficiency for availability-based contracts



Ordinary least squares (OLS) multiple linear regression was used to evaluate the influence of the contract type on efficiency scores while controlling for the effect of all other significant predictors. The baseline for the controlled evaluation of the effect of the contract type on the economic efficiency of the road concessions was the following econometric model:

$$Yi = \beta_0 + \beta_1\, coty + \beta_2\, troi + \beta_3\, ficr + \beta_4\, \mathrm{gdpg} + \beta_5\, \mathrm{unra} + \beta_6\, \mathrm{elye} + \mu i$$

where

coty is a dummy variable, taking the value 0 for the aggregate performance of the road concessions with a toll-based contract and 1 for the group of road concessions with an availability-based contract. This variable allows us to assess the specific impact of the contract type in the concessions' efficiency overall but not that of each individual concession.

troi is a dummy variable assuming the value 1 in the years that Portugal was subject to a bailout programme with the IMF/ECB/EU (between 2011 and 2014) and 0 otherwise. Portugal asked for a financial bailout in 2011 due to a steady increase in public and external debt (Pereira and Wemans, 2015; Reis, 2015). There are several reasons why the Troika period may have impacted on the efficiency of these infrastructures. Firstly, there were substantial financial restrictions, which can lead to a reduction in investment and maintenance, thus decreasing efficiency. Additionally, there was a recession during the Troika programme period, leading to less demand, which can also reduce infrastructure efficiency (De Borger et al., 2002; Sarmento et al., 2017). Furthermore, the programme included several measures concerning the transport sector, aiming to increase the sector's efficiency (Sarmento and Reis, 2019).

fincrisis is a variable assuming the value 1 between 2008 and 2010 and 0 otherwise. This variable is intended to capture the effect of the 2008 financial crisis that culminated in the bailout programme in 2011.

gdpg is GDP growth as a percentage. Better economic times mean more demand for travelling, which can increase infrastructure efficiency *per se*.

unra is the unemployment rate as a percentage. More unemployment leads to less demand for transport, creating pressure in the efficiency of the infrastructures. We also tested with the log of this variable.

elye is a dummy variable assuming the value value 1 if there was a national Parliament election (which elects the government) on that year, and 0 otherwise. It is intended to capture whether an election and a potential change in policies led to more or less efficiency. It was also used to test the option of considering a lead or a lag of one year in relation to the election year.

The selection of the variables to be included in the regression models was done using a best subsets approach and testing the difference between using the Akaike information criterion or the adjusted R2 as the criterion for entry or removal of the predictors in the process of selecting the best subsets. Multicollinearity and heteroscedasticity were assessed through the volume of inflation factor (VIF) and the Breusch-Pagan test, respectively. The normality of the residuals (Shapiro-Wilk test), specification (Linktest), functional form (Ramsey test) and outliers (Cook's distance) was also assessed.

The combined effect of the predictors was evaluated by building a generalized linear model (GLM) with an interaction term, but only for the OLS models determined in the previous step with highest fit (based on the R-squared). All variables were statistically significant, and at least one continuous variable was included.

3.5.4. Results and discussion

The preliminary data analysis results point towards a lower efficiency on the availability-based concession (lower median), and there seems to be a stronger negative correlation between efficiency and the unemployment rate. The Shapiro-Wilk test indicates that, for at least one of the groups of the variable contract type, the efficiency scores are not normally distributed. Efficiency scores globally are normally distributed, as is gross domestic product growth, but not the unemployment rate. Therefore, nonparametric tests were given preference to evaluate the uncontrolled effect of the predictors.

Except for DMU6, the Mann-Whitney U test results (Table 36) indicate that the type of contract has a statistically significant effect on the efficiency score at a 0.10 (DMU40) or 0.05 (DMU 23, 25 and 27) significance level.

Table 36 **Results of the effect of the type of contract**

Variable	DMU6	DMU23	DMU25	DMU27	DMU40
Mann-Whitney U	55.500	20.500	27.000	25.000	48.000
Standard Error	19.497	19.467	19.487	19.500	19.497
Standardized Test Statistic	-1.487	-3.288	-2.951	-3.051	-1.872
Asymptotic Sig.(2-sided test)	0.137	0.001	0.003	0.002	0.061
Exact Sig.(2-sided test)	0.139	0.000	0.002	0.002	0.064

The unemployment rate revealed statistically significant correlations with DMU 6, 25 and 40, while gross domestic product growth did not evidence any statistically significant relationship with them (Table 37). All three statistically significant correlations were negative. Examining the correlations separately for each concession contract type, there is a matching pattern regarding the unemployment rate (negative correlation), with some of them statistically significant, but the opposite is true for gross domestic product growth. The efficiency scores of the toll-based concession contracts (group 0) evidenced positive correlations (statistically significant for some DMUs), while the efficiency scores of the availability-based concession contracts (group 1) evidenced negative correlations (statistically significant for some DMUs). The first relationship is probably explained by people travelling more and using the highways more alongside an increasing gross domestic product, since there will be more wealth, resulting in an increase in toll revenues. A possible explanation for the pattern on the availability-based contracts is that more traffic implies higher operation and maintenance costs, offsetting revenues from tolls. This explanation might be justified by the fact that, in periods of economic growth, costs (particularly labour costs) tend to exhibit higher growth rates than GDP.

Table 37 **Correlations between efficiency scores and the continuous predictors**

	Kendall's tau		Spearman's rho	
Variable	**gdpg**	**unra**	**gdpg**	**unra**
DMU6	0.250	-0.375**	0.357	-0.507**
DMU23	-0.006	-0.110	-0.018	-0.179
DMU25	0.257	-0.325*	0.361	-0.488*
DMU27	0.152	-0.211	0.231	-0.307
DMU40	0.180	-0.491**	0.253	-0.642**

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

The comparison of means and correlation analysis reveals the following: i) the toll-based and availability-based concessions respond differently to gross domestic product growth; ii) DMU25 seems to be the most justified by the explanatory variables considered; iii) the type of contract appears to have a statistically significant effect on most economic efficiency scores of the concessions without controlling for other potential variables.

In the multiple linear regression model, the variable *troi* shows signs of multicollinearity with the *unra* and *gdpg* combined (the VIF test, not formally reported, for *troi* is larger than 5 and over 4 for *unra* and *gdpg* in all efficiency scores). There are no signs of heteroscedasticity (Breusch-Pagan test), nonnormal distribution of the residuals (Shapiro--Wilk test) or influential observations (Cook's distance). Nevertheless, robust standard errors were used in all models. There is also no evidence of specification problems (linktest), and the functional forms seem appropriate (Ramsey test).

The five regression models with the highest explanation power for each DMU are presented in Table 38 (ten models were developed for each DMU using the best subsets method to select the variables included). The results confirm a consistent influence of contract type on economic efficiency. The other influential variables in various models are the unemployment rate, the Troika and the financial crisis.

Table 38 **Results of the controlled effect of the contract type on the concessions' economic efficiency Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1**

	Regression Models				
Variables	**1**	**2**	**3**	**4**	**5**
DMU6					
coty	-0.1596*	-0.1596*	-0.1596*	-0.1596*	-0.1596*
	(0.0803)	(0.0815)	(0.0816)	(0.0818)	(0.0819)
unra	-0.0483***	-0.0442***	-0.0486***	-0.0407	-0.0494***
	(0.0123)	(0.0142)	(0.0126)	(0.0262)	(0.0139)
gdpg		0.0128			
		(0.0174)			
elye			-0.0450		
			(0.0875)		
troi				-0.0616	
				(0.1659)	
ficr					-0.0311
					(0.1130)
Constant	1.1453***	1.0981***	1.1622***	1.0829***	1.1641***
	(0.1431)	(0.1590)	(0.1588)	(0.2387)	(0.1658)
Observations	26	26	26	26	26
R-squared	0.4376	0.4452	0.4441	0.4415	0.4400

Variables	Regression Models 1	2	3	4	5
DMU23					
coty	-0.2623***	-0.2623***	-0.2623***	-0.2623***	-0.2623***
	(0.0608)	(0.0606)	(0.0628)	(0.0607)	(0.0628)
ficr	0.1150**	0.1511**			
	(0.0523)	(0.0581)			
elyelag		-0.0773			
		(0.0565)			
unra			-0.0097	-0.0186**	
			(0.0082)	(0.0086)	
gdpg				-0.0279	
				(0.0180)	
elye					0.0665
					(0.0757)
Constant	0.8588***	0.8743***	0.9891***	1.0925***	0.8649***
	(0.0285)	(0.0343)	(0.0879)	(0.0960)	(0.0341)
Observations	26	26	26	26	26
R-squared	0.4790	0.5046	0.4436	0.5025	0.4446
DMU25					
coty	-0.2638***	-0.2638***	-0.2638***	-0.2638***	-0.2638***
	(0.0525)	(0.0534)	(0.0530)	(0.0533)	(0.0713)
troi	-0.2508***	-0.2946**	-0.2200***	-0.2640***	
	(0.0499)	(0.1214)	(0.0572)	(0.0541)	
unra		0.0079			
		(0.0170)			
gdpg			0.0122		
			(0.0150)		
ficr				-0.0396	
				(0.0789)	

Variables	Regression Models 1	2	3	4	5
elyelead					0.0020
					(0.0794)
Constant	0.8018***	0.7309***	0.7890***	0.8150***	0.7240***
	(0.0490)	(0.1513)	(0.0505)	(0.0498)	(0.0613)
Observations	26	26	26	26	26
R-squared	0.6601	0.6642	0.6688	0.6653	0.3730
DMU27					
coty	-0.2594***	-0.2594***	-0.2594***	-0.2594***	-0.2594***
	(0.0597)	(0.0607)	(0.0602)	(0.0604)	(0.0606)
troi	-0.2160***		-0.1384	-0.2124***	-0.2004***
	(0.0534)		(0.1322)	(0.0526)	(0.0570)
unra		-0.0310***	-0.0140		
		(0.0075)	(0.0184)		
elyelag				0.0443	
				(0.0694)	
ficr					0.0471
					(0.0951)
Constant	0.6939***	0.9597***	0.8196***	0.6791***	0.6782***
	(0.0433)	(0.0926)	(0.1604)	(0.0402)	(0.0397)
Observations	26	26	26	26	26
R-squared	0.5662	0.5514	0.5787	0.5749	0.5734
DMU40					
coty	-0.1631***	-0.1631***	-0.1631***	-0.1631**	-0.1631**
	(0.0571)	(0.0567)	(0.0572)	(0.0598)	(0.0580)
unra	-0.0417***	-0.0389***	-0.0290		-0.0427***
	(0.0082)	(0.0095)	(0.0175)		(0.0081)
ficr		0.0800			
		(0.0914)			

Variables	Regression Models				
	1	2	3	4	5
troi			-0.1027	-0.2643***	
			(0.1134)	(0.0517)	
elyelag					-0.0334
					(0.0794)
Constant	1.0428***	0.9944***	0.9389***	0.6771***	1.0645***
	(0.1038)	(0.1229)	(0.1536)	(0.0567)	(0.0971)
Observations	26	26	26	26	26
R-squared	0.5552	0.5804	0.5721	0.5112	0.5606

The results of the controlled and uncontrolled analyses are consistent. Note that the Troika years had a negative effect on efficiency, but the financial crisis had a positive effect. This result can be explained by the severe decrease in traffic in the Troika years; during the first years after the financial crisis erupted, most of the traffic was unaffected since the portion of the population that usually travels and the industry were only marginally affected at the time.

The existence of interaction between variables was explored for models using the unemployment rate for DMU6, DMU27 and DMU40. The interaction between the unemployment rate and the contract type is statistically significant in all models (Table 39). In the models where the unemployment rate is no longer a statistically significant variable, the sign is negative. Essentially, this result indicates that only the availability-based contracts are affected by the unemployment rate. Regarding DMU40, the difference in sign is explained by the effect of the contract type. In contrast to the other DMUs, in this case, availability-based contracts are less efficient (negative sign of the contract type dummy variable), but the positive sign of the interaction term counteracts this effect. In fact, for an unemployment rate above 16%, the availability-based concession contracts become more efficient.

Table 39 **Results of the controlled effect of the contract type considering interaction Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1**

Variables	Regressions Models		
	DMU6	DMU27	DMU40
coty	0.629**	0.158	-0.494**
	(0.194)	(0.140)	(0.164)
unra	-0.012	-0.012	-0.057***
	(0.009)	(0.009)	(0.009)
coty*unra	-0.074***	-0.039**	0.031**
	(0.018)	(0.13)	(0.013)
Constant	0.751***	0.751***	1.208***
	(0.096)	(0.096)	(0.115)
Observations	26	26	26
R-squared	0.635	0.629	0.610

3.5.5. Conclusions

Previous studies on traffic forecasts have highlighted the importance of accounting for GDP, and unemployment has critical explanatory variables of traffic volumes (see more in Plakandaras et al. (2019)). Although our analysis focussed not only on traffic/revenues (output) but also on overall technical and economic efficiency, the results seem to confirm the importance of accounting for GDP and, in particular, employment. Nonetheless, toll-based contracts and availability-based contracts are distinctly affected by fluctuations in GDP. Toll-based contracts react positively to GDP growth, while availability-based contracts respond negatively.

The analysis also showed the importance of contract types on economic efficiency, with availability contracts being less efficient.

The results of the controlled and uncontrolled analyses show that the Troika years had a negative effect on efficiency. This result might be linked to a significant decrease in the overall levels of traffic. On the other hand, the financial crisis had a positive effect. In the first years after the financial crisis erupted, most of the traffic was unaffected, since the portion of the population that usually travel and the industries were only marginally affected at the time. In the Troika years, there were several renegotiations of road PPPs, with the objective of decreasing capital and operational expenditures. These renegotiations occurred over a long period but were eventually closed, allowing for significant cost savings (more evident after the financial crisis) (see more on these renegotiations in Reis and Sarmento, 2019, and Fernandes et al., 2019).

3.6. Analysis 5: Effects of governance changes on efficiency: EP-Refer merger (IP)

3.6.1. Introduction

The transport sector (infrastructure managers and service providers) plays a key role in any society and is under pressure to meet growing mobility demands with increased efficiency (Buehler and Pusher, 2011). In fact, even in countries with large and developed transportation systems, the ageing of existing infrastructure (e.g., see the ASCE 2017 Report-Card[2]) and emerging drivers (e.g., climate change and carbon emissions – Sentence, 2009) pose significant challenges. The Government Office for Science (GOS, 2019) acknowledges that these and other factors create an opportunity for structural change in the UK transportation system. Considering that the transportation sectors in countries with similar levels of development are somewhat alike, it will be assumed that this statement is applicable to other contexts.

Regarding transport service providers, there are multiple studies offering evidence that horizontal mergers can lead to increased efficiency in the railway (Bitzan and Wilson, 2007; Larson, 2013), shipping (Alexandridis and Singh, 2014), bus (Odeck, 2008b), airline (Manuela et al., 2016; Yan et al., 2019; Doi and Ohashi, 2019; Chen and Gayle, 2019) and freight (Andreou et al., 2012) sectors.

Research on transport infrastructure management has been mostly focussed on the level of project evaluation/prioritization (Bueno et al., 2015; Godsell et al., 2018) and delivery (Flyvberg et al., 2003; Catalão et al., 2019a,b; 2020). Despite the vast literature on firm mergers (see, for instance, Martynova and Renneboog, 2008), there is little evidence of mergers in transport infrastructure management in SOE – State-Owned Enterprises (Cruz and Sarmento, 2017; Bai et al., 2019). However, as roads and railways share a degree of similarity, there is some debate over the benefits of merging the road and the railway infrastructure management. Furthermore, except for very large or island nations, land transportation provides the core of internal mobility services. Thus, integration of road and rail infrastructure management may contribute to the effective and efficient implementation of the concept of mobility management (also called transportation demand management) outside the urban scale.

In this research, the question we pose is: "Does merging the management of infrastructure lead to higher efficiency?" We used the Portuguese case of the merger in 2015 of two infrastructure firms (roads and railways). Following Cruz and Sarmento (2017), we used the case of EP (roads) and Refer (rail), two companies that merged into a single firm (IP). To answer our research question, we used a DEA model to assess the efficiency of those firms before the merger and of the new firm after the merger. Those scores were used as the dependent variable. Our explanatory variable is a dummy merger, assuming the value 0 before 2015 and 1 thereafter. Thus, we can control for a potential difference in endogeneity and assess the potential impact of such a merger on the efficiency of the operation. We control our results for several factors that can also impact efficiency: i) the financial crisis between 2008 and 2010; ii) the period of the Portuguese bailout programme (Troika) between 2011 and 2014 due to the financial crisis; iii) GDP growth; and iv) the unemployment rate. The election years were also controlled since Catalão et al. (2019 a,b; 2020) found elections to be significant to the cost deviation of public infrastructure projects. Following Catalão et al. (2019), a one-year lead and lag of the election year was also considered.

This essay is organized as follows: section 2 provides an overview of the merger process and objectives; the research methods and data are explained in section 3; the results and discussion are presented in section 4; and conclusions are provided in section 5.

3.6.2. Literature review

Mergers are perceived in the literature as a means for firms to increase their scale by creating a large firm (Lambrecht, 2004). The increase in scale may create synergies leading to increased efficiency and value to the shareholders (Campa and Hernando, 2004). Shareholders expect that the higher efficiency is mainly due to lower costs, higher revenues (by increasing market share or entering new markets/segments) and better service levels and quality (Andreou et al., 2012).

In the case of transport, in most cases mergers have resulted in cost reductions and better service (Levin and Weinberg, 1979; Harris and Winston, 1983; Chapin and Schmidt, 1999; Sun and Tang, 2000; Bitzan and Wilson, 2007; Winston et al., 2011; Larson, 2013). Targets' valuation effects are more significant for vertical (mergers between operators at different levels of the production chain) rather than for horizontal mergers (mergers between operators at the same level) (Colangelo, 1995), which indicates a positive valuation for firms that control and manage a more extensive supply chain (Andreou et al., 2012). However, there are tremendous differences across mergers and sectors behind this apparent increase in efficiency.

In the case of rail, mergers show some potential to use economies of traffic density to reduce costs (Bitzan and Wilson, 2007), to generate synergies that increase efficiency (Andreou et al., 2012), to improve service levels and quality (Larson, 2013) and to create scale effects by increasing market share (Levin and Weinberg, 1979, Chapin and Schmidt, 1999). They also tend to consolidate the physical network and traffic flow of the combined carriers, thus improving customer service (Harris and Winston, 1983; Bitzan and Wilson, 2007). In railways, end-to-end mergers and vertical mergers tend to outperform parallel mergers (Levin and Weinberg, 1979, Harris and Winston, 1983). As rail mergers tend to be horizontal, Sun and Tang (2000) conclude that they can have effects on collusion, not only increasing market prices but also efficiency gains by eliminating redundancies. On the other hand, using the US railroads, Winston et al. (2011) found evidence that mergers tend to have negligible effects on transportation prices and consumer welfare in the long term. Using the Chinese experience of mergers in the railway sector, Bai et al. (2019) found that the mergers and acquisitions (M&A) that generate most efficiency are those based on geographic and economic networks (however, the merger of two efficient firms does not ensure efficiency gains *per se*). The authors also found that a proper M&A can produce a so-called "stimulant" effect in the short term. However, as the "stimulant's efficacy" becomes exhausted over time, the M&A's effect will gradually weaken.

There is less evidence and fewer studies pertaining to the road sector (Odeck, 2008; Andreou et al., 2012), but some show the occurrence of synergies. In the case of Europe, there has also been a recent liberalization, increasing competition and market integration following the US example (Stehmann and Zenger, 2011).

Traditionally, mergers within the transport sector mainly occur between firms that operate in the same field, particularly rail firms merging their operations in a specific country or region (Winston et al., 2011; Larson, 2013). Mergers of firms operating in different fields, such as rail and roads, which are the object of this essay, are less common. There are, nevertheless, examples of merging road and rail infrastructure operators in Sweden and Finland. In 2010, the former Swedish Road Administration merged with the Swedish Rail Administration. Finland also adopted a merger between the different infrastructure operators. In both cases, governments supported the decision to increase the interdependency between transport networks and the need to develop coordinated transport policies, capturing synergies and complementarities between the transport modes. As it stands, this goal is extremely broad, ambitious and difficult to measure, which raises questions regarding how to effectively monitor the success (or lack thereof) of these mergers. Additionally, this merger represents an increase not only in scale but also in scope.

3.6.3. The merger between road and rail firms in Portugal

Portugal's historical infrastructure gap has been significantly reduced since the country joined the European Union in 1986 (Pereira and Andraz, 2005; Andrade and Duarte, 2016). In many sectors, such as water and sanitation, education, health and transport, the country indicators are now above or close to the EU average. In terms of transports, roads and railways have diverged substantially. The road infrastructures expanded noticeably, particularly in terms of highways, where the network increased from less than 100 km in 1986 to close to 4,000 km in 2020. The public sector invested a total of 18 billion € in highways through public-private partnerships (Cruz and Marques, 2011; Sarmento and Renneboog, 2015). The national road network was also substantially expanded. However, the railway sector did not secure the same level of investment. In fact, there was some investment in the urban areas of Lisbon and Oporto (Cruz and Marques, 2015), but there has been a pronounced reduction in the rest of the rail network in recent decades (de Bok et al., 2010; Besanko and Gonçalves, 2017).

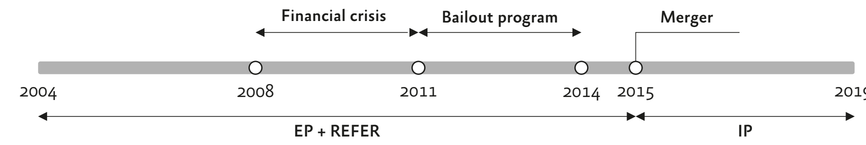
All of this has led to the existence of a vast transport network, where roads constitute the largest transport volume, with high quality, and where the railways network is smaller and of poorer quality. Moreover, this represents a heavy fiscal burden on a country facing a high level of public debt, as well as expenditures and constraints from EU fiscal rules (Sarmento, 2018). Furthermore, in most cases, the two networks (road and rail) have not been coordinated, creating overlaps in structure and service. Both firms were highly indebted, with strong financial limitations and with large internal structures and staff (Cruz and Sarmento, 2017).

Due to all these factors, in 2015 the government decided to merge both firms into a single SOE. The merger had five main strategic objectives (Cruz and Sarmento, 2017): i) to promote a sustainable mobility framework; ii) to increase revenues; iii) to increase the efficiency of the management of infrastructures; iv) to capture synergies; and v) to promote the financial autonomy of the new company. These five main strategic objectives were concentrated on two main operational objectives: firstly, to increase revenues; and secondly, to reduce costs. The cumulative effect over ten years was expected to be 2.6 billion € in revenues minus 800 million € in costs.

3.6.4. Research methods and data

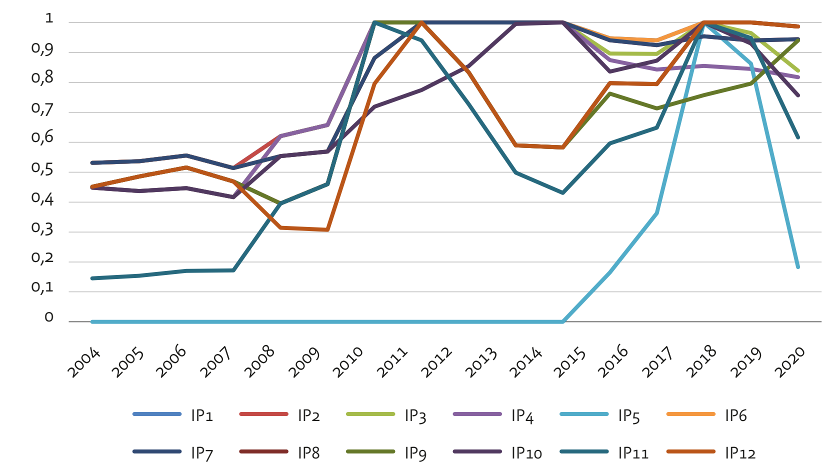
In this essay, we aim to answer whether the merger of two infrastructure firms (roads and rail) leads to higher efficiency. We used the Portuguese case of the 2015 merger between EP (roads) and Refer (rail) into a single company, IP, considering the period between 2004 and 2019. The period preceding the merger was particularly dynamic, encompassing a financial crisis and a bailout programme (Figure 25).

Figure 25 Chronogram of the period under analysis



Efficiency was calculated by using a DEA model for each firm before the merger and for the new firm after the merger, using data from 2004 to 2019 (Figure 26).

Figure 26 Economic efficiency scores for EP, Refer and IP



To answer our research question, a three-step methodology was adopted.

The first step consisted of evaluating the effect of the merger, testing whether the efficiencies before and after the merger are statistically distinct. This testing was done with either the t-test or the Mann--Whitney test.

In the second step, the merger was evaluated, controlling for exogenous factors and resorting to an OLS regression to build the following econometric model:

$$Yi = \beta_0 + \beta_1\, merge + \beta_2\, troika + \beta_3\, fincrisis + \beta_4\, \mathrm{gdpg} + \beta_5\, \mathrm{unemp} + \beta_6\, \mathrm{ely} + \mu i$$

where

merge is the explanatory variable. This variable is a dummy variable, represented as 0 for the years before the merger and 1 thereafter. This variable allows us to assess the specific impact of the merger on firm efficiency. To control our results, we used the following control variables that may also impact infrastructure efficiency.

troika is a dummy variable assuming the value 1 in the years that Portugal was subject to a bailout programme with the IMF/ECB/EU (between 2011 and 2014) and 0 otherwise. Portugal asked for a financial bailout in 2011 due to a steady increase in public and external debt (Pereira and Wemans, 2015; Reis, 2015). There are several reasons why the Troika period may have impacted on the efficiency of these infrastructures. Firstly, there were substantial financial restrictions, which can lead to a reduction in investment and maintenance, thus decreasing efficiency. Additionally, there was a recession during the Troika programme period, leading to less demand, which can also reduce infrastructure efficiency (De Borger et al., 2002; Sarmento et al., 2017). Furthermore, the programme included several measures concerning the transport sector, aiming to increase the sector's efficiency (Sarmento and Reis, 2019).

fincrisis is a variable assuming the value 1 between 2008 and 2010 and 0 otherwise. This variable is intended to capture the effect of the 2008 financial crisis that culminated in the bailout programme in 2011.

gdpg is GDP growth as a percentage. Better economic times mean more demand for travelling, which can increase infrastructure efficiency *per se*.

unemp is the unemployment rate as a percentage. More unemployment leads to less demand for transport, creating pressure on the efficiency of the infrastructures. We also tested with the log of this variable.

elye is a dummy variable assuming the value value 1 if there was a national Parliament election (which elects the government) on that year, and 0 otherwise. It is intended to capture whether an election and a potential change in policies led to more or less efficiency. It was also used to test the option of considering a lead or a lag of one year in relation to the election year.

The last step consists of evaluating whether there is any interaction between the merger and a continuous variable (*gdpg* or *unemp*). This evaluation was done by building a generalized linear model (GLM) with an interaction term, but only for the OLS models determined in the previous step with highest fit (based on the R-squared). All variables were statistically significant, and at least one continuous variable was included.

Table 40 presents the descriptive statistics of the continuous variables, and Table 41 reports the crosstabs of the categorical variables.

Table 40 Descriptive statistics of continuous variables

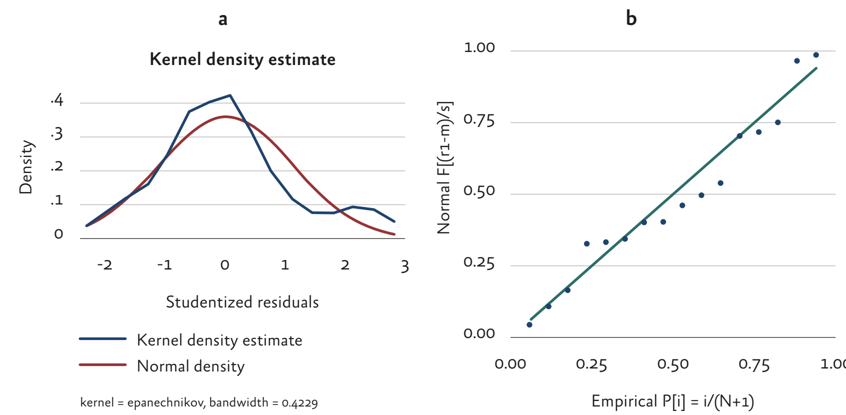
Variable	Obs.	Min.	Max.	Mean	Std. Dev.
DMU1	16	0.51	1.00	0.83	0.21
DMU2	16	0.42	1.00	0.79	0.24
DMU3	16	0.42	1.00	0.77	0.23
DMU5	16	0.42	1.00	0.73	0.22
DMU6	16	0.15	1.00	0.56	0.31
gdpg	16	-4.06	3.51	0.74	2.14
unemp	16	6.5	16.2	10.11	3.21

Table 41 Crosstab of the categorical variables

CLASS	troika	fincrisis	ely	mergeip
0	12	13	11	12
1	4	3	5	4

The dependent variables show no sign of nonnormality of the residuals (Figure 27 shows the kernel density and the p-norm graph for DMU1).

Figure 27 Kernel density graph (a) and P-norm density graph (b) for DMU1



There are signs of multicollinearity between *gdpg* and *troika* and *unemp* (as shown in the correlation matrix and the VIF test – not formally reported, but VIF for *troika* >5). Despite the apparent absence of heteroscedasticity (the Breusch-Pagan test) and the normality of the residuals (Shapiro-Wilk test), we used robust standard errors. The Wald test shows a p-value of 0, and the linktest does not reveal any specification problems in the model.

3.6.5. Results and discussion

In 2014, the year before the merger, the combined revenue of both firms (EP and Refer) was approximately 1.2 billion €. In 2019, the revenue generated by the new firm had increased by almost 300 million €, to approximately 1.5 billion €. Costs increased from 700 million to 1.2 billion €. However, several aspects need to be considered. Firstly, in 2016, the new government decided to revoke the salary cuts in the public sector that had been instituted in 2010. Those cuts represented 5% of staff salaries.

The effect of the merger is statistically significant for all DMUs except DMU5, using the t-test, and is only statistically significant for DMU6 ($p<0.05$) and DMU5 ($p<0.10$) using the Mann-Whitney test. Since the data show nonnormal distribution of efficiency before the merger for DMU1, 2 and 3, the Mann-Whitney U test (Table 42) was given preference. Conversely, the *troika* has a statistically significant effect on efficiency for DMU1, DMU2 and DMU3 ($p<0.05$) and DMU5 ($p<0.10$). The remaining categorical variables have no statistically significant effect.

Table 42 **Results of the effect of the merger**

Variable	DMU1	DMU2	DMU3	DMU5	DMU6
Mann-Whitney U	32.000	28.500	24.000	38.500	40.500
Standard Error	7.899	8.031	8.124	8.240	8.240
Standardized Test Statistic	1.013	0.560	0.000	1.760	2.002
Asymptotic Sig.(2-sided test)	0.311	0.575	1.000	0.078	0.045
Exact Sig.(2-sided test)	0.379	0.599	1.000	0.078	0.042

Complementarily, the correlation between efficiency scores and *unemp* and *gdpg* was evaluated using nonparametric methods (Spearman and Kendall's tau), since the efficiency scores are not normally distributed. A significantly positive correlation was found between all DMUs and *unemp*. The *gdpg* is only negatively correlated with *unemp*, which indicates that *troika* and *unemp* are the most relevant variables.

The results of the evaluation of the merger, controlling for exogenous variables, are presented in Table 43. The selection of the variables included in the various OLS regressions was done with a best-subsets approach and using the Akaike information criterion to define the entry and removal of variables. We can conclude that in all models (even when controlling for the Troika period, GDP growth, the financial crisis, the unemployment rate and the election years), the merger is significant and has a positive coefficient, showing evidence that the decision and process of merging the two firms have improved the overall efficiency of these operations, which was masked by the Troika years in the analysis.

Table 43 **Results of the controlled effect of the merger Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$**

	Regressions				
Variables	1	2	3	4	5
			DMU1		
mergeip	0.3261***	0.3436***	0.3425***	0.3555***	0.3449***
	(0.0775)	(0.0709)	(0.0807)	(0.0798)	(0.0709)
unemp	0.0537***	0.0576***	0.0578***	0.0585***	0.0553**
	(0.0073)	(0.0070)	(0.0087)	(0.0074)	(0.0222)
elylag		0.1027*	0.1022*	0.0916*	0.1010
		(0.0495)	(0.0507)	(0.0420)	(0.0591)
gdpg			0.0006		
			(0.0129)		
fincrisis				0.0426	
				(0.0635)	

Variables	Regressions 1	2	3	4	5
troika					0.0204
					(0.1593)
Constant	0.2056**	0.1297	0.1281	0.1132	0.1487
	(0.0829)	(0.0759)	(0.0907)	(0.0830)	(0.1918)
Observations	16	16	16	16	16
R-squared	0.7689	0.8189	0.8190	0.8240	0.8195
DMU2					
mergeip	0.3284***	0.3533***	0.3680***	0.3821***	0.3769***
	(0.0860)	(0.0739)	(0.0788)	(0.0838)	(0.0916)
unemp	0.0636***	0.0691***	0.0670***	0.0713***	0.0682***
	(0.0089)	(0.0079)	(0.0091)	(0.0073)	(0.0085)
elylag		0.1453**	0.1516**	0.1182**	
		(0.0545)	(0.0552)	(0.0396)	
gdpg			-0.0077		
			(0.0143)		
fincrisis				0.1039*	0.1507*
				(0.0530)	(0.0782)
Constant	0.0637	-0.0436	-0.0227	-0.0840	-0.0238
	(0.1048)	(0.0866)	(0.0932)	(0.0789)	(0.0952)
Observations	16	16	16	16	16
R-squared	0.7593	0.8378	0.8403	0.8615	0.8149
DMU3					
mergeip	0.2447***	0.2680***	0.2895***	0.2985***	0.2691***
	(0.0768)	(0.0668)	(0.0746)	(0.0749)	(0.0673)
unemp	0.0632***	0.0684***	0.0654***	0.0707***	0.0663**
	(0.0085)	(0.0078)	(0.0087)	(0.0071)	(0.0216)
elylag		0.1361**	0.1452**	0.1074**	0.1346*
		(0.0552)	(0.0545)	(0.0374)	(0.0663)

Variables	Regressions 1	2	3	4	5
gdpg			-0.0113		
			(0.0135)		
fincrisis				0.1100*	
				(0.0528)	
troika					0.0182
					(0.1599)
Constant	0.0657	-0.0348	-0.0044	-0.0776	-0.0180
	(0.1011)	(0.0882)	(0.0921)	(0.0791)	(0.1958)
Observations	16	16	16	16	16
R-squared	0.7502	0.8271	0.8331	0.8568	0.8275
DMU5					
mergeip	0.3519***	0.3721***	0.3546***	0.3685***	0.3733***
	(0.0720)	(0.0630)	(0.0658)	(0.0701)	(0.0620)
unemp	0.0574***	0.0619***	0.0643***	0.0616***	0.0594***
	(0.0074)	(0.0054)	(0.0062)	(0.0058)	(0.0146)
elylag		0.1176***	0.1102***	0.1210***	0.1160***
		(0.0280)	(0.0335)	(0.0326)	(0.0248)
gdpg			0.0092		
			(0.0114)		
fincrisis				-0.0128	
				(0.0326)	
troika					0.0210
					(0.0990)
Constant	0.0569	-0.0300	-0.0548	-0.0251	-0.0105
	(0.0759)	(0.0530)	(0.0640)	(0.0609)	(0.1168)
Observations	16	16	16	16	16
R-squared	0.8481	0.9111	0.9154	0.9115	0.9116

Variables	Regressions 1	2	3	4	5
	DMU6				
mergeip	0.4397***	0.5365***	0.5557***	0.4647***	0.4166**
	(0.1403)	(0.1441)	(0.1342)	(0.1262)	(0.1458)
unemp	0.0478**	0.0571***		0.0533**	
	(0.0171)	(0.0156)		(0.0195)	
fincrisis		0.3009*	0.3710*		
		(0.1542)	(0.2020)		
troika			0.4017**		0.2626
			(0.1469)		(0.1567)
elylag				0.1461	
				(0.1531)	
Constant	-0.0365	-0.2113	0.2475**	-0.1445	0.3866***
	(0.1790)	(0.1442)	(0.0902)	(0.1991)	(0.1102)
Observations	16	16	16	16	16
R-squared	0.4507	0.5858	0.5401	0.4991	0.3583

When comparing with the analysis, there seems to be a contradiction regarding the importance of the Troika years. In fact, there is no contradiction; the explanation resides in the fact that the Troika coincided with the highest unemployment rates, making them two alternative variables. Replacing the unemployment rates with *troika* in the models used in Table 43 results in a statistically significant variable in most cases, but in a lower explanation power of the model. To avoid repetition, this result is illustrated in Table 44 only for DMU1. Similar results were obtained for the remaining DMUs, as can be observed in model 3 for DMU6 (Table 43), where replacing *unemp* with *troika* decreased the R-squared from 0.59 to 0.54. This result, along with the statistically significant correlation between the *gdpg* and the *unemp*, explains the multicollinearity between the three variables. This result can derive from the decisions made in both firms to improve their service and financial viability. However, as mentioned above, we stress that the Troika period included a salary cut that reduced costs substantially throughout the public sector.

Table 44 Results of the controlled effect of the merger for DMU1 using *troika* instead of *unemp* Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Variables	Regressions 1	2	3	4	5
mergeip	0.3115***	0.3174***	0.3152**	0.3643***	0.3449***
	(0.0724)	(0.0724)	(0.1028)	(0.0902)	(0.0709)
troika	0.3298***	0.3356***	0.3385***	0.3826***	0.0204
	(0.0711)	(0.0722)	(0.0518)	(0.0892)	(0.1593)
elylag		0.0470	0.0457	0.0115	0.1010
		(0.0892)	(0.1016)	(0.0625)	(0.0591)
gdpg			0.0012		
			(0.0184)		
fincrisis				0.1371	
				(0.1343)	
unemp					0.0553**
					(0.0222)
Constant	0.6702***	0.6526***	0.6519***	0.6145***	0.1487
	(0.0711)	(0.0729)	(0.0674)	(0.0949)	(0.1918)
Observations	16	16	16	16	16
R-squared	0.6080	0.6190	0.6191	0.6648	0.8195

The interaction between the merger and the unemployment rate is statistically significant for the models of all DMUs except DMU6 (Table 45). However, the p-value of the interaction term on the DMU6 model is 0.108, falling slightly short of the 0.1 threshold. The negative sign of the interaction term is an indication that the efficiency score of IP is less sensitive to the exogenous economic variables. It is legitimate to admit that after incorporating the efficiency gains brought on by the optimization of the operational and organization synergies of the merger, the efficiency of IP is less influenced by the exogenous variables than Refer and EP were.

Table 45 **Results of the controlled effect of the merger considering interaction Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1**

	Regressions				
Variables	DMU1	DMU2	DMU3	DMU5	DMU6
mergeip	0.896***	0.918***	0.849***	0.698***	1.207**
	(0.092)	(0.104)	(0.077)	(0.134)	(0.399)
unemp	0.063***	0.077***	0.077***	0.065***	0.065***
	(0.006)	(0.006)	(0.006)	(0.004)	(0.014)
elylag	0.085*	0.096***	0.085***	0.107***	
	(0.041)	(0.026)	(0.026)	(0.022)	
fincrisis		0.125***	0.131***		0.316**
		(0.039)	(0.041)		(0.128)
mergeip*unemp	-0.065***	-0.062***	-0.064***	-0.038**	-0.078
	(0.010)	(0.013)	(0.009)	(0.017)	(0.044)
Constant	0.077	-0.142**	-0.138**	-0.061	-0.299**
	(0.054)	(0.052)	(0.051)	(0.039)	(0.113)
Observations	16	16	16	16	16
R-squared	0.891	0.912	0.917	0.935	0.636

The models presented in Table 45 show that an increase in the unemployment rate will not increase the efficiency of IP as much as it did with Refer and EP. Nevertheless, comparing the magnitude of the regression coefficients of the *mergeip* and *mergeip*unemp* variables, only an unemployment rate above 14% would cancel out the efficiency gains of the merger.

It is somewhat difficult to make interpretations based on an analysis of the unemployment rate. However, considering that GDP growth is negatively correlated with the unemployment rate, and that it would be possible to exchange the variables in the models presented in Table 45 (not shown herein, but this is possible at the cost of losing explanation power and a decrease in the statistical significance level of the variables – in some cases, the p-value becomes larger than 0.1), the following conclusions may be drawn: i) efficiency increases with a decrease in the *gdpg*; ii) a contraction of the *gdpg* of more than –2% annuls the efficiency gains acquired with the merger; and iii) in a context of positive GDP growth, efficiency increases for IP and decreases for Refer and EP combined. These results should be examined with caution; since the overall timeframe considered is short, the period of Refer and EP was extremely dynamic, and IP has only five years of existence reported in the data. Nevertheless, the relationship between efficiency and GDP growth had a positive sign with IP and a negative sign with Refer and EP combined. This result may be an indication that the new company is more capable of potentiating the opportunities in an expansionist economic context and that Refer and IP were more flexible in addressing the challenges in a contracting economy.

The new firm had also evolved under different strategic objectives. It is now more focussed on energy transition and on decarbonizing operations due to climate change demands, mainly by completing the electrification of the rail network. There is also a plan for strong investment in the rail network, mainly financed through EU funds. Digitalization and "mobility as a service" are two other key issues in the transformation of the firm. There have also been investments in innovation and R&D, with the firm participating in EU programmes such as Horizon 2020, Shift2Rail and CEF (Connecting Europe facility). It is transitioning from being a typical infrastructure provider to becoming a mobility service provider and an asset manager. There were some initial costs resulting from the merger, but the concentration of facilities and the creation of multimodal teams have significantly improved firm efficiency.

Additionally, the firm went from an initial vision of maximizing the merger to a more different approach that tends to concentrate on the similarities between the previous two firms that can potentially generate synergies and gains, leaving some level of autonomy in the areas that are different, allowing for adaptation to some specificities of those areas. This adaptation was particularly important to new investments in railways. By having the opportunity to use EU funding that is allocated specifically to rail (and there are no EU funds to roads), the merger allows the new firm to acquire sufficient scale to face challenges (both technical and financial) and respond to the high level of project, bidding, finance and investment demand from the government.

3.6.6. Conclusions, limitations and future work

The merger of EP and Refer faced some public opposition, given the lack of experience in operating both the road and rail sectors, and given the efforts employed in the 1990s to vertically unbundle the rail sector. The international trend in recent decades has been towards specialization rather than horizontal bundling. However, from an efficiency perspective, this case seems to confirm that "bigger is better".

In fact, the merger not only had a positive impact on efficiency but also improved overall performance towards negative economic cycles. The number of years post-merger is still relatively reduced, and it would be useful to have a longer period of analysis. Nevertheless, the results seem to encourage the analysis on mergers in the infrastructure sector. The overall challenges of climate change, securing financing, dealing with societal changes, and digitalization, among others, might justify the need to have better equipped and more resilient companies.

Chapter 4
Government, infrastructure and productivity

4.1. Government and infrastructure

The government has three basic functions, as defined by Musgrave, in 1959: i) determination, or guidance, of the best allocation of economic resources; ii) redistribution of income; and iii) macroeconomic stabilization.

Although the neoclassical paradigm considers individuals or households as an economic unit of observation, the analysis of society as a whole and the study of the impact of political decisions is measured based on the principle of alternative resource allocation. That is, seeking to improve the usefulness of an individual, or group of individuals, without thereby diminishing the usefulness of another individual, or group. When any change in the allocation of resources implies decreasing the well-being of an individual, or group of individuals, it means that Pareto's optimum has been achieved (see more in Sean, 1993; Barr, 2004). The search for solutions to increase efficiency is abandoned to enter the domain of public or political choices.

The question of infrastructure planning, management and financing model belongs to the first function: the allocation of economic resources. It is the government's responsibility to use strict cost--benefit analyses to identify the projects that have the greatest merit (absolute and relative) and, as such, the one that must be developed, maximizing the social welfare, while attending to the needs of the populations and other economic agents. The allocation of resources can, and should, address concerns of a social, economic and/or environmental nature, such as concerns of geographic equity.

In the field of infrastructure planning and management, the function of allocating economic resources is realized in different activities:

- Selection of projects with the highest economic value;
- Redistribution of public subsidies to projects, considering their capacity to contribute to economic and social development;
- Regulation of infrastructures and services, ensuring a strategic alignment between the performance of services (and their respective operators) and the policies for the defence of the general interest associated with these economic activities.

These objectives can be traced back to the original research questions of this study.

The fulfilment of the first two objectives can be measured on the impact of productivity. Although the benefits are beyond productivity gains, these are a fundamental requisite for economic and social development. Regarding the third, it can be measured through efficiency (already discussed in a previous report).

The case of public infrastructure – roads, railways, airports, water supply systems, etc. – is a particular one, as the nature of these markets requires active intervention by the State. This can be summarized as follows: these markets share characteristics with natural monopolies, that is, the service provision is more efficient with only one operator; alternatively, when there is not a "natural monopoly", there are "market failures". Furthermore, these types of assets provide positive externalities, related to environmental, economic and social impacts, which affect not only system users, but society at large. This relates to the fact that infrastructures are, in several cases, public or semi-public goods.

4.2. Infrastructure as public / semi-public goods

Public goods fulfil the conditions of non-rivalry and non-exclusion. Transport infrastructure should be classified as semi-public goods, i.e., characterized by the possibility of rivalry, but not exclusion. Musgrave (1969) uses as an example the case of a national park, where rivalry can come from congestion in demand. Desmarais-Tremblay (2014) points to the examples of most natural resources (common-pool resources), although the existence of raw material markets transforms, from a strictly economic point of view, these goods into private ones, although exploited with public concessions.

In the case of semi-public goods, there may be non-rivalry between consumption but the possibility of exclusion from consumption. For example, when tolls are introduced on the roads, a mechanism for excluding consumption is being created, regulating demand. The same is true of water supply systems whereby, in normal situations, water consumption by one individual does not make it impossible for other individuals to consume water, but it comes at a price.

As common or semi-public goods, infrastructure systems are a direct responsibility of the government, who can either provide them directly (as is the case of Infraestruturas de Portugal), or through concessions/PPPs, as happens in the case of airports, many highways, underground systems and commuter rail.

4.3. Infrastructure and productivity

The link between transport infrastructure and productivity has been an important topic of research over the last few decades. There are several reasons for this. Firstly, it is often used as an argument in favour of transport investments. Secondly, most countries have been investing in the densification of transport networks over the last few decades, particularly in road infrastructure, and, in some countries, rail infrastructure, which provides a valuable case study.

From a macroeconomic perspective, public infrastructure can be seen as a contributor to technical change and, therefore, it might affect (increase) economic growth, as was claimed by Aschaeur (1990). The theory is that public investment, in the form of infrastructure, can positively affect production technology. The author developed three studies (Aschauer 1989a, b, c) where he established three main empirical implications (in Aschaeur, 1990):

1. *That infrastructure capital carries a positive marginal product in a private-sector neoclassical production technology;*
2. *That infrastructure capital is complementary to private capital and is capable of enhancing the marginal product of private capital;*
3. *That private infrastructure investment is likely to spur private investment in plant and equipment.*

Garcia-Mila and McGuire (1992) have used the stock of highway infrastructure to explain per capita output. This is the same approach followed by Aschauer (1988). The authors concluded that a higher and better quality of highway capacity expands transportation services, thus raising the marginal product of private capital.

Transport costs, assuming the generalized cost function of transport[3], affect firms competitiveness in different ways. Firstly, they are a part of logistic costs, which are consumer traded goods and represent a significant share of or the overall product cost (Cardos and Garcia--Sabater, 2006; Wiengarten et al., 2014). Any improvement in the transportation system that enables a reduction in the transport costs will also reduce the firm's costs and increase its factor productivity (Holl and Mariotti, 2018).

Furthermore, using the location theory, the development of transportation systems, which increases accessibility and mobility, will allow firms within the same sector (or providing complementary services) to locate to similar regions, in what is known in the economic literature as "agglomeration effects" (see more in Chung and Kalnins, 2001; Ciccone, 2002). Firms can share know-how, human capital, and benefit from synergies and economies of scale, which, in turn, increases their competitiveness. The "easier" it is to move, the bigger these "agglomeration effects", with all the positive externalities that derive from proximity, and the bigger the impact on productivity (Beeson, 1987; Graham, 2007).

The initial estimates of output elasticities have been criticized by "model misspecifications and spurious relationships" (Melo et al., 2013), caused by simultaneity bias and omitted variable bias (covariates not included) (Melo et al., 2013).

In the past, most studies have used production functions. The most common form of production function – Cobb-Douglas – is the following:

$$Y = TFP.\ L^{\alpha}.K^{\beta}$$

Y – private output
TFP – Total Factor Productivity
α – output elasticity related to labour
β – output elasticity related to capital

It is frequent to apply logarithms (ln) and obtain:

$$\ln(Y)= \alpha \ln(L) + \beta \ln(K)$$

Other studies have used a form based on the translog production function:

$$\ln(Y)= \ln(TPF) + \alpha \ln(K) + (1-\alpha) \ln(L) +1/2\ \gamma\alpha\ (1-\alpha)[\ln(K)-\ln(L)]^2$$

The component related to the transport systems can be incorporated in one of two ways: i) input factor together with K and L in the production function; ii) using a Hicks-neutral technical change g(Z,T), where Z are several external factors and T is transport infrastructure. The Hicks neutrality ensures that the balance of labour and capital are not affected. See more in Hicks (1966).

Therefore, equation (2) becomes

$$Ln(Y)= \alpha \ln(L) + \beta \ln(K) + \eta \ln (Z) + \Phi \ln (T)$$

where, Φ is the elasticity of output related with transport.

The translog function provides a more flexible approach, as it allows many inputs into the production function. For example, Agbelie (2014) used foreign direct investment as a proxy for private capital stock and number of employable people as a proxy for labour.

Most traditional approaches for productivity analysis focus on the impact of the infrastructure stock in a certain region (T_i) on the productivity of that region *i*. The impacts of the T_i might not be exclusive for that same region, but can affect a distinct set of regions that may, or may not, share boundaries with region *i*.

The notion that the regional impacts might be underestimated by simply considering the direct impacts on one region, ignoring the contributions to other regions, is known as broader effects (or spillover effects). With the advent of spatial econometrics (Cliff and Ord, 1981), new tools became available to grasp the broader effects of infrastructure, thus shedding new light on traditional infrastructure literature.

Cohen (2010) used a cross-sectional production function model for the US manufacturing sector in 1996 to show that omitting a spatially--lagged dependent variable can result in the underestimation of the benefits.

As discussed by Gutiérrez et al. (2010) infrastructure investment is a tool that translates into the improvement of accessibility in regions. There are important spatial relationships to consider, since one region's accessibility affects the accessibility of the neighbouring regions.

Some past studies have considered public capital as the sum of all public capital investments (transport, energy, environment, public services, etc.). This is relevant for understanding the impact of public investment, but it does not allow us to consider the specific contribution of transport infrastructure.

Understanding that it is not possible to measure transport contribution if all investment is accounted for as a "public capital" variable, some authors have evolved towards considering the specific contribution of transport infrastructure. That was the case of Pereira and Pereira (2017) and Pereira et al. (2017), who considered variations in transport investment for three different decades. The idea that it is necessary to segregate transport investment is also mentioned by Melo et al. (2013).

Chapter 5
Geographical analysis of accessibility

5.1. Introduction

Accessibility has been commonly defined as "the potential of opportunities for interaction" (Hansen, 1959) or "some measure of spatial separation of human activities" (Morrison et al., 1979). In general terms, accessibility is the possibility of reaching desired places and activities. While accessibility creates socio-economic advantages for the areas that have previously been out-of-reach, increases in distance, cost or travel time decrease the interaction between locations. However, the extent to which additional investments on accessibility improvements help socio-economic development is not as straightforward. Furthermore, there is no universally accepted single method of measuring accessibility; instead, depending on the research objectives, several groups of variables are utilized to measure accessibility.

5.2. Literature review

Geurs and van Wee (2004) identify four perspectives on accessibility measurement as infrastructure-based, location-based, person-based and utility-based measures.

Infrastructure-based accessibility measures refer to the operational quality of transport infrastructure, such as travel time, level of congestion and operating speed. Infrastructure-based measures concentrate on the efficiency of the transport infrastructure and services. Thus, decreasing travel time by increasing travel speed or decreasing the congestion level would result in improved accessibility, when this measurement method is used. For instance, according to infrastructure-based measuring, the transport regulation changes made in central London, respectively traffic calming by reducing the speed limit and the imposition of other restrictions, had decreased the level of accessibility in London. As a result, London has the lowest average accessibility of jobs in the United Kingdom in comparison with Scotland, which holds the highest rate of UK's job-accessibility, although these results do not reflect reality (Linneker and Spence, 1992). The indicators used to measure accessibility were travel times, road distances, transport costs, car travel times, car road distances, and car generalized transport costs; with and without M25 London Orbital Motorway.

As the infrastructure-based measures take into account the efficiency of the transport system, the areas with higher job and population density result in lower accessibility than the areas with lower overall density. In another example, the Randstad area in the Netherlands also showed lower accessibility according to infrastructure-based measurement. Infrastructure-based measures are criticized for only considering transport infrastructure efficiency, and for their lack of attention paid to the effects that "infrastructure improvements" have on land-use patterns, e.g. the impacts of increased travel speed on sprawl or road accidents.

Location-based measures take into account the accessibility advantages of an area. A typical measurement would be "the number of jobs within 30 minutes of travel". The factors under consideration are travel time and cost between activities. Additionally, differing travel times can be considered to take into account travel during peak hours, weekdays, or others. Person-based accessibility measures aim to establish the activities accessible to an individual within a given period.
The difference between the two forms of measurement is the consideration of the accessibility of places and of individuals, which, when ideally calculated, should produce the same results.

Location-based measures and person-based measures are referred to as activity-based measures (Geurs and Eck, 2001) and include metrics of distance, isochrones, potential, spatial interaction models, and space--time geography.

1. Distance Measures were developed by Ingram (1971) and consider the connectedness between two given points, which can be similar to infrastructure-based measures. This metric considers the connection to a single destination, but if there are two or more possible destinations, contours (isochrones) can be added. Distance measures are frequently used in land-use policy and geographical studies, for instance when choosing the optimal location for primary services, such as hospitals or bus stops, taking into consideration the parameters set for maximum distance or travel time of each inhabitant to the respective public services (e.g. 30 minutes to a hospital or 500 meters to a bus stop).

2. The Contour Measures (or isochrones measure) are based on the lines connecting points that can be reached within a specific time or budget from a particular point (e.g. Sullivan et al., 2000). The number of opportunities determines accessibility – more opportunities mean increased accessibility. This measure was developed by Breheny (1978) that identifies three types of contour measures: (1) fixed cost (number of opportunities within a fixed cost limit); (2) fixed opportunities (the average time/cost or total time/cost required to access a fixed number of opportunities); and (3) fixed population (the average number of opportunities available within various fixed travel costs for a fixed number of residents) (Geurs and Eck, 2001).

3. The Potential Accessibility Measurement is based on Hansen's definition of accessibility – the potential of opportunities for interaction – and has been widely used to assess the accessibility of jobs, health services, education institutions, green spaces, etc. (see e.g. Nicholls, 2001). One downside of this approach is demonstrated with the example presented in Geurs and Eck (2001: p.56): if there are two locations given, a and B, wherein location A has 10 000 inhabitants and 10 000 jobs, whereas location B has 1 000 inhabitants and 10 jobs, and 1000 jobs have to be added either to location A, or location B, the potential accessibility measure results would prioritise location A. The greater importance of larger urban centres is one of the fundamental components of this form of measuring. Another disadvantage of this form of measurement is the dismissal of the competitiveness factor.
Keeble et al (1988, 1981) analysed the centrality of economic centres in Europe using a potential measure with GDP as a destination activity.
The general potential accessibility measure is:

$$A_i = \sum_j D_j F(c_g)$$

wherein D is the distance to j, F is impedance, and C is cost. Furthermore, a normalization factor is introduced, e.g. with the total number of opportunities available in the area of origin for the residents. The analysis can be done for separate or combined transport modes. This measures the accessibility from the point of origin to destinations.

Potential accessibility indicators were also used in the paper by Rokicki and Stepniak (2018) to evaluate the impacts of transport infrastructure investments in Poland NUTS 3 regions during 2004-2014, with two approaches of national and international accessibility. The data used from the Local Data Bank is on added regional value, wages, employment and fixed capital of market sectors. Accessibility is used as potential accessibility with population data from the Central Statistical Office. Additionally, variables include spatial lags. The paper aims to analyse the impact of transport investments on regional population growth. Findings show that accessibility improvement is positively associated with regional employment growth. Although the scenario wherein no additional improvement is made is not statistically significant for urban areas, it has negative effects on the accessibility of rural areas.

4. The spatial interaction models, also referred to as inverse balancing factors, aim to show the interaction between locations. Wilson (1971) identified four types of spatial interaction models: i) production--constrained; ii) attraction-constrained; iii) production and attraction constrained; iv) and unconstrained type (Geurs and Eck 2001: p.57). He suggested that accessibility should be measured as:

$$T_{jj} = a_i b_j O_i D_j F(d_{jj})$$

wherein: T_{jj} is the magnitude of flows (trips) between zones, $a_i b_j$ is the impedance caused by transport infrastructure, $O_i D_j$ is the number of activities (inhabitants and jobs) in zones i and j, and $F(d_{jj})$ is a (negative) function, representing the friction imposed by the infrastructure connecting zones i and j.

The balancing factors that would ensure the flow from a particular area match the number of activities in another area and take into account competition for jobs or workers.

The competition variable for a shopping centre, for instance, is a factor taken from the perspective of the shopkeepers from the area where residents live, but it can also derive from potential purchasing factors.

5. The space-time geography measures are based on individual daily movements and aim to show accessibility on an individual level. The fundamental assumption is that the location of an individual's home is not the only determinant in one's accessibility, taking into account that throughout the day people move around the city to accomplish their daily tasks. Weber (2003) assessed individuals' accessibility to employment centres in Portland, using the travel-activity diary-surveys from 1994-1995 which included 10 084 individuals from 4 451 households. Five indicators were used: i) miles; ii) opportunities; iii) area; iv) weighted area; and v) timed area. The "miles" indicator measured the total distances that an individual travels throughout the day to reach their destinations considering the time spent, by considering variables of travel speed and congestion. The "opportunities" indicator used data (all commercial and industrial property parcels) from the Regional Land Information System. Afterwards, for a more realistic representation of these opportunities, three other indicators were used: i) area (representing the scope of the opportunities);

ii) weighted area (a factor to represent the importance of opportunities); and iii) timed area (most of these opportunities are only available between 9 am and 6 pm – therefore, only travel between this time is weighted with a factor of importance). Study findings have indeed shown that more than the proximity to the central business district, it is the individual's activity schedule that influences a persons' accessibility (Weber 2003).

Utility-based measures, founded in economic theory, are underpinned by the belief that individuals' travel choices depend on the utility of any given choice in contrast to all the other choices. It takes into account individual characteristics and constraints, such as economic budget and travel behaviour. As it is impossible to objectively choose the average between the choices and constraints people face, the utility-based measures need assumptions for such averages. In a similar example, as mentioned previously: considering two given locations, a and B, wherein location A has 10 000 inhabitants and 10 000 jobs whereas location B has 1 000 inhabitants and 10 jobs, and 1 000 jobs have to be added either to location A or location B, the utility-based accessibility measure results would prioritise location B because the utility level of the rich area does not get a statistically significant increase in utility with the additional jobs, whereas location B does, and their combined accessibility results are higher (Geurs and Eck, 2001: p.67).

Levine (1998) studied a utility-based job-accessibility in Minneapolis and St. Paul by forming two groups of single-worker households and two-worker households, divided into three groups of low income, medium income and high income. Variables considered were: i) travel time to the workplace during peak hours (of worker 1); ii) commuting time (for worker 2); iii) housing units; iv) housing price per annual household income; v) houses occupied by owners; vi) school finances (e.g. schools in poorer communities have greater governmental help); vii) number of people in the household; and viii) dummy variables. Most of these variables tend to incorporate social and economic characteristics that would help in forming assumptions regarding the individuals' travel choices and constraints. In another study, Sweet (1997) used this measure for private and public transport in London:

$$V_{in} = \tilde{V}_i + \tilde{V}_n + \tilde{V}_{in}$$

where V_{in} is the total utility; $\tilde{V}_i$ is the utility of the location (attractiveness factor); $\tilde{V}_n$ is the individual's perception of the utility to travel; and $\tilde{V}_{in}$ represents a joint effect factor (Geurs and Eck, 2001: p.66). The *i*- is the destination whereas, *n*- is the traveller.

The advantage of utility-based measures lies in the consideration of individual travel behaviour, rather than assuming individuals living in the same location have the same level of accessibility. But a range of complex formulas based on travel behaviour theories or assumptions are required to address the destination choices.

In another classification, Handy and Niemeier (1997) group accessibility measures as cumulative opportunity measures, gravity-based measures, and utility theory-based measures. In this grouping, the cumulative opportunities measure the number of opportunities within a given timeframe, whereas the gravity-based measures add further constraints, such as costs, or add weight to the opportunities. Utility--based measures refer to the same grouping as previously described.

Given the pros and cons of the aforementioned accessibility measurement groups, a large number of studies select a combination of variables based on the research objectives. Infrastructure-based measurements are almost always used to show the effects an investment has had on accessibility changes, whereas utility-based measurements are not used as often due to complex assumptions and interpretation. The activity-based measurement types are used widely with studies that try to incorporate estimated factors to balance the disadvantages of individual choice variables and competition for opportunities.

The study methods in accessibility measurements include household travel surveys and GIS-based models built upon existing data. As accessibility to residents living in the same neighbourhood can vary depending on variables other than location, considering for example socio-economic conditions, the household surveys provide more comprehensive data to facilitate the understanding of the real level of accessibility. In his accessibility study, in Washington, Levinson (1998) used household surveys and treated housing location and job location separately. According to this study, the highest ratio of a job to housing accessibility is found in central business districts, whereas the suburbanization of jobs and increasing urban housing was found to shorten commutes (Levinson, 1998). In another study, Zegras and Srinivasan (2007) used household travel surveys which showed the implications of income on accessibility in a comparative analysis between Chengdu in China and Santiago in Chile. As expected, findings associated higher income with higher accessibility levels in Santiago, whereas accessibility in Chengdu did not seem to be related to income, which is attributed to low motorization rates (Zegras and Srinivasan, 2007). Despite the detailed accessibility findings achieved with household travel surveys, researchers have turned to GIS systems for socio-spatial analysis of accessibility. Accessibility models based on GIS systems offer more realistic representations of transport networks. Sullivan et al. (2000) have investigated accessibility analysis models based on GIS, using isochrones. A computer algorithm was designed to select the shortest route, with the added limitations of train timetables and constant bus speed. The investigation resulted in a map with isochrones featuring pedestrian, railway and bus travel. Nicholls (2001) has also used GIS models to measure the potential opportunity-based accessibility of public parks in Bryan, Texas. The study found that although there were few public parks (less than 40% of individuals had good access to a public park), they were distributed evenly.

The difficulty in these studies lies in defining the fixed variable, i.e. the limit of travel time or distance that differentiate between what is accessible and what is not.

5.3. Accessibility scores

Regional accessibility to fundamental infrastructures for mobility area were analysed to: i) demonstrate the importance of having a chronological database when considering transport infrastructure investments; and ii) provide a quantified analysis of its impact on the same territories, measuring the degree of (in)equity of transport infrastructure investments. The infrastructures considered are the railroad and the road infrastructures, wherein each of them is studied with the appropriate distinction and treatment.

To respond to the project premises, three geographical databases were developed, in several stages and using a GIS – Geographic Information System (software ArcGIS 10.6 ESRI's company) –, wherein each of them is crucial in obtaining a quantitative final result:

- Principal routes (IP), Complementary routes (IC) and National routes (EN);
- Passenger railway (light and heavy);
- Freight railway (heavy).

Taking into account the information shared by the entities responsible for the management and maintenance of the Portuguese roadway and railway infrastructures, IP – Infraestruturas de Portugal, S.A, a database including the classification of road geometry from 1987 until 2019 was developed.

This geographic database, listed by year, has significant potential for several spatial analyses, including the accessibility measure of mainland Portugal territory, which has been developed in this work.

Several variables were calculated, and are summarized in Table 46.

Table 46 List of transport variables

Variable	Description
dist_min_rod_aero_porto	Road distance, in minutes, to Francisco Sá Carneiro Airport
dist_min_rod_aero_lisboa	Road distance, in minutes, to Humberto Delgado Airport
dist_min_rod_aero_faro	Road distance, in minutes, to Faro Airport
dist_km_rod_aero_porto	Road distance, in kilometres, to Francisco Sá Carneiro Airport
dist_km_rod_aero_lisboa	Road distance, in kilometres, to Humberto Delgado Airport
dist_km_rod_aero_faro	Road distance, in kilometres, to Faro Airport
dist_min_ferr_aero_porto	Railway distance, in minutes, to Francisco Sá Carneiro Airport
dist_min_ferr_aero_lisboa	Railway distance, in minutes, to Humberto Delgado Airport
dist_min_ferr_aero_faro	Railway distance, in minutes, to Faro Airport
dist_km_ferr_aero_porto	Railway distance, in kilometres, to Francisco Sá Carneiro Airport
dist_km_ferr_aero_lisboa	Railway distance, in kilometres, to Humberto Delgado Airport
dist_km_ferr_aero_faro	Railway distance, in kilometres, to Faro Airport
dist_min_rod_port_leixoes	Road distance, in minutes, to the Port of Leixões
dist_min_rod_port_lisboa	Road distance, in minutes, to the Port of Lisbon
dist_min_rod_port_setubal	Road distance, in minutes, to the Port of Setúbal
dist_min_rod_port_sines	Road distance, in minutes, to the Port of Sines
dist_min_rod_port_viana	Road distance, in minutes, to the Port of Viana do Castelo
dist_min_rod_port_aveiro	Road distance, in minutes, to the Port of Aveiro
dist_min_rod_port_ffoz	Road distance, in minutes, to the Port of Figueira da Foz
dist_km_rod_port_leixoes	Road distance, in kilometres, to the Port of Leixões
dist_km_rod_port_lisboa	Road distance, in kilometres, to the Port of Lisbon
dist_km_rod_port_setubal	Road distance, in kilometres, to the Port of Setúbal
dist_km_rod_port_sines	Road distance, in kilometres, to the Port of Sines
dist_km_rod_port_viana	Road distance, in kilometres, to the Port of Viana do Castelo
dist_km_rod_port_aveiro	Road distance, in kilometres, to the Port of Aveiro
dist_km_rod_port_ffoz	Road distance, in kilometres, to the Port of Figueira da Foz
acess_viaria	Road accessibility
sinuosidade	Winding road index
vel_reta	Straight Equivalent Speed
ext_ferr_merc	Freight railroad extension
ext_ferr_pass	Passenger railroad extension
ext_rod_tot	Total road extension
ext_rod_ip	Principal routes extension
ext_rod_ic	Complementary routes extension
ext_rod_outros	Other routes extension

To measure accessibility, three indicators were considered for both road and rail infrastructure: (1) Geographical Accessibility, (2) Sinuosity Index and (3) Infrastructural Accessibility. These indicators have been developed by Infraestruturas de Portugal[4].

To obtain those three indicators – Geographic Accessibility, Sinuosity Index and Infrastructure Accessibility –, it was necessary to calculate travel time and distance time using the Network Analyst toolbox (ArcGIS 10.6). The Geographical Accessibility considers the weighted average travel time to other municipalities (or regions, depending on the geographical unit of the indicator). The travel time is weighted for population. The Sinuosity Index considers the ratio between the straight travel distance (km), and the real travel road distance (km), and is also weighted by population in each region. Finally, the Infrastructural Accessibility (or equivalent speed in a straight line) was calculated using the relationship between the distance between two municipalities (km) and the travel time (min) also properly weighted for population.

To calculate those variables – travel time and travel distance –, it is necessary to find an origin (i) and a destination (j), that is, an adequate reference point to calculate this measure. Two similar methodologies were used with specificities that depend on their application, such as in the calculation of road accessibility indicators in contrast to rail accessibility indicators.

On the roadway accessibility indicators, the municipality "reference points" (or connection points) that are used in calculating these variables correspond to a central point which is usually the municipality. In total, 278 municipalities in mainland Portugal have been considered.

The results obtained for travel time (min.) correspond to the fastest route between origin (i) and destination (j). But the data obtained for travel distance (km) resulting from the fastest travel time route is not necessarily the shortest one.

This calculation is influenced by road hierarchy (1=higher; 5=lower), in which the average speed considered is as follows:

- Level 1: 120 km/h (principal routes / highway).
- Level 2: 100 km/h (principal routes and complementary routes).
- Level 3: 80 km/h (complementary routes and national routes).
- Level 4: 50 km/h (national routes and municipal routes).
- Level 5: 40 km/h (municipal routes).

In the process of calculating the indicators, the need for a railway network subdivision into passengers and freight was confirmed. To clarify this need, an example of the calculation of these indicators originating from two specific points is given: the Port of Leixões and the Francisco Sá Carneiro Airport. Considering that the railway passengers transport infrastructure comprises the heavy and light network (train and underground network from Porto, Lisboa and Metro Sul do Tejo), it would not be correct to use the same basis for calculations that was used for the Port of Leixões, for instance. This is due to the fact that the underground network is located very close by, but it is not compatible with freight transport. The Port of Sines depicts a similar case, wherein passenger transport has not been in operation since 1991, but freight transport continues.

To calculate rail accessibility indicators, a different and more complex methodology was used to identify the "connection points". In general, a distance of four kilometres from Municipality capital was considered and eight kilometres if railway station and Municipality capital coincide.

There are some exceptions, for instance, when the point considered is located in a given municipality but the railway station and its area of influence is located in a different municipality; since they are both still relatively close, these cases are also compiled, as in the examples provided in Figure 28.

Figure 28 **Examples of railway stations located in a given municipality, but whose area of influence is located in a different municipality.**

For freight railway, stations with an exclusive service were considered, for instance, the Neves Corvo station (since 1990) or the Elvas station (since 2012).

In Porto and Lisbon, Trindade and Cais do Sodré station were used as "connecting points", respectively, as they are important intermodal points in these municipalities.

Taking these criteria into account, it must be noted that not all municipalities with railway access have been considered to have efficient service, as the railway presents an eccentric route to most territories, and especially to municipalities.

The data used for the population parameter (*Pj*) was sourced from the Institute of Statistics and Censuses (INE) for the years 1981, 1991, 2001 and 2011. INE has updated the census of 1991 containing retroactive information for the municipalities of Vizela, Trofa and Odivelas, which were only created in 1998. However, data from 1986 to 1991 is missing for these municipalities.

For the purpose of providing a spatial format to the information and results, an administrative basis according to the current limits for all years since 1987 was used: CAOP, Carta Administrativa Oficial de Portugal (2018), shared by DGT (Direção-Geral do Território). Considering the changes and the evolution of administrative limits over the years, using the same basis with an updated version for the purposes of the analysis facilitates the process, which is the reason why the 2018 CAOP has been chosen for the entire analysis.

5.4. Analysis

This geographic accessibility database is more than a geographic data repository. It aims to be a tool used for measuring the accessibility of territories and for establishing comparisons and rankings between them.

Geographical accessibility, Sinuosity index and Infrastructural accessibility are examples of composite indicators because other variables are used in the indicator's construction. Moreover, travel time and distance can be composed with other variables, such as economic or financial, enabling other types of measurements.

Table 47, Table 48 and Table 49 detail the analyses carried out, identifying the source, indicators, period, infrastructure and origin--destination used.

Table 47 **Results obtained for Portugal 2030 indicators, for municipalities and NUT 3**

Source	Indicators	Period	Infrastructure	Origin (O) – Destination (D)
Portugal 2030 Indicators	Geographical Accessibility	1986 to 2019	Roads	Municipality (O) – Municipality (D)
				NUT 3 (O) – NUT 3 (D)
			Passenger Railway	Municipality (O) – Municipality (D)
				NUT 3 (O) – NUT 3 (D)
	Sinuosity Index		Roads	Municipality (O) – Municipality (D)
				NUT 3 (O) – NUT 3 (D)
			Passenger Railway	Municipality (O) – Municipality (D)
				NUT 3 (O) – NUT 3 (D)
	Infrastructural Accessibility		Road	Municipality (O) – Municipality (D)
				NUT 3 (O) – NUT 3 (D)
			Passenger Railway	Municipality (O) – Municipality (D)
				NUT 3 (O) – NUT 3 (D)

Table 48 **Results obtained for travel time and travel distance for municipalities and NUT 3.**

Source	Indicators	Period	Infrastructure	Origin (O) – Destination (D)
Ingram (1971)	Travel Time [Minutes] / Travel Distance Km	1986 to 2019	Roads	Municipality (O) – Municipality (D)
				NUT 3 (O) – NUT 3 (D)
			Passenger Railway	Municipality (O) – Municipality (D)
				NUT 3 (O) – NUT 3 (D)

Table 49 **Results obtained for travel time and travel distance from a specific origin to municipalities and NUT 3.**

Source	Indicators	Period	Infrastructure	Origin (O) – Destination (D)
Ingram (1971)	Travel Time [Minutes] / Travel Distance Km]	1986 to 2019	Roads	Airports (O) – Municipality (D)
				Airports (O) –NUT 3 (D)
				Fancisco Sá Carneiro Airport (O) – Municipality (D)
				Fancisco Sá Carneiro Airport (O) – NUT 3 (D)
				Humberto Delgado Airport (O) – Municipality (D)
				Humberto Delgado Airport (O) –NIT III (D)
				Faro Airport (O) – Municipality (D)
				Faro Airport (O) – NUT 3 (D)
				Ports (O) – Municipality (D)
				Ports (O) –NUT 3 (D)
				Port of Leixões (O) – Municipality (D)
				Port of Leixões (O) – NUT 3 (D)
				Port of Lisboa (O) –Municipality (D)
				Port of Lisboa (O) – NUT 3 (D)
				Port of Sines (O) – Municipality (D)
				Port of Sines (O) – NUT 3 (D)
			Passenger Railway	Airports (O) – Municipality (D)
				Airports (O) –NUT 3 (D)
				Fancisco Sá Carneiro Airport (O) – Municipality (D)
				Fancisco Sá Carneiro Airport (O) – NUT 3 (D)
				Humberto Delgado Airport (O) – NUT 3 (D)
				Humberto Delgado Airport (O) –Municipality (D)
				Faro Airport (O) – Municipality (D)
				Faro Airport (O) – NUT 3 (D)
			Freight Railway	Ports (O) – Municipality (D)
				Ports (O) –NUT 3 (D)
				Port of Leixões (O) – Municipality (D)
				Port of Leixões (O) – NUT 3 (D)
				Port of Lisboa (O) –Municipality (D)
				Port of Lisboa (O) – NUT 3 (D)
				Port of Sines (O) – Municipality (D)
				Port of Sines (O) – NUT 3 (D)

5.5. Results

The advantage of using accessibility indicators to measure accessibility levels is that it provides a way to compare geographical areas and to rank them according to their scores. This can provide good results by itself, depending on what kind of accessibility we want to measure, but it can also be a part of a wider analysis with other indicators.

The results obtained deliver the ranking of accessibility and travel time among Portuguese regions (NUTS 3[5]) in the mainland, though the same can be done with other geographical categorizations (as can be found in Annex 1 of this study when using a smaller territorial unit: LAU 1 [Local Administrative Unit], the municipality).

Table 50 presents the value of Geographic Accessibility on NUT 3 measured for each year of analysis and the value of absolute variation between the first and last year (1986 to 2019). These results demonstrate how roadway geographical accessibility has evolved throughout the years and the absolute variation demonstrates the improvements observed within the period analysed. Additionally, Table 50 compiles the population density among regions as the indicator incorporates the number of inhabitants per census.

Table 50 **Ranking of road accessibility among mainland Portuguese NUTS 3**

NUTS 3	Years								Absolute variation
	1986	1991	1996	2001	2006	2011	2016	2019	1986 –2019
AM do Porto	126,3	141,7	144,4	155,0	159,0	160,6	156,0	156,0	29,7
AM de Lisboa	114,1	127,7	133,1	138,8	139,5	145,1	143,6	143,6	29,5
Ave	82,8	93,8	96,0	105,2	110,9	113,3	110,9	110,9	28,1
Cávado	80,4	91,3	93,8	102,9	106,0	108,0	105,6	105,6	25,2
Tâmega e Sousa	77,1	85,7	88,3	96,9	104,1	106,2	104,2	104,2	27,1
Região de Aveiro	76,8	90,4	91,9	101,5	103,4	104,9	102,5	102,5	25,7
Lezíria do Tejo	74,9	80,6	86,9	93,7	95,2	99,6	98,1	98,1	23,2
Oeste	71,4	75,6	80,6	89,2	92,2	96,7	95,5	95,5	24,1
Região de Leiria	64,5	74,9	77,9	84,6	85,8	89,6	88,3	88,3	23,8
Região de Coimbra	61,5	72,1	74,0	81,2	83,0	84,9	83,5	83,5	22,0
Médio Tejo	56,4	63,1	72,3	78,0	79,4	82,5	82,0	82,0	25,6
Alto Minho	57,5	63,7	64,6	74,2	76,3	77,4	75,6	75,6	18,1
Viseu Dão Lafões	55,8	64,2	66,2	72,6	76,6	77,0	74,9	74,9	19,1
Douro	49,6	54,0	56,5	60,9	64,0	66,2	65,6	65,6	16,0
Alentejo Central	47,7	50,4	55,0	59,5	60,5	62,3	61,2	61,2	13,5
Beiras e Serra da Estrela	42,8	46,9	47,9	51,8	58,8	59,1	57,5	57,5	14,7
Beira Baixa	38,9	40,4	45,1	48,3	55,6	56,4	56,6	56,6	17,7
Alentejo Litoral	40,6	43,1	48,5	53,1	55,1	56,7	55,6	55,6	15,0
Alto Tâmega	42,5	45,2	46,6	49,3	56,2	56,9	55,6	55,6	13,1
Alto Alentejo	38,6	40,0	47,3	51,7	53,4	54,2	53,6	53,6	15,0
Baixo Alentejo	36,4	38,6	42,0	46,9	48,5	49,9	48,9	48,9	12,5
Terras de Trás-os-Montes	31,7	34,4	37,9	41,2	44,3	45,2	45,2	45,2	13,5
Algarve	29,7	31,6	34,4	39,0	42,2	44,3	43,4	43,4	13,7

The ranking of 2019 for roadway geographic accessibility on Portuguese NUTS 3 indicates that the Metropolitan Area of Oporto (AM do Porto) has the best accessibility and recorded the highest increase between 1986 and 2019 (29,7). This does not mean that the investments made there were more significant than in other regions, such as the Metropolitan Area of Lisbon (AM de Lisboa), which is a more densely populated region, but compared with AM do Porto it has recorded a decrease in its accessibility level.

The regions with the lowest roadway geographic accessibility in 2019 were Terras de Trás-os-Montes and the Algarve. These regions are located in the northern (Terras de Trás-os-Montes) and southern (Algarve) borders of the Portuguese mainland territory. As such, the number of long trips between these regions and others is higher than in other regions, resulting in lower accessibility level.

Although the Lower Alentejo region (Baixo Alentejo) is not the one ranked with the lowest accessibility, it has the smallest absolute variation, which demonstrates that it is the region that has undergone the least change.

Table 51 presents the roadway travel time measured from an infrastructure, in this case, an airport, to NUTS 3 for each year of analysis, as well as the value of absolute variation between the first and last year (1986 to 2019). The outcome is presented in the form of progress throughout the years, and the absolute variation column shows the improvements in roadway travel time within the period in analysis. The negative values in the absolute variation column have a positive connotation because they indicate a decreased travel time between Origin and Destination: the lower variation absolute value corresponds to the highest decrease in travel time.

Table 51 Roadway travel time (minutes) from Francisco Sá Carneiro Airport (Oporto) to mainland Portuguese NUTS 3

NUTS 3	Years 1986	1991	1996	2001	2006	2011	2016	2019	Absolute variation 1986 –2019
AM do Porto	25,9	25,7	25,7	22,1	21,9	21,6	21,6	21,6	-4,3
Ave	39,6	39,6	32,4	32,4	32,4	32,4	32,4	32,4	-7,2
Cávado	38,3	38,3	34,8	34,8	34,8	34,8	34,8	34,8	-3,5
Tâmega e Sousa	56,2	49	49	48,9	41,1	41,1	41,1	41,1	-15,1
Região de Aveiro	62,8	52,2	52	49,5	49,5	49,5	49,5	49,5	-13,3
Alto Minho	68,6	67,2	61,5	61,5	60,5	60,5	60,5	60,5	-8,1
Douro	121,4	108,2	98,1	98	94,7	87,9	81,7	81,7	-39,7
Viseu Dão Lafões	108,3	87	86,8	84,2	84,2	84,2	84,2	84,2	-24,1
Região de Coimbra	90,9	89,7	89,5	86,9	86,3	86,3	86,3	86,3	-4,6
Alto Tâmega	108,5	108,5	101,6	101,6	90,6	90,6	90,6	90,6	-17,9
Região de Leiria	121,2	117,1	116,9	114,4	114,4	103,8	103,8	103,8	-17,4
Beiras e Serra da Estrela	166	132,7	132,5	129,9	111,8	111,8	111,8	111,8	-54,2
Médio Tejo	151,6	150,4	149,6	147,1	147,1	147,1	116,8	116,8	-34,8
Terras de Trás-os-Montes	191,8	191,3	147	146,9	138,7	127,9	120,8	120,8	-71
Lezíria do Tejo	179,8	163,5	146,6	141,7	141,7	141,7	141,7	141,7	-38,1
Oeste	170,8	167,4	163,7	152	147,5	146,5	146,5	146,5	-24,3
Alto Alentejo	228,2	221,5	193,1	185,2	180,7	180,7	170,1	170,1	-58,1
Beira Baixa	220,7	192,1	191,9	189,4	170,2	170,2	170,2	170,2	-50,5
AM de Lisboa	216,2	178,8	178,6	176,1	176,1	176,1	176,1	176,1	-40,1
Alentejo Litoral	289,3	251,9	230,2	225,5	213,9	213,9	213,9	213,9	-75,4
Alentejo Central	260,6	230,6	227,4	220,7	219,8	219,8	219,8	219,8	-40,8
Baixo Alentejo	318	287,7	276,3	264,5	252,9	252,9	252,9	252,9	-65,1
Algarve	374,2	338,5	313	298,9	275,9	275,9	275,9	275,9	-98,3

From Francisco Sá Carneiro Airport (Oporto), it is possible to arrive in less than one hour to the following regions/NUT 3: AM do Porto, Ave, Cávado, Tâmega e Sousa and Região de Aveiro. Absolute variation demonstrates a decrease in travel time for all regions from this airport, with special emphasis on the regions of Beiras e Serra da Estrela, Douro and Tâmega e Sousa, since these belong to the hinterland served by Francisco Sá Carneiro airport.

Table 52 draws a similar analysis to the previous one, measuring travel time from another infrastructure: Humberto Delgado Airport (Lisbon). It takes less than one hour to travel from this airport to the following regions/NUT 3: AM de Lisboa, Oeste and Lezíria do Tejo. Absolute variation demonstrates a decrease in travel time from this point to all regions, with special emphasis on Médio Tejo and Baixo Alentejo, since these two belong to the hinterland served by Humberto Delgado airport.

Table 52 Roadway travel time (minutes) from Humberto Delgado Airport (Lisbon) to mainland Portuguese NUTS 3

NUTS 3	Years 1986	1991	1996	2001	2006	2011	2016	2019	Absolute variation 1986 –2019
AM de Lisboa	14,7	14,7	14,7	14,7	14,7	14,7	14,7	14,7	0,0
Oeste	51,8	51,8	47,2	42,0	42,0	42,0	42,0	42,0	-9,8
Lezíria do Tejo	58,6	58,6	50,7	48,3	48,3	48,3	48,3	48,3	-10,3
Alentejo Litoral	87,8	87,8	80,6	69,0	69,0	69,0	69,0	69,0	-18,8
Região de Leiria	83,1	75,0	70,6	70,6	70,3	70,3	70,3	70,3	-12,9
Alentejo Central	93,4	93,4	87,4	76,6	76,6	76,6	76,6	76,6	-16,8
Médio Tejo	123,2	107,9	98,2	90,8	90,8	83,1	83,1	83,1	-40,1
Baixo Alentejo	137,7	137,7	126,7	107,9	107,9	107,9	107,9	107,9	-29,8

NUTS 3	Years 1986	1991	1996	2001	2006	2011	2016	2019	Absolute variation 1986 –2019
Região de Coimbra	148,5	114,6	114,6	114,6	114,6	114,6	114,6	114,6	-33,9
Alto Alentejo	152,4	152,4	125,4	120,0	115,5	115,5	115,5	115,5	-36,9
Região de Aveiro	175,6	134,5	134,5	130,6	130,6	130,6	130,6	130,6	-45,0
Algarve	174,4	174,4	163,4	142,3	130,9	130,9	130,9	130,9	-43,4
Beira Baixa	216,0	216,0	191,7	186,4	149,1	149,1	149,1	149,1	-66,9
AM do Porto	197,3	156,2	156,2	151,4	151,4	151,4	151,4	151,4	-45,9
Beiras e Serra da Estrela	264,1	218,5	214,5	193,5	160,4	160,4	160,4	160,4	-103,7
Viseu Dão Lafões	225,8	172,8	172,8	166,3	164,9	164,9	164,9	164,9	-60,8
Ave	236,6	191,6	187,4	183,6	183,6	183,6	183,6	183,6	-53,0
Cávado	242,7	196,0	189,8	186,0	186,0	186,0	186,0	186,0	-56,7
Tâmega e Sousa	241,3	197,2	196,8	193,0	188,5	188,5	188,5	188,5	-52,9
Alto Minho	270,4	218,6	216,5	212,6	211,6	211,6	211,6	211,6	-58,8
Douro	295,2	245,1	244,8	235,7	223,1	223,1	223,1	223,1	-72,1
Alto Tâmega	305,5	260,6	256,6	252,8	241,8	241,8	241,8	241,8	-63,8
Terras de Trás-os--Montes	381,9	305,2	294,8	278,6	267,2	260,1	260,1	260,1	-121,9

In Table 53, the same analysis is made with the Faro airport. It takes less than one hour to travel from this airport only to the region where the airport is located (Algarve). There has been a considerable decrease in travel time throughout the years in some of the closer regions, especially Lezíria do Tejo, Alentejo Central and Baixo Alentejo.

Table 53 Roadway travel time (minutes) from Faro Airport to mainland Portuguese NUTS 3

NUTS 3	Years 1986	1991	1996	2001	2006	2011	2016	2019	Absolute variation 1986 –2019
Algarve	30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	0,0
Baixo Alentejo	130,1	130,1	102,8	102,8	86,8	86,8	86,8	86,8	-43,3
Alentejo Litoral	129,0	129,0	123,9	121,3	104,5	104,5	104,5	104,5	-24,5
Alentejo Central	170,8	170,8	143,3	143,3	127,2	127,2	127,2	127,2	-43,5
Lezíria do Tejo	226,0	226,0	208,0	195,5	154,9	154,9	154,9	154,9	-71,1
AM de Lisboa	203,8	203,8	187,3	173,3	156,5	156,5	156,5	156,5	-47,2
Oeste	248,3	248,3	216,6	197,1	180,3	177,9	177,9	177,9	-70,4
Região de Leiria	279,6	271,5	235,6	223,9	200,9	197,0	197,0	197,0	-82,7
Alto Alentejo	242,4	242,4	223,8	221,5	205,5	203,3	203,3	203,3	-39,1
Médio Tejo	297,6	297,6	263,6	244,5	215,5	207,8	207,8	207,8	-89,8
Região de Coimbra	345,0	311,1	280,0	268,3	239,3	239,3	239,3	239,3	-105,7
Região de Aveiro	372,1	331,0	299,9	284,3	255,3	255,3	255,3	255,3	-116,8
Beira Baixa	334,4	334,4	302,0	299,6	273,8	273,8	273,8	273,8	-60,5
AM do Porto	393,8	352,7	321,6	305,0	276,1	276,1	276,1	276,1	-117,8
Beiras e Serra da Estrela	386,8	386,8	354,4	345,2	285,0	285,0	285,0	285,0	-101,7
Viseu Dão Lafões	422,3	369,3	338,2	320,0	289,6	289,6	289,6	289,6	-132,7
Ave	433,1	388,1	352,8	337,2	308,3	308,3	308,3	308,3	-124,8
Cávado	439,2	392,5	355,2	339,6	310,7	310,7	310,7	310,7	-128,5
Tâmega e Sousa	437,8	393,8	362,2	346,6	313,2	313,2	313,2	313,2	-124,7
Alto Minho	466,9	415,1	381,9	366,3	336,3	336,3	336,3	336,3	-130,6
Douro	483,7	441,7	410,2	389,4	347,8	347,8	347,8	347,8	-135,9
Alto Tâmega	502,1	457,1	422,0	406,4	366,5	366,5	366,5	366,5	-135,6
Terras de Trás-os--Montes	524,7	493,0	459,0	432,2	391,8	384,8	384,8	384,8	-139,9

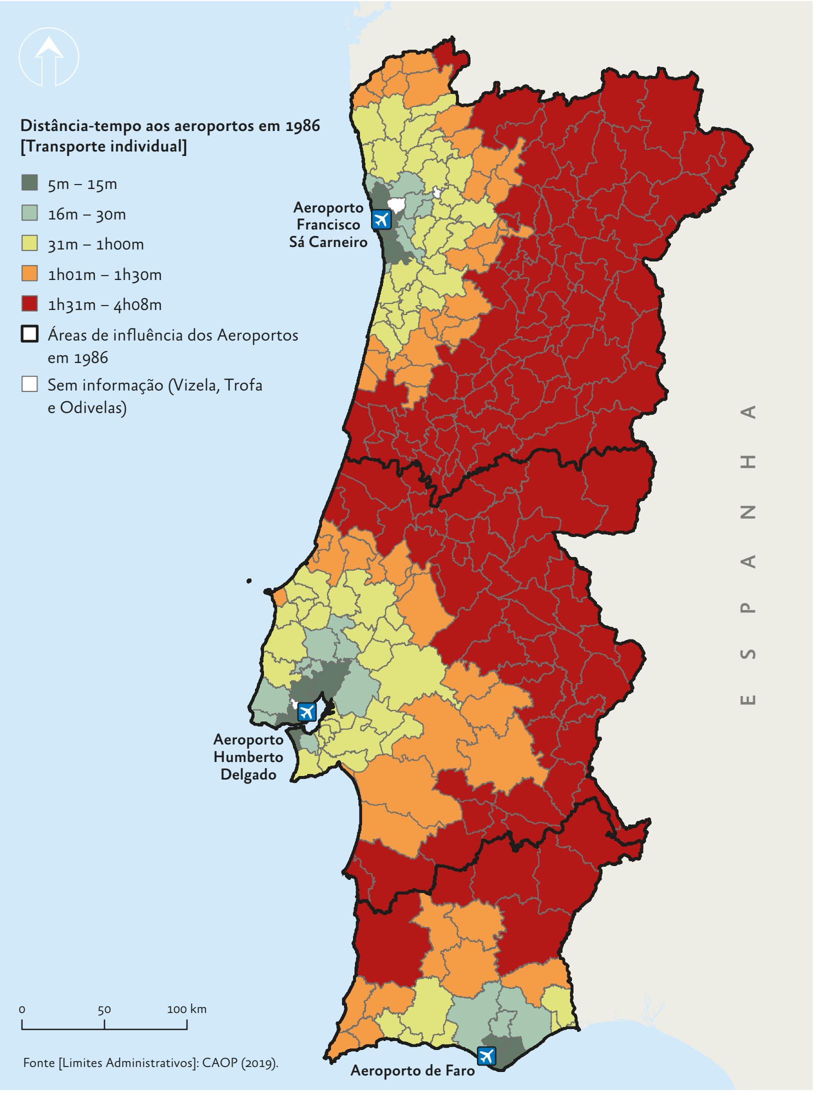
It can be concluded that Francisco Sá Carneiro airport has the largest area of influence among the three airports in Portugal mainland.

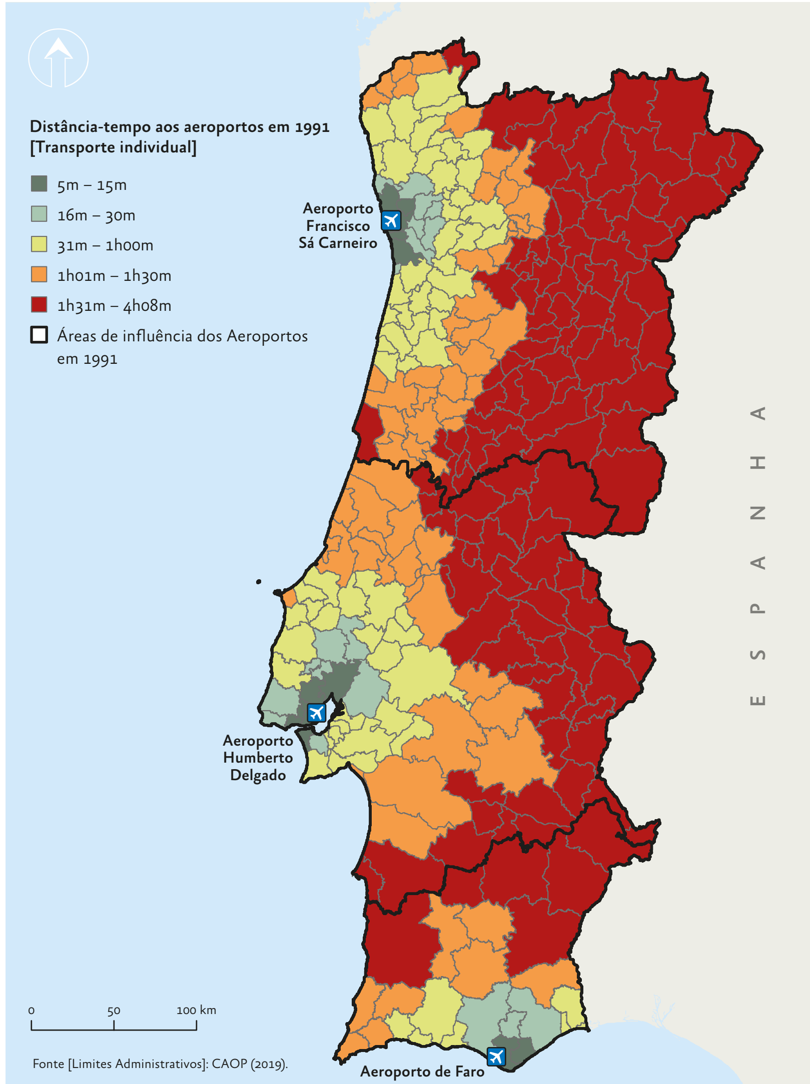
The same accessibility data could be used for several other studies. Rankings can classify different indicators, measurements of the increase in accessibility, travel time and others. There is great potential among these to portray the attractiveness of a territory or to compare it with other regions. The same principle can be applied to infrastructures, as in the example provided with airports; the same study could be used for maritime ports, for instance.

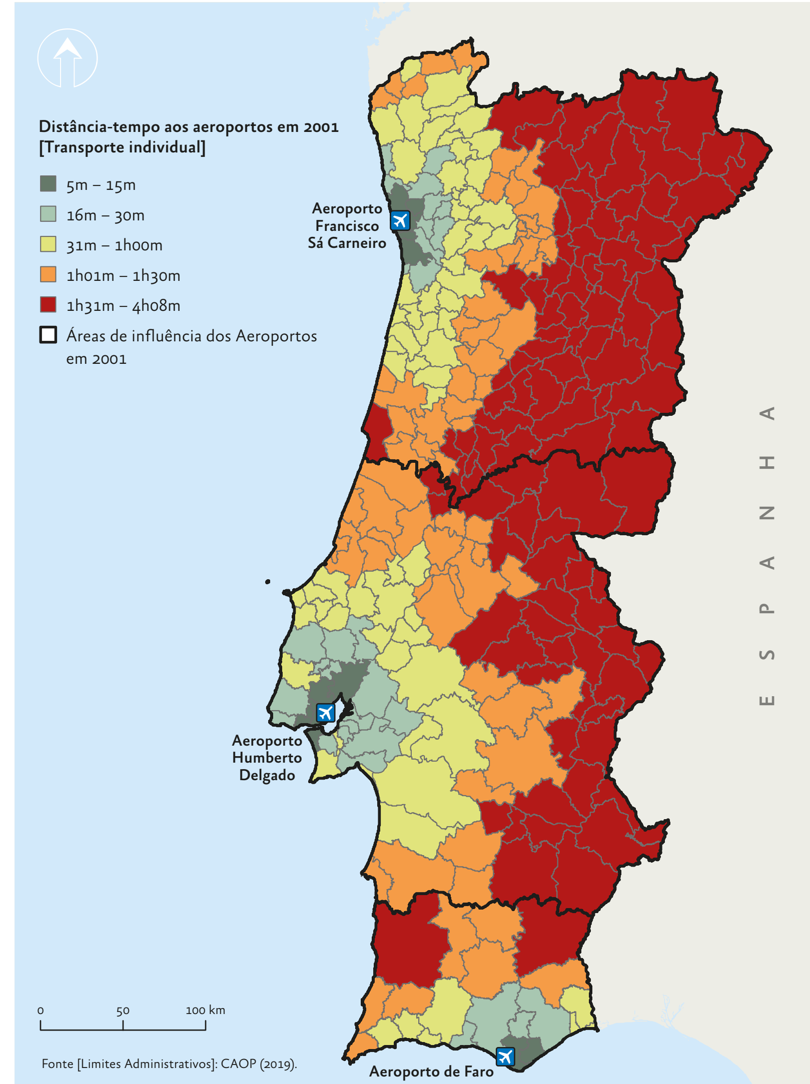
Although data from NUT 3 is useful in certain regional analyses, at the municipality level data is more disaggregated and detailed. Disaggregated data is more realistic in territory analyses, especially when defining areas of influence (Figure 29). It is also vital to mention that data can be provided using tables or maps, depending on the analysis required, the amount of data delivered and the target audience that will use or scrutinize the information.

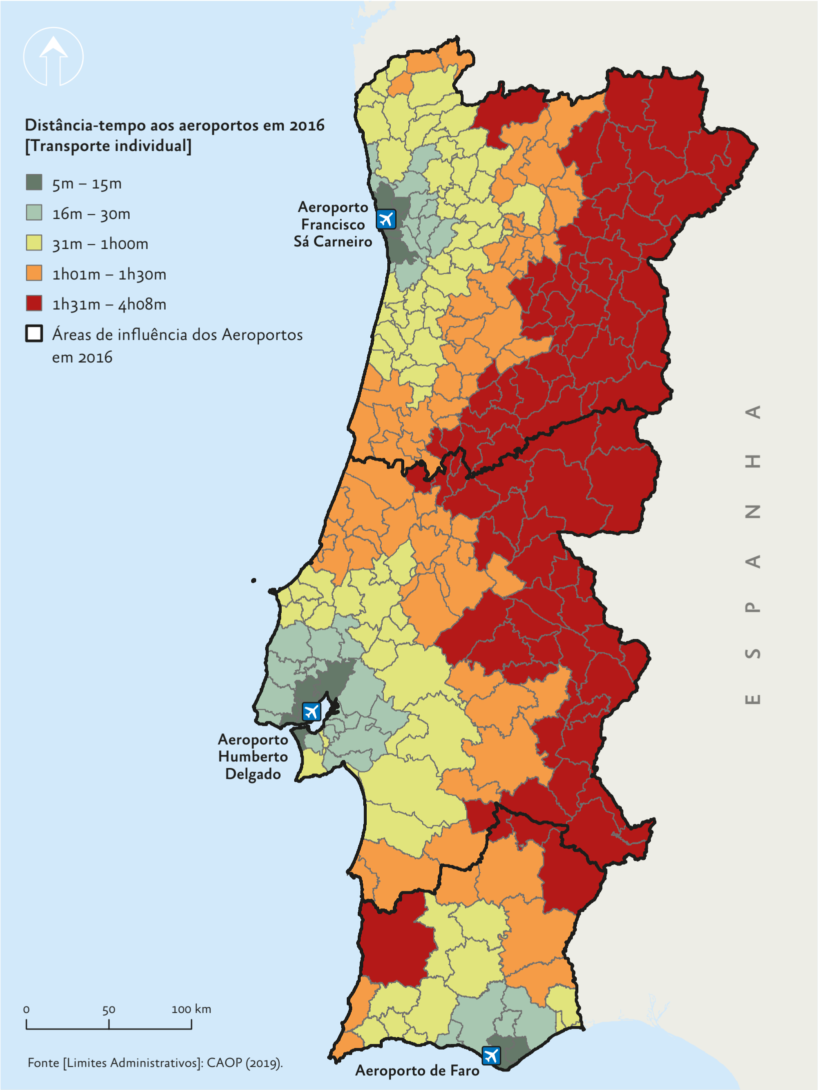
Of the 278 municipalities under analysis, it could be concluded that 148 belong to the area of influence of Francisco Sá Carneiro airport, 105 to Lisbon Airport and 26 to Faro Airport. Taking as an example the municipality of Castanheira de Pêra, it belonged to the area of influence of Francisco Sá Carneiro airport until 2011, but in 2016 this municipality shifted from Porto's airport hinterland to the area of influence of Humberto Delgado airport (Lisbon).

Figure 29 **Roadway travel time from airports in 1986, 1991, 2001 and 2016 by area of influence.**




Distância-tempo aos aeroportos em 1991
[Transporte individual]
5m – 15m
16m – 30m
31m – 1h00m
1h01m – 1h30m
1h31m – 4h08m
Áreas de influência dos Aeroportos em 1991
Aeroporto Francisco Sá Carneiro
Aeroporto Humberto Delgado
Aeroporto de Faro
E S P A N H A
0
50
100 km
Fonte [Limites Administrativos]: CAOP (2019).


Distância-tempo aos aeroportos em 2001
[Transporte individual]
5m – 15m
16m – 30m
31m – 1h00m
1h01m – 1h30m
1h31m – 4h08m
Áreas de influência dos Aeroportos em 2001
Aeroporto Francisco Sá Carneiro
Aeroporto Humberto Delgado
Aeroporto de Faro
E S P A N H A
0
50
100 km
Fonte [Limites Administrativos]: CAOP (2019).



Similarly to the data presented previously, the following information concentrates on the geographic accessibility and travel time data regarding the mainland Portuguese railway. Figure 29 exhibits the ranking of 2019 for railway geographical accessibility and it indicates that AM do Porto has the best accessibility rate among all regions, although it presents a similar value as the AM de Lisboa. However, AM do Porto has shown a slow increase, as the 2019 accessibility is very close to the observation in 1986, with an increase of 3.2. On the other hand, AM de Lisboa, which tops the list alongside AM do Porto, has had a sharp increase in the level of accessibility.

Some regions do not have railway service anymore, for instance Terras de Trás-os-Montes and Alto Tâmega. Others registered a decrease in railway accessibility, like Viseu Dão Lafões, Alto Alentejo, Alentejo Litoral, Alentejo Central, Douro, Região de Coimbra, Tâmega e Sousa, Baixo Alentejo, Região de Aveiro, Lezíria do Tejo and Beiras e Serra da Estrela.

The regions with the lowest railway accessibility in 2019 were Alto Alentejo and Douro. Although Alto Minho was not the region with the lowest accessibility level, the absolute variation demonstrates that it is the region that received the least investment, since the variation is very low.

Table 54 Ranking of railway accessibility among mainland Portuguese NUTS 3

NUTS 3	Years 1986	1991	1996	2001	2006	2011	2016	2019	Absolute variation 1986 –2019
AM do Porto	58,9	59,5	59,3	63,1	68,7	67,7	62,1	62,1	3,2
AM de Lisboa	34,7	32,0	31,9	51,3	62,3	64,0	62,0	62,0	27,3
Ave	40,6	38,9	38,8	43,2	41,8	43,3	42,0	42,0	1,4
Cávado	34,5	35,4	35,2	39,1	37,9	38,4	37,1	37,1	2,6
Região de Aveiro	38,6	37,0	36,9	40,5	40,4	39,8	35,9	35,9	-2,7
Região de Coimbra	33,9	33,1	32,9	36,6	36,8	29,7	28,1	28,1	-5,8
Região de Leiria	25,2	24,6	24,5	27,9	28,2	28,7	27,5	27,5	2,3
Lezíria do Tejo	29,4	27,7	27,6	30,8	28,0	31,8	27,3	27,3	-2,1
Algarve	17,8	17,4	17,4	20,0	22,4	24,4	23,4	23,4	5,6
Tâmega e Sousa	26,3	24,9	24,8	26,8	26,4	22,3	21,6	21,6	-4,7
Alto Minho	20,6	21,3	18,6	21,3	20,9	21,5	20,7	20,7	0,1
Médio Tejo	18,3	17,9	17,8	20,0	20,4	20,8	19,8	19,8	1,5
Beira Baixa	14,5	14,5	14,4	17,1	17,4	18,2	17,4	17,4	2,9
Oeste	13,5	13,0	13,0	15,0	15,8	16,4	15,8	15,8	2,3
Alentejo Central	21,8	10,1	10,1	11,9	14,3	15,4	14,8	14,8	-7,0
Beiras e Serra da Estrela	13,0	11,9	12,3	14,3	14,5	13,1	12,5	12,5	-0,5
Baixo Alentejo	12,5	6,9	6,8	8,0	9,0	9,8	9,2	9,2	-3,3
Viseu Dão Lafões	19,9	6,9	6,8	7,2	7,2	6,9	6,5	6,5	-13,4
Alentejo Litoral	17,1	7,4	7,4	8,3	11,8	12,2	6,0	6,0	-11,1
Douro	9,4	7,6	7,6	8,6	8,6	2,8	2,7	2,7	-6,7
Alto Alentejo	14,1	11,4	11,4	12,7	12,9	12,9	1,2	1,2	-12,9
Terras de Trás-os--Montes	8,4	6,3	2,4	2,8	2,8	n/a	n/a	n/a	-8,4
Alto Tâmega	6,7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-6,7

Figure 29 presents the railway travel time measurements for each year and its absolute variation between the first and last year in analysis. Until 2006, Francisco Sá Carneiro Airport was not served by rail. This only came into existence in 2006 when the E Line (Violet) was inaugurated, expanding the light rail network of Oporto's Metropolitan Area.

Table 55 Railway travel time (minutes) from Francisco Sá Carneiro Airport to mainland Portuguese NUTS 3

NUTS 3	Year 1986	1991	1996	2001	2006	2011	2016	2019	Absolute variation
AM do Porto	n/a	n/a	n/a	n/a	35,2	35,2	35,2	35,2	0,0
Cávado	n/a	n/a	n/a	n/a	71,4	71,0	71,0	71,0	-0,4
Ave	n/a	n/a	n/a	n/a	80,1	79,7	79,7	79,7	-0,4
Alto Minho	n/a	n/a	n/a	n/a	93,0	92,6	92,6	92,6	-0,4
Região de Aveiro	n/a	n/a	n/a	n/a	97,2	97,2	97,2	97,2	0,0
Tâmega e Sousa	n/a	n/a	n/a	n/a	106,8	106,8	106,8	106,8	0,0
Região de Coimbra	n/a	n/a	n/a	n/a	110,8	110,8	110,8	110,8	0,0
Região de Leiria	n/a	n/a	n/a	n/a	143,2	143,2	143,2	143,2	0,0
Viseu Dão Lafões	n/a	n/a	n/a	n/a	168,1	168,1	168,1	168,1	0,0
Médio Tejo	n/a	n/a	n/a	n/a	181,5	181,5	181,5	181,5	0,0
Douro	n/a	n/a	n/a	n/a	186,8	186,8	186,8	186,8	0,0
Lezíria do Tejo	n/a	n/a	n/a	n/a	195,6	195,6	195,6	195,6	0,0
Beiras e Serra da Estrela	n/a	n/a	n/a	n/a	205,6	205,6	205,6	205,6	0,0
Oeste	n/a	n/a	n/a	n/a	248,5	248,5	248,5	248,5	0,0
Alto Alentejo	n/a	n/a	n/a	n/a	250,1	250,1	250,1	250,1	0,0
AM de Lisboa	n/a	n/a	n/a	n/a	260,6	260,6	260,6	260,6	0,0
Beira Baixa	n/a	n/a	n/a	n/a	262,9	262,9	262,9	262,9	0,0

Alentejo Litoral	n/a	n/a	n/a	n/a	304,3	297,9	297,9	297,9	-6,4
Alentejo Central	n/a	n/a	n/a	n/a	316,4	316,4	316,4	316,4	0,0
Baixo Alentejo	n/a	n/a	n/a	n/a	340,4	340,4	340,4	340,4	0,0
Algarve	n/a	n/a	n/a	n/a	388,2	381,8	381,8	381,8	-6,4
Alto Tâmega	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Terras de Trás-os--Montes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Humberto Delgado Airport did not have a connection to the railway service until 2012. It was only in that year that this connection was created, through the expansion of the red line of Lisbon's underground system.

Table 56 Railway travel time (minutes) from Humberto Delgado Airport to mainland Portuguese NUTS 3

	Year									Absolute variation
NUTS 3	1986	1991	1996	2001	2006	2011	2012	2016	2019	
AM de Lisboa	n/a	n/a	n/a	n/a	n/a	n/a	37,8	37,8	37,8	0
Lezíria do Tejo	n/a	n/a	n/a	n/a	n/a	n/a	43,3	43,3	43,3	0
Alentejo Litoral	n/a	n/a	n/a	n/a	n/a	n/a	75,1	75,1	75,1	0
Médio Tejo	n/a	n/a	n/a	n/a	n/a	n/a	83,1	83,1	83,1	0
Alentejo Central	n/a	n/a	n/a	n/a	n/a	n/a	93,6	93,6	93,6	0
Região de Leiria	n/a	n/a	n/a	n/a	n/a	n/a	95,7	95,7	95,7	0
Baixo Alentejo	n/a	n/a	n/a	n/a	n/a	n/a	117,6	117,6	117,6	0
Oeste	n/a	n/a	n/a	n/a	n/a	n/a	119,9	119,9	119,9	0
Região de Coimbra	n/a	n/a	n/a	n/a	n/a	n/a	129,0	129,0	129,0	0
Alto Alentejo	n/a	n/a	n/a	n/a	n/a	n/a	n/a	142,3	142,3	0
Beira Baixa	n/a	n/a	n/a	n/a	n/a	n/a	155,1	155,1	155,1	0
Algarve	n/a	n/a	n/a	n/a	n/a	n/a	159,0	159,0	159,0	0
Região de Aveiro	n/a	n/a	n/a	n/a	n/a	n/a	179,0	179,0	179,0	0
Viseu Dão Lafões	n/a	n/a	n/a	n/a	n/a	n/a	202,6	202,6	202,6	0
AM do Porto	n/a	n/a	n/a	n/a	n/a	n/a	209,0	209,0	209,0	0
Beiras e Serra da Estrela	n/a	n/a	n/a	n/a	n/a	n/a	240,1	240,1	240,1	0
Cávado	n/a	n/a	n/a	n/a	n/a	n/a	244,8	244,8	244,8	0
Ave	n/a	n/a	n/a	n/a	n/a	n/a	253,5	253,5	253,5	0
Alto Minho	n/a	n/a	n/a	n/a	n/a	n/a	266,4	266,4	266,4	0
Tâmega e Sousa	n/a	n/a	n/a	n/a	n/a	n/a	280,6	280,6	280,6	0
Douro	n/a	n/a	n/a	n/a	n/a	n/a	360,6	360,6	360,6	0
Alto Tâmega	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Terras de Trás--os-Montes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Although Faro airport has access to rail service, the average distance to NUTS 3 is very high, which is reflected by a low level of rail accessibility.

From Faro Airport it is possible to enter the Algarve region in less than one hour. Absolute variation demonstrates a travel time increase for a few regions from this point, with special emphasis on Baixo Alentejo and Alentejo Central, since these belong to the area of influence of Humberto Delgado airport.

Table 57 **Railway travel time (minutes) from Faro Airport to mainland Portuguese NUTS 3**

NUTS 3	Year 1986	1991	1996	2001	2006	2011	2016	2019	Absolute variation
Algarve	33,6	33,6	33,6	33,6	33,6	33,6	33,6	33,6	0,0
Alentejo Litoral	117,5	117,5	117,5	117,5	117,5	117,5	117,5	117,5	0,0
Alentejo Central	189,5	189,5	189,5	189,5	189,5	189,5	200,3	200,3	10,8
AM de Lisboa	290,5	290,5	290,5	290,5	210,2	203,8	203,8	203,8	-86,6
Lezíria do Tejo	238,2	238,2	238,2	238,2	226,2	219,9	219,9	219,9	-18,3
Baixo Alentejo	142,9	142,9	142,9	142,9	142,9	142,9	224,3	224,3	81,3
Médio Tejo	277,9	277,9	277,9	277,9	266,0	259,6	259,6	259,6	-18,3
Região de Leiria	290,5	290,5	290,5	290,5	278,6	272,2	272,2	272,2	-18,3
Oeste	372,5	372,5	372,5	372,5	292,2	285,9	285,9	285,9	-86,6
Região de Coimbra	323,8	323,8	323,8	323,8	311,9	305,6	305,6	305,6	-18,3
Alto Alentejo	318,6	337,2	337,2	337,2	325,2	318,9	318,9	318,9	0,3
Beira Baixa	350,0	350,0	350,0	350,0	338,1	331,7	331,7	331,7	-18,3
Região de Aveiro	373,9	373,9	373,9	373,9	362,0	355,6	355,6	355,6	-18,3
Viseu Dão Lafões	397,4	397,4	397,4	397,4	385,5	379,1	379,1	379,1	-18,3
AM do Porto	403,8	403,8	403,8	403,8	391,9	385,5	385,5	385,5	-18,3
Beiras e Serra da Estrela	434,9	434,9	434,9	434,9	423,0	416,6	416,6	416,6	-18,3
Cávado	440,0	440,0	440,0	440,0	428,1	421,3	421,3	421,3	-18,7
Ave	448,8	448,7	448,7	448,7	436,8	430,1	430,1	430,1	-18,7
Alto Minho	461,6	461,6	461,6	461,6	449,7	442,9	442,9	442,9	-18,7
Tâmega e Sousa	475,4	475,4	475,4	475,4	463,5	457,1	457,1	457,1	-18,3
Douro	555,4	555,4	555,4	555,4	543,5	537,1	537,1	537,1	-18,3
Terras de Trás-os-Montes	733,9	733,9	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Alto Tâmega	633,9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Faro airport has the biggest area of influence in the analysis of the three Portuguese airports in the mainland due to the fact that until 2006 it was the only airport with railway service.

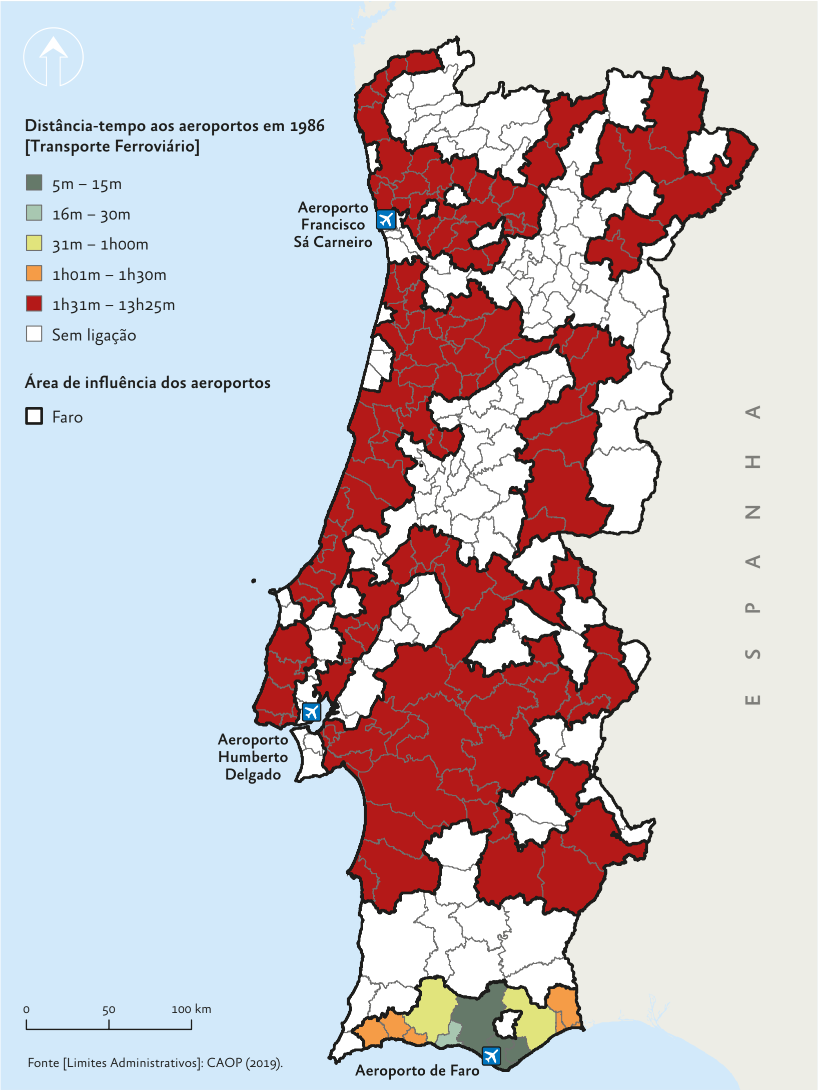
Although data from NUTS 3 is useful in certain regional analyses, in cases like this municipality comparison is the best option. With more disaggregated data we can accomplish more realistic analyses of the territory, for instance when defining areas of influence (Figure 29 and Table 54).

Of the total of 278 municipalities analysed in 1986, only 146 had railway service. In 2019, only 98 municipalities had this service.

Over the reviewed period, travel distance has been shifting significantly due to constant changes in the Portuguese railway network – either when closing or creating some railway services, for instance the light railway network created in Porto, the Metro Sul do Tejo or the expansion of the Lisbon underground network –, thus changing the area of influence of each airport (Figure 29 and Table 54).

In conclusion, until 2006 Faro was the only airport with railway service. From 2006 onwards, with the connection of the airport of Oporto to the railway network, the municipalities with railway service from the north of Portugal and some municipalities in other regions became part of the area of influence of the Francisco Sá Carneiro airport. In 2012, with the connection of Humberto Delgado airport to the Lisbon underground network, mainland Portugal developed three areas of influence for the three airports. Currently, the area of influence of Faro airport is very specific and concentrated in the south part of the country, while Francisco Sá Carneiro airport has the most extensive area of influence throughout the Portuguese territory.

Figure 30 Railway travel time from airports in 1986 and 1991 by area of influence (1/2).



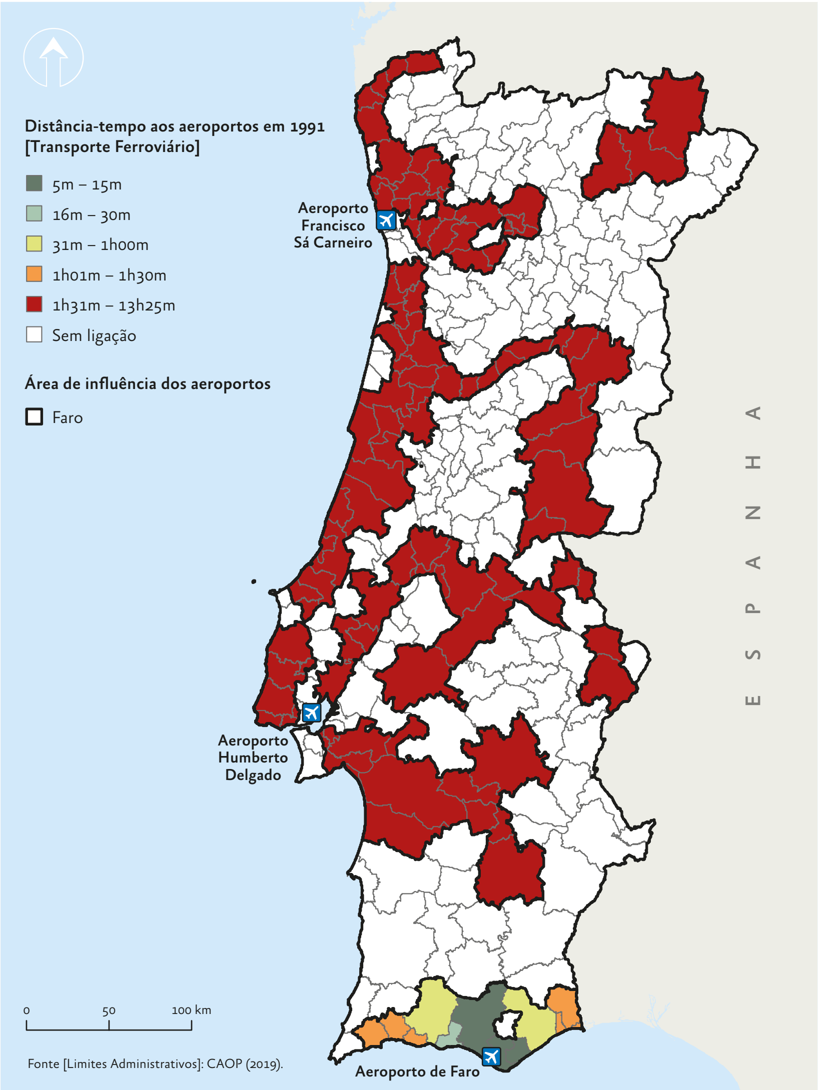
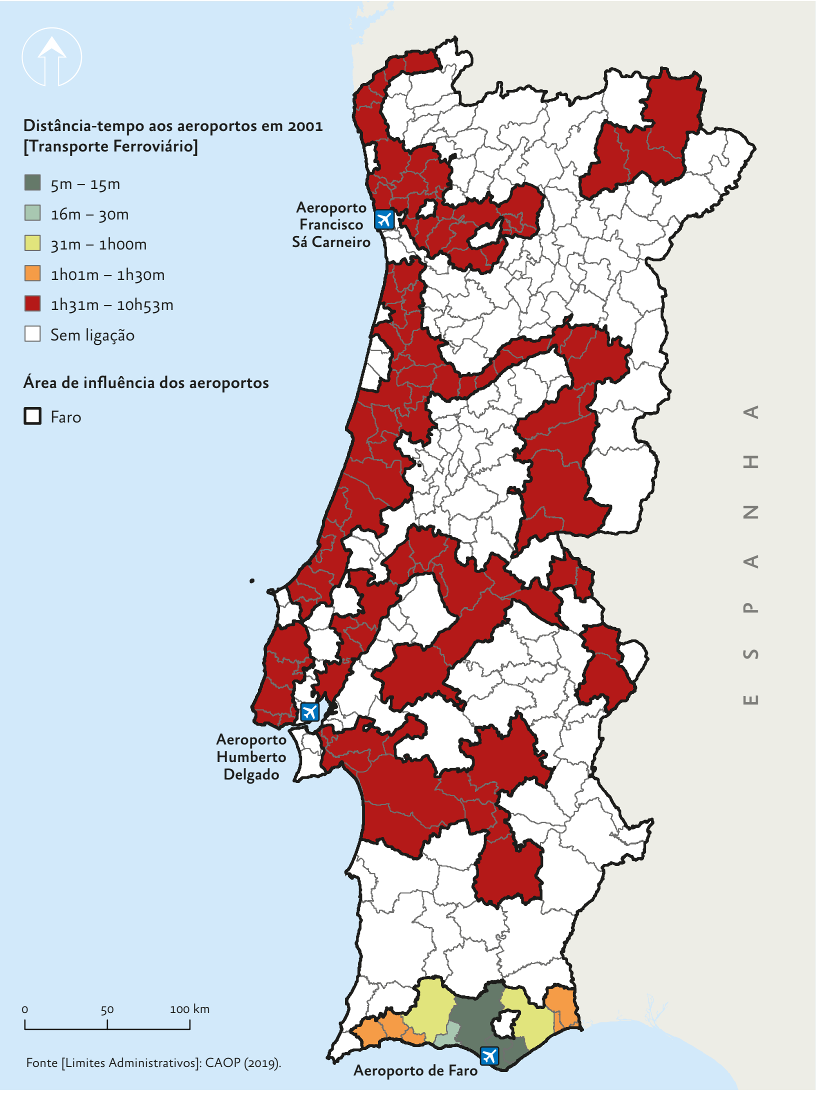
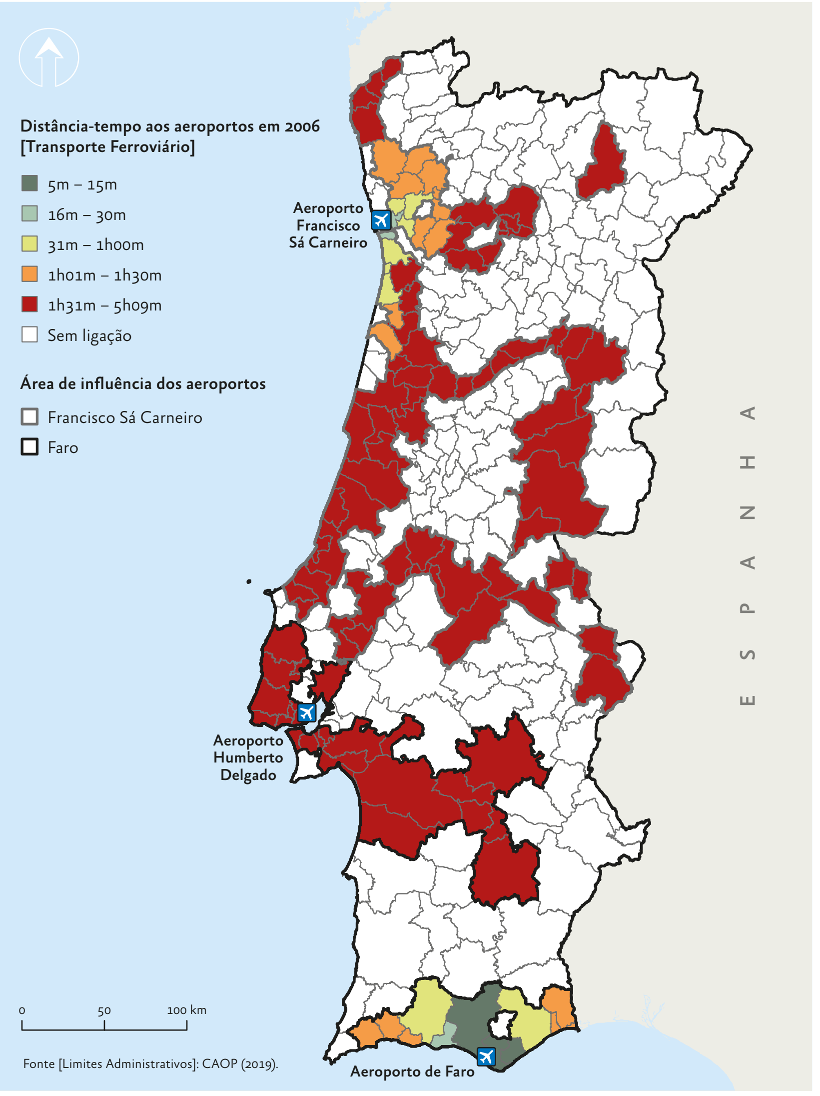
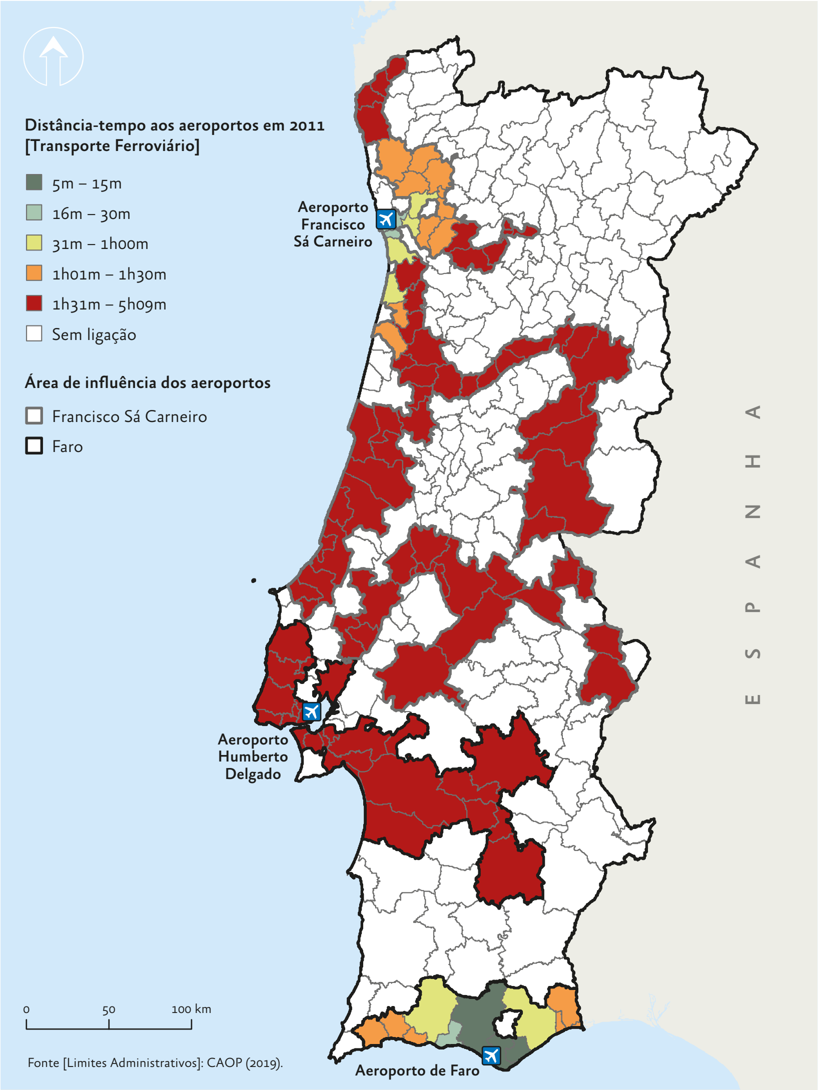
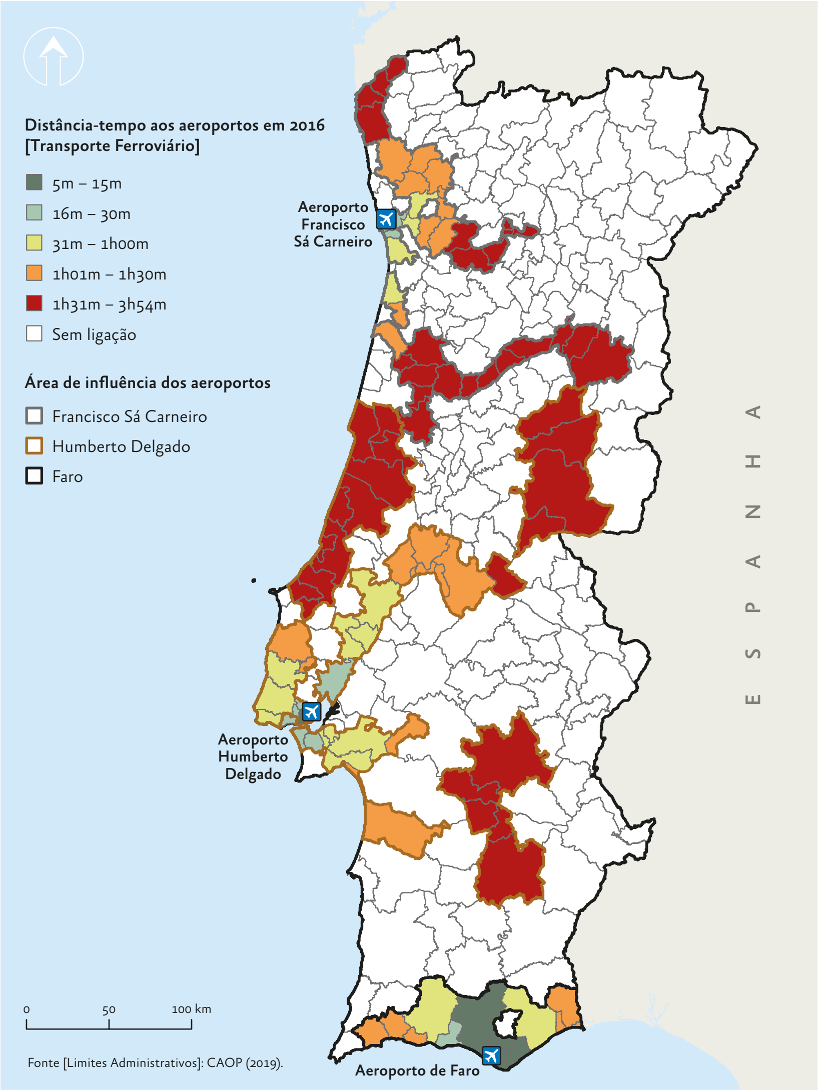


Figure 31 Railway travel time from airports in 2001, 2006, 2011 and 2016, by area of influence (2/2).






Distância-tempo aos aeroportos em 2011
[Transporte Ferroviário]
5m – 15m
16m – 30m
31m – 1h00m
1h01m – 1h30m
1h31m – 5h09m
Sem ligação
Área de influência dos aeroportos
Francisco Sá Carneiro
Faro
Aeroporto Francisco Sá Carneiro
Aeroporto Humberto Delgado
Aeroporto de Faro
ESPANHA
0
50
100 km
Fonte [Limites Administrativos]: CAOP (2019).


Distância-tempo aos aeroportos em 2016
[Transporte Ferroviário]
5m – 15m
16m – 30m
31m – 1h00m
1h01m – 1h30m
1h31m – 3h54m
Sem ligação
Área de influência dos aeroportos
Francisco Sá Carneiro
Humberto Delgado
Faro
Aeroporto Francisco Sá Carneiro
Aeroporto Humberto Delgado
Aeroporto de Faro
ESPANHA
0
50
100 km
Fonte [Limites Administrativos]: CAOP (2019).

Chapter 6
Productivity and accessibility

6.1. Introduction

The purpose of this chapter is to analyse the relationship between accessibility and productivity. It is important to mention that previous literature on productivity analysis and the impact of transport systems has focused on the discussion and calculation of transport infrastructure investment elasticities, using translog, Cobb-Douglas or VAR. This approach meant to identify the impact that an additional euro of investment would have on productivity. Some authors have used different forms of accessibility in productivity analysis, such as Krugman (1987, 1995), but accessibility was modelled as a trade flow. Although trade flows can provide a measure of accessibility, they are also correlated with productivity itself, creating additional difficulties. Maroto and Zofio (2016) also analyse accessibility using a DEA, but they employ road networks as an input. However, there has been growing concern about incorporating physical variables of accessibility rather than infrastructure stock (of infrastructure growth).

Most studies using physical measures have used the most standard metric – travel time. That is the case with the studies carried out by Graham (2007), Néchet el al. (2012), Melo et al (2017) or Rice et al. (2006).

This research will expand on the use of physical indicators of accessibility instead of infrastructure investments or stock. It intends to grasp the relationship between accessibility and productivity by using a spatial model accounting for potential spillover effects deriving from accessibility. The dependent variable will be "apparent labour productivity".

6.2. Methodological approach

The main focus of this chapter is to understand in what ways the investment in transport infrastructure impacts productivity, measured through apparent labour productivity. Firstly, it was necessary to test the influence of all transport indicators on productivity. The approach followed a "drill-down" structure, analysing the relationship at a national level, and only then at regional level (NUTS 3) (to be developed in Section 6.3).

Secondly, we selected and tested the best econometric approach (with or without spatial analysis). We have tested whether the location of the regions on the Portuguese territory would have an influence on their apparent labour productivity as we find several examples in the literature highlighting the importance of location in the economic development of a region (Porter, 2000; Borth, 1955). However, it is necessary to conduct a spatial analysis to prove spatial dependence of productivity (Baumont, et al., 2000). If no spatial dependence is proven, there is no point in applying spatial modelling techniques, since each region does not interact with its neighbours. On the other hand, if there is spatial correlation, then the spatial model is the best approach. Therefore, we have conducted a Global Moran-I test and also looked at regional clusters through the use of Local Indicators of Spatial Association (LISA) (Anselin, 1993) (to be developed in Section 6.4).

In order to model time series, there are some critical steps required to ensure the validity of results (Pereira & Pereira, 2015)[6]. To model the spatial effects, our approach was based on a production function, creating a spatial regression model using three regressors to estimate productivity, one for each of the following aspects: labour, capital and transportation (Melo et al, 2017). The global effects of spatial association were analysed using a spatially weighted 2-Step Least Squares approach, with a queen contiguity matrix (Section 6.5). Next, a cross-regression model based on the work of Bazzi (2017) was used, designed to isolate the spillover effects of neighbouring regions through a case-by-case analysis. It was necessary to account for a detailed distance matrix, measuring the proximity of location based on the road distance (time), updated for each year of the time series (Section 6.6).

6.3. Accessibility vs Productivity

As mentioned in the methodological section, the first step in our approach was to analyse the potential correlation between apparent labour productivity and the various transport variables calculated in Chapter 5, through a pairwise simple regression. Additionally, infrastructure stock variables for each region were also used. Table 55 summarizes all the transport variables analysed.

Table 58 Transport variables

Variable	Description	Type	Unit
dist_min_rod_aero_porto	Road distance, in minutes, to Francisco Sá Carneiro Airport	Transport	minutes
dist_min_rod_aero_lisboa	Road distance, in minutes, to Humberto Delgado Airport	Transport	minutes
dist_min_rod_aero_faro	Road distance, in minutes, to Faro Airport	Transport	minutes
dist_km_rod_aero_porto	Road distance, in kilometres, to Francisco Sá Carneiro Airport	Transport	km
dist_km_rod_aero_lisboa	Road distance, in kilometres, to Humberto Delgado Airport	Transport	km
dist_km_rod_aero_faro	Road distance, in kilometres, to Faro Airport	Transport	km
dist_min_ferr_aero_porto	Railway distance, in minutes, to Francisco Sá Carneiro Airport	Transport	minutes
dist_min_ferr_aero_lisboa	Railway distance, in minutes, to Humberto Delgado Airport	Transport	minutes
dist_min_ferr_aero_faro	Railway distance, in minutes, to Faro Airport	Transport	minutes
dist_km_ferr_aero_porto	Railway distance, in kilometres, to Francisco Sá Carneiro Airport	Transport	km
dist_km_ferr_aero_lisboa	Railway distance, in kilometres, to Humberto Delgado Airport	Transport	km
dist_km_ferr_aero_faro	Railway distance, in kilometres, to Faro Airport	Transport	km
dist_min_rod_port_leixoes	Road distance, in minutes, to the Port of Leixões	Transport	minutes
dist_min_rod_port_lisboa	Road distance, in minutes, to the Port of Lisbon	Transport	minutes
dist_min_rod_port_setubal	Road distance, in minutes, to the Port of Setúbal	Transport	minutes
dist_min_rod_port_sines	Road distance, in minutes, to the Port of Sines	Transport	minutes
dist_min_rod_port_viana	Road distance, in minutes, to the Port of Viana do Castelo	Transport	minutes

dist_min_rod_port_aveiro	Road distance, in minutes, to the Port of Aveiro	Transport	minutes
dist_min_rod_port_ffoz	Road distance, in minutes, to the Port of Figueira da Foz	Transport	minutes
dist_km_rod_port_leixoes	Road distance, in kilometres, to the Port of Leixões	Transport	km
dist_km_rod_port_lisboa	Road distance, in kilometres, to the Port of Lisbon	Transport	km
dist_km_rod_port_setubal	Road distance, in kilometres, to the Port of Setúbal	Transport	km
dist_km_rod_port_sines	Road distance, in kilometres, to the Port of Sines	Transport	km
dist_km_rod_port_viana	Road distance, in kilometres, to the Port of Viana do Castelo	Transport	km
dist_km_rod_port_aveiro	Road distance, in kilometres, to the Port of Aveiro	Transport	km
dist_km_rod_port_ffoz	Road distance, in kilometres, to the Port of Figueira da Foz	Transport	km
acess_viaria	Road accessibility	Transport	index
sinuosidade	Sinuosity / Winding road index	Transport	index
vel_reta	Straight Equivalent Speed	Transport	km/h
ext_ferr_merc	Freight railroad extension	Transport	km
ext_ferr_pass	Passenger railroad extension	Transport	km
ext_rod_tot	Total road extension	Transport	km
ext_rod_ip	Principal routes extension	Transport	km
ext_rod_ic	Complementary routes extension	Transport	km
ext_rod_outros	Other routes extension	Transport	km

Figure 30 presents the results of a pairwise regression of the transportation variables with productivity[7].

Table 59 Results for Portugal

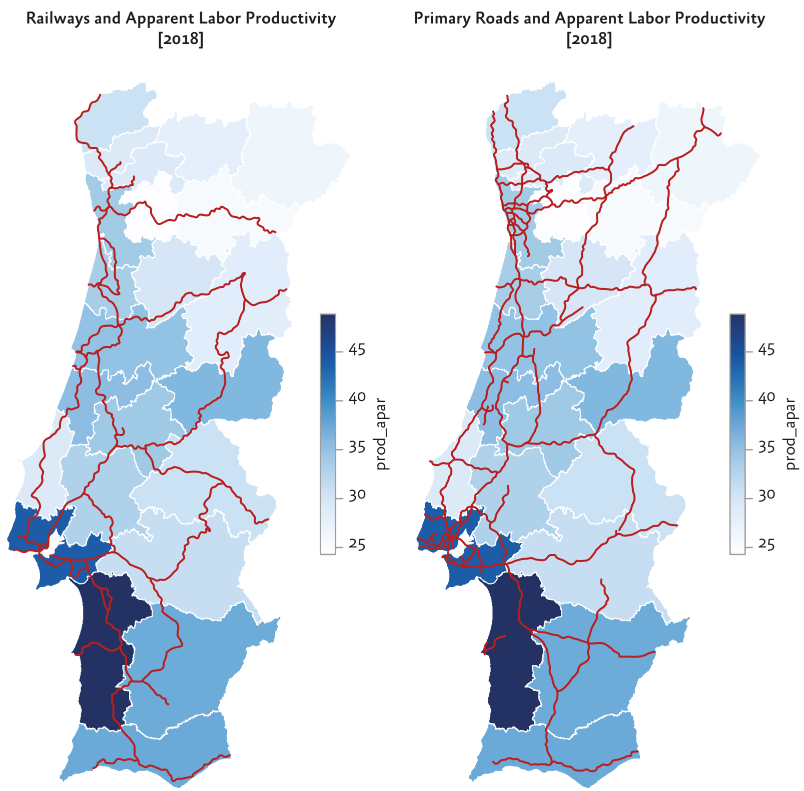
variable	correlation	coefficient	r_sq	n_obs	MAPE
acess_viaria	0.891	1.459	0.794	17	5.396
sinuosidade	0.871	8.749	0.759	17	5.27
vel_reta	0.968	2.529	0.938	17	2.97
ext_rod_tot	0.982	0.007	0.964	19	2.075
ext_rod_ic	0.972	0.011	0.945	19	2.65
ext_rod_outros	0.967	0.146	0.935	19	2.856

The results show that transportation variables have a high correlation with productivity. It is relevant to note that among the variables with some type of correlation there are none related to rail systems. Road related variables are predominant, as are distances to ports and seaports, these latter probably related to proximity to the coast (as discussed below).

As we have seen previously, the railway network in Portugal suffered significant reductions during the second half of the 20th century, leading to a strong modal shift to the road system. Therefore, it is unsurprising that rail-related variables are dismissed. The accessibility analysis presented in Chapter 5 highlighted the asymmetric development of road and the railway systems, and corresponding accessibility indexes, since the 1980s: the former experiencing an improvement in all regions, and the latter deteriorating in the majority of the regions.

When plotting the 2018 geographical distribution of productivity, it becomes clear that the majority of the regions with higher apparent labour productivity are located near the coast (Figure 32). This means that there is an apparent strong negative correlation between the distance to seaports and airports and the apparent labour productivity, which may be subject to a spatial bias and, therefore, should not be used as a prime indicator of the influence of transportation infrastructure on productivity.

Figure 32 **Spatial distribution of primary roads and railway networks**



On the other hand, the group of indicators presented in Figure 30 are not directly dependent on proximity to the coastline, and therefore should provide a more reasonable indicator of how the investment on infrastructure would impact productivity. By overlaying the primary road and railway networks (Figure 32), we can see that both infrastructure networks tend to be located near the coast, as is also the case with productivity.

After analysing the correlation coefficient between first group indicators, we came to the conclusion that only sinuosity index, straight equivalent speed and road accessibility would present a reasonably strong (>0.5) Pearson correlation with apparent labour productivity (Figure 31).

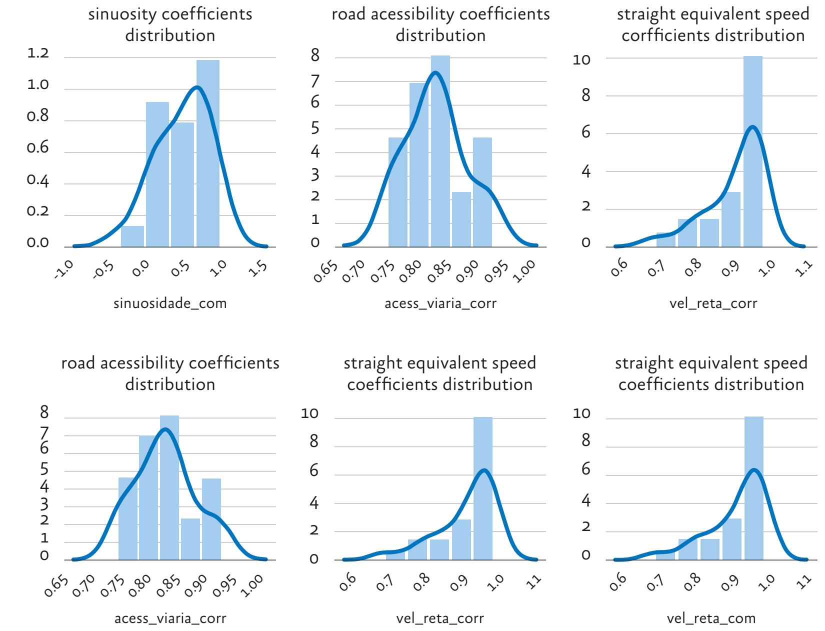
Table 60 **Pearson correlation coefficient between accessibility and apparent labour productivity at regional level**

region	acess_viaria_corr	sinuosidade_corr	vel_reta_corr
Alto Minho	0.749	-0.034	0.931
Alto Tâmega	0.925	0.701	0.947
Alentejo Central	0.759	-0.427	0.862
Cávado	0.776	0.334	0.952
Ave	0.821	0.375	0.886
Área Metropolitana do Porto	0.778	0.896	0.976
Tâmega e Sousa	0.897	0.592	0.940
Douro	0.897	0.491	0.963
Terras de Trás-os-Montes	0.926	0.649	0.966
Oeste	0.843	0.774	0.820
Região de Aveiro	0.747	0.146	0.964

Região de Coimbra	0.813	0.688	0.960
Região de Leiria	0.835	0.222	0.934
Viseu Dão Lafões	0.839	0.892	0.960
Beira Baixa	0.856	0.574	0.882
Médio Tejo	0.844	0.432	0.928
Beiras e Serra da Estrela	0.811	0.761	0.875
Área Metropolitana de Lisboa	0.808	0.561	0.802
Alentejo Litoral	0.738	0.046	0.753
Baixo Alentejo	0.799	-0.068	0.792
Lezíria do Tejo	0.855	0.013	0.945
Alto Alentejo	0.819	0.500	0.921
Algarve	0.819	0.124	0.675

Apparently, there is evidence that both road accessibility and straight equivalent speed would have a clear positive impact on a region's productivity. With regard to the sinuosity index, the relationship is not so evident in some cases, leading to negative and near-null values in some regions, such as Baixo Alentejo, Alentejo Central and Alto Minho (Table 58).

Figure 33 Pearson correlation coefficients distribution



6.4. Spatial analysis of productivity and spillover effects

The highest values of apparent labour productivity are registered in the regions of Área Metropolitana de Lisboa and Alentejo Litoral (Table 59).

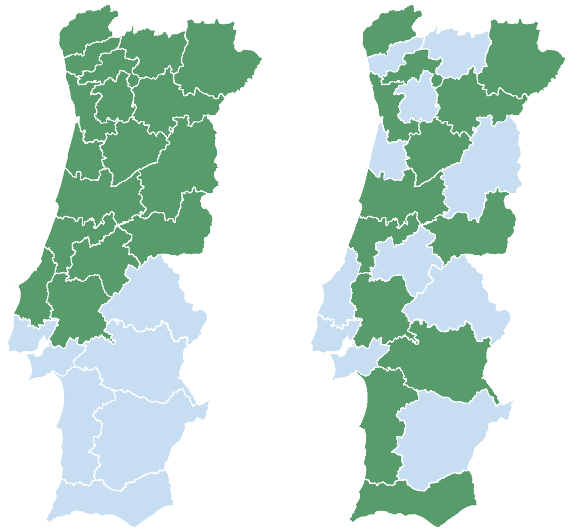
Table 61 Distribution of apparent labour productivity for each region (2008-2018) higher to lower mean value

Region	n_obs	mean	std	min	25%	median	75%	max
Alentejo Litoral	11	44.757	4.337	37.799	42.185	42.667	48.581	51.357
Área Metropolitana de Lisboa	11	42.985	0.824	41.518	42.428	43.208	43.595	44.119
Baixo Alentejo	11	33.820	2.561	28.122	33.029	34.374	35.322	37.157
Algarve	11	33.580	2.409	30.243	31.861	33.905	35.197	37.320
Beira Baixa	11	32.860	2.228	28.776	31.794	32.879	34.208	36.085
Região de Leiria	11	32.145	2.407	28.585	30.124	32.895	33.985	35.502
Área Metropolitana do Porto	11	31.911	1.483	30.071	30.736	32.071	32.961	34.274
Região de Coimbra	11	31.743	2.198	28.214	30.559	31.192	33.418	35.208
Região de Aveiro	11	30.627	2.042	27.660	29.143	30.318	32.141	33.913
Médio Tejo	11	30.553	2.520	26.903	28.719	30.849	32.542	34.396
Lezíria do Tejo	11	30.215	1.865	27.479	28.878	30.105	31.226	33.393
Alto Alentejo	11	28.681	1.704	25.622	27.657	28.725	29.998	31.250
Alentejo Central	11	28.652	1.751	26.028	27.670	28.283	29.572	31.654
Alto Minho	11	28.389	2.085	24.144	27.495	28.918	29.781	31.251
Viseu Dão e Lafões	11	27.359	1.624	25.026	25.972	27.401	28.537	29.988
Ave	11	26.621	2.219	22.935	25.038	27.179	28.559	29.318
Alto Tâmega	11	26.062	0.948	24.904	25.253	26.219	26.473	27.894
Cávado	11	25.783	2.179	22.544	23.911	26.291	27.270	29.073
Oeste	11	25.544	2.584	22.008	23.473	25.618	27.852	29.261
Beiras e Serra da Estrela	11	24.541	2.416	21.355	22.979	23.732	26.207	28.483
Terras de Trás-Os-Montes	11	23.251	1.585	21.328	22.067	22.882	24.353	26.417
Tâmega e Sousa	11	22.524	1.495	19.625	21.646	23.221	23.649	24.273
Douro	11	21.077	2.320	18.229	19.296	20.452	22.919	25.347

This shift of productivity towards coastal regions suggests that location is a factor that should not be neglected when assessing productivity. Spatial autocorrelation can be a factor of influence, creating bias on the results of spatial econometrics models, and therefore should be tested.

The Spatial Autocorrelation (Global Moran's I) tool measures correlation based on both feature locations and feature values simultaneously, and it evaluates whether the pattern expressed is clustered, dispersed or random (Boots and Tiefelsdorf, 2000). It tests the null hypothesis that the values on the map where randomly generated. When the null hypothesis is rejected, it is possible to assume that there is an underlying pattern in the feature under analysis, otherwise it would mean that a spatial analysis was not required since the location could be altered without affecting the information contained in each region (spatial randomness).

Figure 34 Edge examples of positive spatial correlation (left) and negative spatial correlation (right) patterns

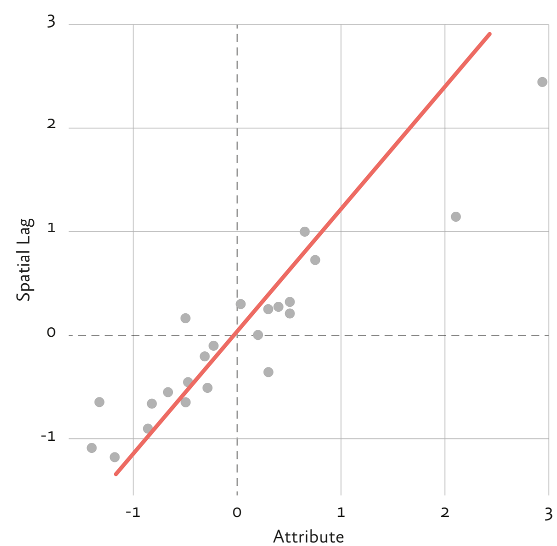


Overall, the geographic occurrences of high and low values would resemble a checkerboard pattern in the case of negative spatial correlation and a clustered pattern in the case of positive spatial correlation (Figure 34). A case of no spatial correlation, or spatial randomness, would be somewhere in between the two edge cases, with higher heterogeneity than positive spatial autocorrelation but lower negative spatial autocorrelation.

The distribution of apparent labour productivity was tested under a Global Moran I, using kernel distance spatial weights with a triangular function, for three distinct moments: 2008, 2012 and 2016. The results show that in all three cases the null hypothesis was rejected at a 5% significance level, proving that the distribution of productivity across the country is not random, and thus the location and interaction between regions has a non-negligible effect which should be taken into account.

The example in Figure 35 refers to the results for 2008 and shows that the null hypothesis can be rejected at 0.007 significance level. This figure presents the scatter plot of the average standardized apparent productivity in the neighbourhood of all regions (NUT-III). The spatial variable is calculated as the sum of spatial weights multiplied by values for observations at neighbouring locations, and it is an essential part of any analysis of spatial autocorrelation.

Figure 35 Moran scatter plot



The plot displays a positive relationship between the standardized apparent productivity and the spatial lag variable. This pattern is associated with the presence of positive spatial autocorrelation: similar values tend to be located close to one another. Consequently, the overall trend is for high values to be close to other high values and for low values to be surrounded by other low values. This, however, does not mean that it is always the case within the dataset: there can be particular cases where high values are surrounded by low ones, and vice versa (geographic outliers). It only means that, if we had to summarize the main data pattern in terms of how clustered similar values are, the best way would be to say they are positively correlated and, hence, clustered over space.

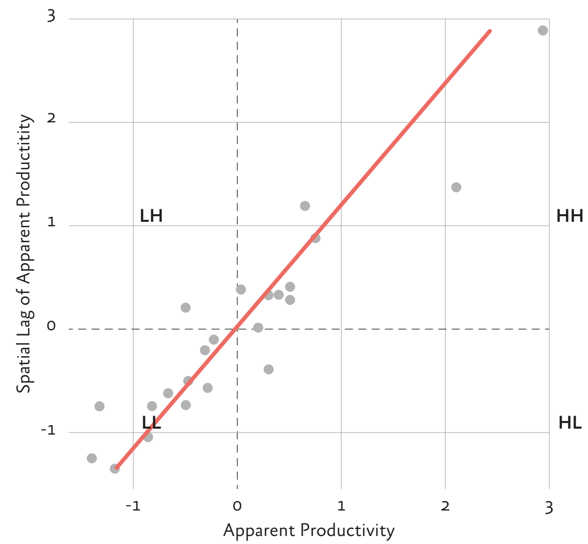
Therefore, we have analysed where the clusters of productivity might be located in the Portuguese territory. In order to evaluate these clusters, Local Indicators of Spatial Autocorrelation (LISA[8]) (Anselin, 1993) were used.

The Moran scatter plot can be divided into four quadrants:

- high values of the variable under analysis that are surrounded by other high value regions (HH);
- high values surrounded by low value regions (HL);
- low values of the variable surrounded by other low value regions (LL);
- low values surrounded by high value regions (LH).

LH and HL quadrants indicate an association of dissimilar values, while HH and LL indicate an association of similar values (Figure 36). The objective is to identify cases in which the comparison between the value of an observation and the average of its neighbours is either more similar (HH, LL) or more dissimilar (HL, LH) than would be expected from randomness. The mechanism used for this is similar to the one in the global Moran's I, but applied in this case to each observation[9].

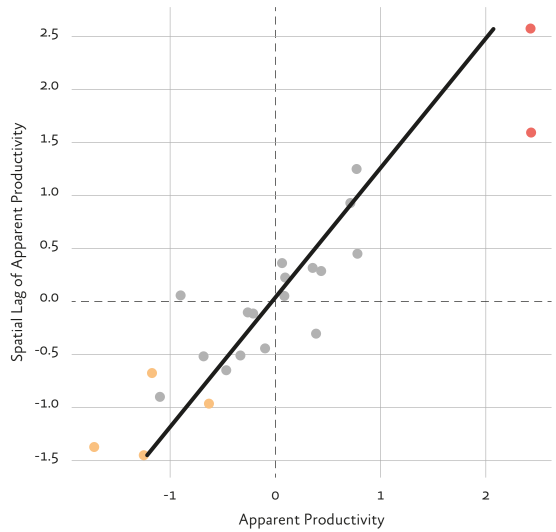
Figure 36 Moran scatter plot



The majority of regions are located either in the HH or LL quadrants, constituting a global positive value for Moran I statistic. Therefore, there is evidence of the existence of spatial productivity clusters. In order to maintain consistency, we have also used kernel weights with triangular functions to develop this analysis.

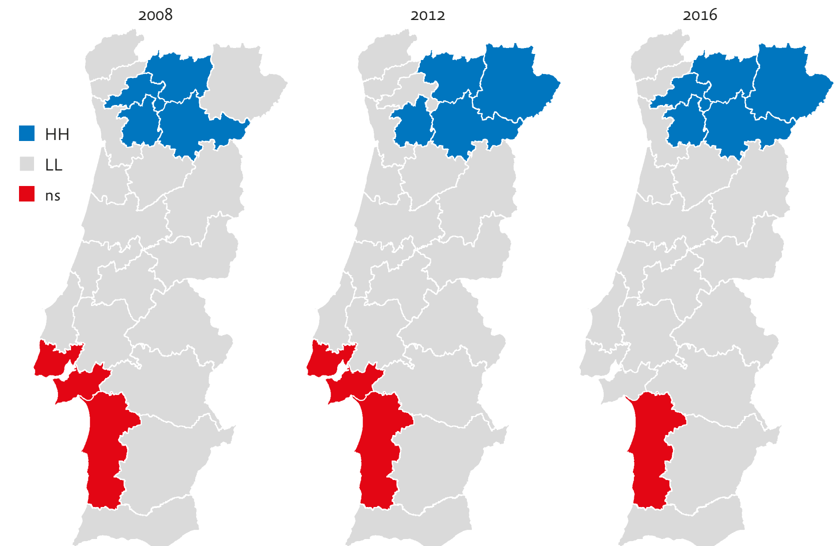
Based on the value of local statistics, two different clusters have been identified: one composed of two regions contained in the HH quadrant (in red) and other composed of five regions in the LL quadrant (in yellow) (Figure 37).

Figure 37 Moran local scatter plot (2012)



By plotting these points geographically, the high value cluster comprises Área Metropolitana de Lisboa and Alentejo Litoral (figure 38). This means that the productivity in these regions is positively affected by the productivity in surrounding regions, forming a cluster of high productivity. On the other side of the spectrum, there is an LL cluster composed of the regions of Alto Tâmega, Douro, Tâmega e Sousa and Ave. This means that the relative low values in these regions are, in part, the result of the low values present in the surrounding regions, forming an LL cluster.

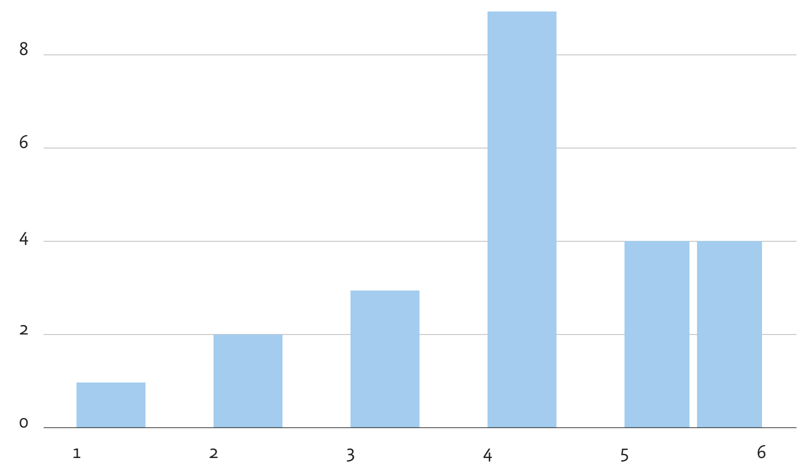
Figure 38 LISA indicators for the years of 2008, 2012 and 2018. Kernel distance weights with triangular function and considering the two nearest neighbours



There is a slight shift in the location of these clusters throughout these three years of analysis, with the region of Terras de Trás-os-Montes being added to the 2008 initial cluster in later years. In the southern cluster, the pattern seems to have excluded Área Metropolitana Lisboa, which might be justified by a decrease in apparent labour productivity in neighbouring regions.

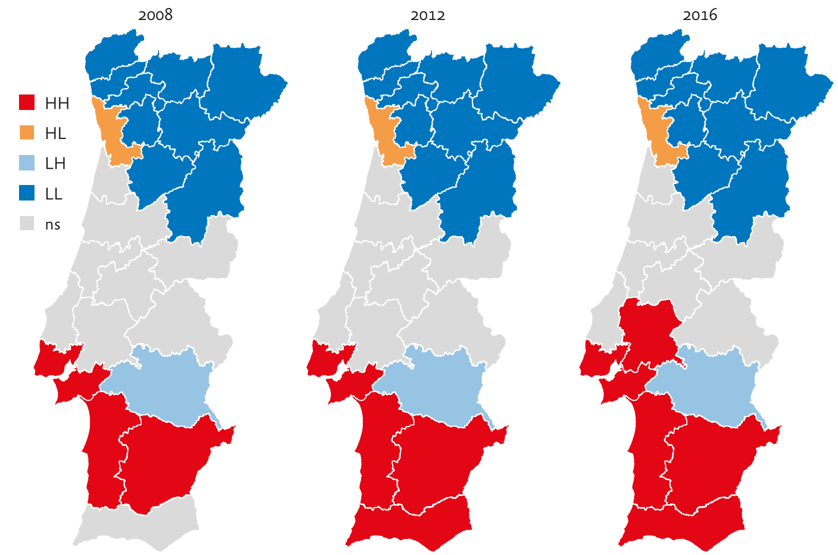
Each region is surrounded, on average, by four neighbours (Figure 39). Thus, in order to test the robustness of our results, we have increased the number of neighbours considered when defining the kernel weights triangular function to four.

Figure 39 Histogram for number of neighbours



The results show that having a wider range of nearest neighbours led to more extensive clusters. In the south, we see a larger cluster, which comprises the regions of Área Metropolitana de Lisboa, Alentejo Litoral and Baixo Alentejo, and which extends to the regions of Algarve and Lezíria do Tejo in 2018 (Figure 40). The region of Alentejo Central appears as an outlier in the region, given its relatively lower apparent labour productivity. In the northern area, the cluster is composed of the regions of Alto Minho, Cávado, Ave, Alto Tâmega, Tâmega e Sousa, Douro, Terras de Trás-os-Montes, Viseu Dão e Lafões and Beiras e Serra da Estrela. Área Metropolitana do Porto appears as an outlier given its higher apparent labour productivity.

Figure 40 SA indicators for the years of 2008, 2012 and 2018. Kernel distance weights with triangular function and considering the four nearest neighbours



Based on these findings, we may suggest the hypothesis that spillover effects will have a stronger impact within each one of these clusters. In order to assess these spillover effects, it is necessary to build a model that could isolate the effect of spatial dynamics on each region (NUTIII). Hence, our first step was to analyse how productivity varied for each of our regions in relation to its neighbours.

These analyses would then be used to build a spatial proximity matrix in order to weigh the effect of each neighbour on spillover effects[10].

The results show that the following regions appear to have a linear decay of productivity influenced by distance: Cávado; Área Metropolitana do Porto; Tâmega e Sousa; Trás-os-Montes; Região de Leiria; Beira-Baixa; Médio Tejo; Serra da Estrela; Área Metropolitana de Lisboa; Alentejo Litoral; and Lezíria do Tejo. The following regions appear to have a quadratic decay of productivity influenced by distance: Ave; Alto Tâmega; Douro; Algarve; Oeste; Aveiro; Coimbra; Viseu Dão e Lafões; Baixo Alentejo; Alto Alentejo; and Alentejo Central. Both decay functions are valid for Alto Minho, since it only has one neighbouring region.

6.5. Granger causality and time series analysis of the relationship between accessibility and productivity

In the previous subsections, it was possible to verify the existence of correlation between accessibility (under different metrics) and productivity. However, as discussed earlier, correlation does not mean causality. In this subsection, we will search for evidence of causality, i.e., whether better accessibility leads to increases in productivity, by using the Granger causality approach.

After a simple correlation analysis of the national time series, we have found evidence of high correlation between some of our transport indicators and apparent labour productivity. However, the specific indicators may vary depending on the region under analysis. At a national level, the following indicators are best suited to explain productivity:

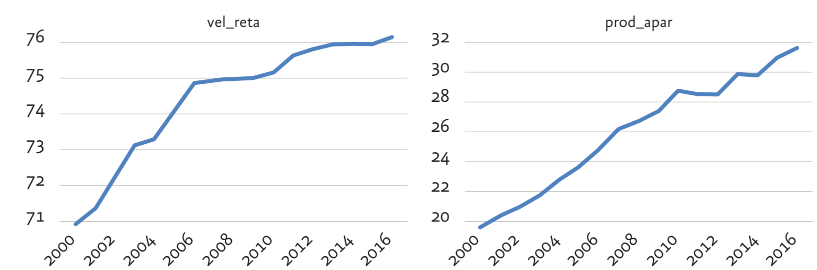
- Sinuosity (*sinuosidade*).
- Straight Equivalent Speed (*vel_reta*).
- Road accessibility (*acess_viaria*).
- Principal routes extension (*ext_rod_ip*).
- Complementary routes extension (*ext_rod_ic*).
- Total road extension (*ext_rod_tot*).

The first three indicators are especially relevant when modelling national aggregated data for productivity. At the regional level, straight equivalent speed (*vel_reta*) and road sinuosity (*sinuosidade*) proved to be better predictors.

6.5.6.1. Testing for Granger causality

Analysing the trend of both straight equivalent speed and apparent labour productivity, it is clear that both variables have been increasing since the beginning of the century (Figure 42). Both sinuosity index and road accessibility share similar upward trends.

Figure 41 **straight equivalent speed (national average time series) on the left and apparent labour productivity (national average time series) on the right**



However, correlation does not imply causality. The notion of causality has been explained by Clive Granger (Granger, 1969) when he established the principles for the *Granger causality*.

The results show that, at a 5% significance level, straight equivalent speed Granger-causes[11] apparent labour productivity; therefore, at an aggregated national level, there seems to be an indication that an increase in straight equivalent speed leads to an increase in productivity.

We have also conducted a causality test for the two remaining transportation variables under analysis (*road accessibility* and *sinuosity index*), but both failed to prove causality at a national level. At a regional level, both sinuosity index and straight equivalent speed proved to Granger--cause apparent labour productivity in several cases. Road accessibility only proved to Granger cause apparent labour productivity in the case of Alentejo Central, as seen on table 62.

Table 62 Granger causality analysis

Region	sinuosidade	vel_reta	acess_viaria	emprego	tax_inv_tot
Alto Minho	0.833	0.451	0.915	0.006*	0.001*
Alto Tâmega	0.000*	0.128	0.637	0.914	0.476
Alentejo Central	0.491	0.000*	0.012*	0.247	0.262
Cávado	0.952	0.926	0.904	0.000*	0.083
Ave	0.0418*	0.005*	0.863	0.0013*	0.611
Área Metropolitana do Porto	0.051	0.0046*	0.488	0.0069*	0.0014*
Tâmega e Sousa	0.055	0.0072*	0.799	0.0377*	0.105
Douro	0.129	0.075	0.564	0.390	0.930
Terras de Trás-os-Montes	0.002*	0.0215*	0.588	0.619	0.929
Oeste	0.287	0.104	0.231	0.543	0.744
Região de Aveiro	0.575	0.0194*	0.445	0.619	0.517
Região de Coimbra	0.128	0.0031*	0.705	0.474	0.457
Região de Leiria	0.400	0.659	0.478	0.000*	0.335
Viseu Dão Lafões	0.335	0.979	0.776	0.0102*	0.868
Beira Baixa	0.378	0.796	0.770	0.060	0.807
Médio Tejo	0.182	0.388	0.364	0.0324*	0.392
Beiras e Serra da Estrela	0.595	0.000*	0.423	0.925	0.995
Área Metropolitana de Lisboa	0.000*	0.0002*	0.094	0.106	0.000*
Alentejo Litoral	0.231	0.333	0.596	0.309	0.266
Baixo Alentejo	0.000*	0.0301*	0.297	0.227	0.125
Lezíria Do Tejo	0.0001*	0.230	0.067	0.190	0.357
Alto Alentejo	0.0416*	0.839	0.959	0.417	0.0388*
Algarve	0.0128*	0.073	0.088	0.009*	0.0008*

*p-value lesser than 5%

Overall, at a regional level, increasing straight equivalent speed, or the sinuosity index, would lead to an increase in apparent productivity for the average Portuguese region.

Table 60 shows a map of the spatial distribution of results for Granger--causality. Highlighted in green are the regions where each of the main two transportation variables have been proven to Granger-cause apparent labour productivity.

Figure 42 Granger causality and the road network

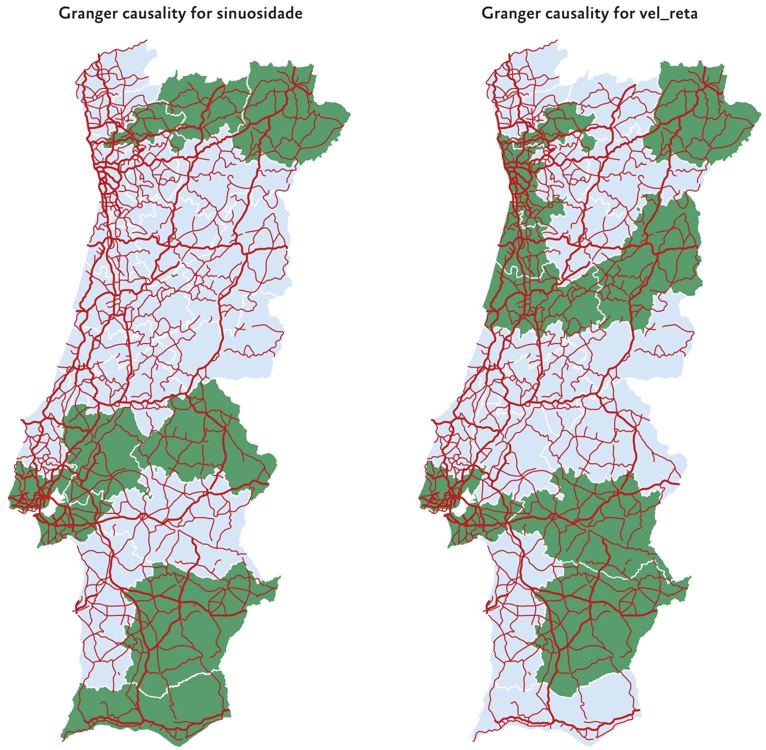


Table 63 shows the results of the reverse granger-causality, to test whether the causality relationship could be reversed.

Table 63 Reverse Granger-causality results for apparent labour productivity

Region	sinuosidade	vel_reta	acess_viaria	emprego	tax_inv_tot
Alto Minho	0.799	0.800	1.000	0.000*	0.000*
Alto Tâmega	0.511	0.681	0.875	0.175	0.829
Alentejo Central	0.798	0.418	0.989	0.002*	0.339
Cávado	0.257	0.123	0.793	0.000*	0.928
Ave	0.029*	0.036*	0.613	0.039*	0.487
Área Metropolitana do Porto	0.394	0.151	0.864	0.094	0.021*
Tâmega e Sousa	0.897	0.992	0.915	0.023*	0.014*
Douro	0.389	0.430	0.581	0.879	0.408
Terras de Trás-os-Montes	0.339	0.418	0.739	0.791	0.078
Oeste	0.350	0.890	0.845	0.779	0.688
Região de Aveiro	0.229	0.879	0.558	0.083	0.556
Região de Coimbra	0.633	0.181	0.191	0.020*	0.013*
Região de Leiria	0.859	0.617	0.749	0.005*	0.000*
Viseu Dão Lafões	0.981	0.468	0.200	0.532	0.857
Beira Baixa	0.426	0.701	0.267	0.139	0.808
Médio Tejo	0.220	0.584	0.655	0.000*	0.464
Beiras e Serra da Estrela	0.033*	0.113	0.517	0.687	0.027*
Área Metropolitana de Lisboa	0.600	0.899	0.667	0.174	0.171
Alentejo Litoral	0.011*	0.020*	0.802	0.330	0.044*
Baixo Alentejo	0.150	0.283	0.933	0.263	0.705
Lezíria do Tejo	0.061	0.816	0.815	0.000*	0.031*
Alto Alentejo	0.019*	0.223	0.326	0.000*	0.442
Algarve	0.010*	0.058	0.258	0.000*	0.137

*p-value less than 5%

There are only a few cases where we find evidence of the transport variables being Granger-caused by apparent labour productivity. However, we have found broader evidence of this in the case of employment and private investment: both have been proven, in several cases, to be Granger-caused by apparent labour productivity.

6.5.6.2. Testing for Cointegration

Before modelling a time series, one should test its variables for cointegration. If they are cointegrated, it is proven that they share a significant statistical relationship, and hence will yield non-spurious results.

Following the work of Pereira and Pereira (2015), we have used the Engle-Granger cointegration test.

The results (Table 64) show that the null hypothesis can be rejected 69% of times in the case of sinuosity index, 60% in the case of straight equivalent speed, 39% of times in the case of road accessibility, 30% in the case of employment and 56% in the case of investment rate. In these cases, we can find evidence of cointegration between time series. However, there is still a fairly large percentage of cases where we could not reject the null hypothesis. Thus, when applying a regression, it would be prudent to look further for statistical soundness as we may face spurious results. The distribution of these findings appears not to follow a geographical pattern, so it would need to be taken into account on a case-by-case basis (Figure 42).

Figure 43 Regions with no rejection for null hypothesis (α = 10%)

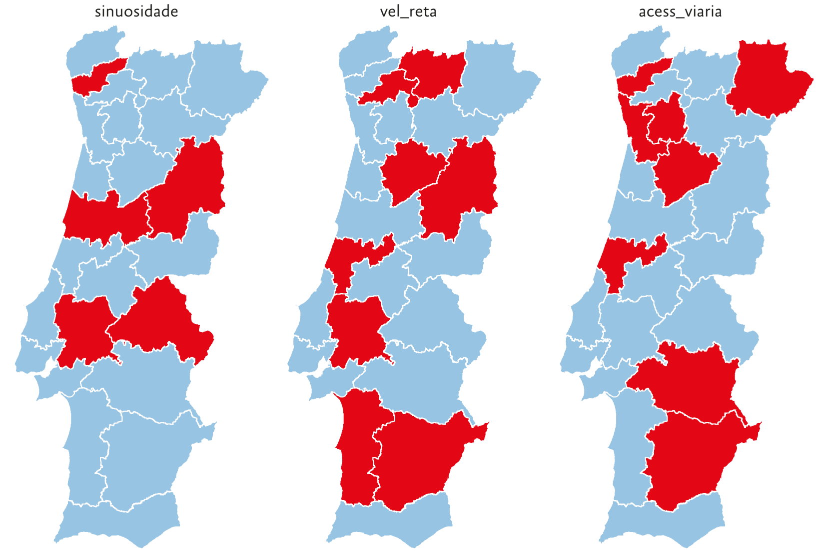


Table 64 Engle-Granger Cointegration Test Results

	sinuosidade		vel_reta		acess_viaria		emprego		tax_inv_tot	
Region	t-statistic	p-value	t-statistic	p-value	t-statistic	p-value	t-statistic	p-value	t-statistic	p-value
Alto Minho	-6.436***	1.76E-07	-5.168**	7.96E-05	-4.013*	6.87E-03	7.701	1.00E+00	-0.301	9.76E-01
Alto Tâmega	-4.67**	6.36E-04	0.457	9.92E-01	-5.686**	7.46E-06	-2.015	5.20E-01	-1.763	6.47E-01
Alentejo Central	-4.431**	1.59E-03	-4.906**	2.43E-04	-0.045	9.85E-01	-0.431	9.69E-01	-3.592	2.50E-02
Cávado	-3.076	9.31E-02	-16.231***	2.91E-28	-3.368	4.60E-02	-1.224	8.51E-01	-6.136***	8.20E-07
Ave	-4.737**	4.87E-04	0.144	9.89E-01	-6.739***	3.52E-08	-6.347***	2.79E-07	-6.051***	1.25E-06
Área Metropolitana do Porto	-3.361	4.68E-02	-4.697**	5.70E-04	-4.148	4.36E-03	-3.931*	8.96E-03	-0.672	9.49E-01
Tâmega e Sousa	-24.043***	0.00E+00	-20.817***	0.00E+00	-4.145	4.40E-03	-5.192**	7.17E-05	-6.215***	5.48E-07
Douro	-13.260***	8.30E-24	-8.609***	8.62E-13	-5.977***	1.81E-06	-2.700	1.99E-01	-3.899	9.93E-03
Terras de Trás-os-Montes	-4.984**	1.75E-04	-4.947***	2.06E-04	-3.601	2.44E-02	-14.163***	1.90E-25	-5.914***	2.48E-06
Oeste	-4.598**	8.39E-04	-4.507***	1.19E-03	-4.015*	6.83E-03	-2.481	2.87E-01	-10.925***	1.26E-18
Região de Aveiro	-4.180*	3.90E-03	-4.538**	1.06E-03	-3.933*	8.92E-03	-8.234***	7.74E-12	-0.639	9.53E-01
Região de Coimbra	-0.700	9.47E-01	-4.677**	6.17E-04	-5.387**	3.00E-05	-6.424***	1.87E-07	-4.910**	2.40E-04
Região de Leiria	-6.355***	2.67E-07	-2.822	1.58E-01	-3.236	6.40E-02	-6.502***	1.24E-07	-9.550***	3.42E-15
Viseu Dão Lafões	-5.193**	7.13E-05	-1.983	5.37E-01	-3.594	2.49E-02	0.731	9.94E-01	-7.497***	5.38E-10
Beira Baixa	-6.134***	8.26E-07	-6.167***	6.99E-07	-5.820***	3.92E-06	-2.969	1.18E-01	-6.110***	9.32E-07
Médio Tejo	-6.748***	3.36E-08	-3.715*	1.75E-02	-3.862*	1.12E-02	-1.324	8.22E-01	-0.281	9.77E-01
Beiras e Serra da Estrela	-2.715	1.94E-01	-2.625	2.28E-01	-4.121*	4.77E-03	7.983	1.00E+00	-1.651	6.99E-01
Área Metropolitana de Lisboa	-13.863***	6.36E-25	-13.64***	1.61E-24	-18.014***	1.85E-29	-3.382	4.43E-02	-4.585**	8.83E-04
Alentejo Litoral	-5.917***	2.44E-06	-3.058	9.69E-02	-132.813***	0.00E+00	-4.795**	3.84E-04	-10.869***	1.72E-18
Baixo Alentejo	-5.442**	2.34E-05	4.541	1.00E+00	-4.028*	6.54E-03	22.443	1.00E+00	-2.190	4.29E-01
Lezíria Do Tejo	-2.611	2.32E-01	0.762	9.94E-01	0.484	9.93E-01	-2.510	2.75E-01	1.519	1.00E+00
Alto Alentejo	-2.27	3.84E-01	-11.452***	6.97E-20	-4.760**	4.43E-04	-3.192	7.12E-02	-4.031*	6.46E-03
Algarve	-6.712***	4.08E-08	-5.282**	4.82E-05	-5.893***	2.74E-06	-3.712*	1.77E-02	-33.618***	0.00E+00

* p-value < 10%
** p-value < 5%
*** p-value < 1%

6.6. Spatial analysis of productivity and spillover effects

Spillover effects derive from the influence that the productivity of a certain region has on its neighbouring regions. The literature provides evidence that these effects should be accounted for, since there is a wide range of evidence of their existence. The objective of this subsection is to identify whether the spillover effects are relevant.

A Cross-Regressive Model (Lagged Exogenous Variable) was built to assess the spatial influence of neighbouring regions. The first step consisted of calculating the centroid for each of our 23 regions (Figure 44).

Figure 44 Centroids for each NUTS 3

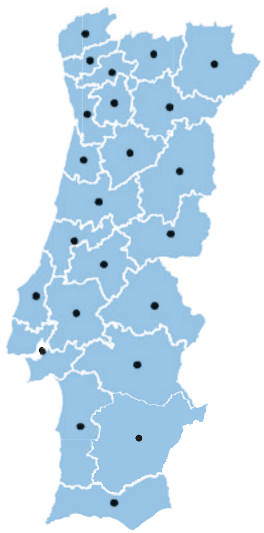
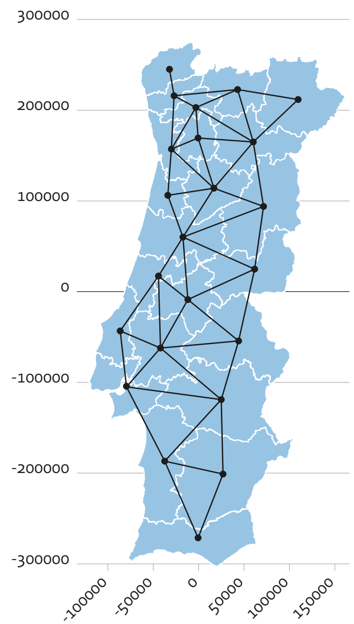


Figure 45 Regional connectivity



Each centroid is connected to its nearest neighbour, in order to form a spatial net (Figure 44). Based on the calculated road distance between each node, the influence of each neighbour is weighted and normalized in each row of the spatial proximity matrix.

Following this procedure, a regressive model was built using 2SLS estimation. This method applies a cross-sectional spatially weighted least squares regression for any given year. Given the lack of data available for some variables before 2008, we have conducted this analysis in three specific moments: 2008, 2012 and 2016.

We followed an approach similar to a production function, taking one variable to account for Capital (investment rate), one to account for labour (employment) and another to account for transportation (straight equivalent speed).

Table 65 Spatially Weighted 2-Stage Least Squares (2SLS)

	2008	2012	2016
Pseudo R-squared	0.565	0.609	0.466
Spatial Pseudo R-squared:	0.565	0.609	0.466
Number of Observations:	23	23	23
Anselin-Kelejian Test	0.087	0.05	0.002
(probability)	(0.768)	(0.824)	0.961
Constant	1.719***	1.640***	1.854***
(standard error)	(0.374)	(0.370)	(0.437)
vel_reta	0.019***	0.020***	0.018***
(standard error)	(0.004)	(0.004)	(0.005)
emprego	0.0002***	0.0003***	0.0002
(standard error)		(0.000)	(0.000)

	2008	2012	2016
tax_inv_tot	0.003**	0.007***	0.004
(standard error)		(0.002)	(0.005)
W_ln (prod_apar)	0.005	0.003	0.004
(instrumented variable)	(0.005)	(0.005)	(0.005)

* p-value lesser than 10%
** p-value lesser than 5%
*** p-value lesser than 1%

Table 65 shows the regression results. We see that the coefficient for the transport variable is statistically significant in all cases (p-value <0.01), proving that, on average, the transportation in surrounding regions also has a non-negligible effect on the productivity of each region. That effect seems to be especially relevant during the year of 2012 (highest coefficient and lowest p-value of all three cross--sectional moments).

Based on the work of Bazzi (2017), we have developed a model based on the cross-regressive model. Since we will be basing our analysis on exogenous regressors, we can base our estimation using Ordinary Least Squares (Le Gallo, 2014).

The model is defined as:

$$y_{it} = \theta_0 + z'_{it}\,\theta_{z'} + \bar{y}_{(i)t}\,\theta_1 + \bar{z}_{(i)t}\,\theta_{\bar{z}}$$

where:

- y_{it} is $n \times 1$ vector of the apparent labour productivity (*prod_apar*) of region *i* at year *t,* functioning as our dependent variable, with *n* being the number of years in our time series analysis;
- z'_{it} is the $n \times 1$ self-transport variable of region *i* at time *t*;
- $\theta_{z'}$ is the coefficient for the transport variable at region *i*, and should translate the effects on productivity of increasing variable *z′* in region *i*;
- $\bar{y}_{(i)t}$ is the $n \times 1$ spatially weighted average of apparent labour productivity in neighbouring regions at time *t*. It results from multiplying a spatial proximity matrix ($j \times j$) by the value of apparent productivity of each neighbouring region, with *j* being the total number of regions under analysis. In order to obtain the average weighted value of the variable, in the shape of a $n \times 1$ vector, we multiply the row of the spatial weighted matrix corresponding to region *i* by the value of the variable in each region *j* at a given year *t*. With this multiplication, we obtain one value of the final vector to be used in the regression. Since the distance time between regions is not constant between years, we update it for every new year calculated for vector $n \times 1$. The proximity matrix accounts only for direct neighbours (*Queen* contiguity matrix) of region *i*. The proximity is then calculated by inverting the square of the distance between the two regions ($\frac{1}{d_{ij}^2}$), and it is then row normalized so that the sum of each row is equal to 1. This way, we can weigh the influence of each neighbouring region *j* on region *i* based on its distance for that given year *t*. The diagonal of this matrix is null, so that self-effects within region *i* are not accounted for. Simply put, each element of vector $n \times 1$ is the result of multiplying row *i*, which means multiplying a vector $1 \times j$ by the corresponding values of productivity for a given year, contained in a $j \times 1$ vector;
- θ_1 is the coefficient which should translate how the productivity in region *i* is affected by the productivity in neighbouring regions;
- $\bar{z}_{(i)t}$ is the $n \times 1$ weighted average transport variable value in the neighbouring regions, and it is calculated similarly to.

- $\theta_{\bar{z}}$ is the coefficient which should translate how the productivity in region *i* is affected by the transport variable in neighbouring regions.
- θ_0 is a constant term;

Therefore, it is possible to obtain one regression per region, thus isolating the spillover effects on each region. The values obtained will translate the average spillover effect of that region in relation to its neighbours. It is important to note that, in order to model this time series, we have been forced to mathematically alter the time series by applying a log transformation and a first differential. Thus, the interpretation of the resulting coefficients should not be straightforward; rather, it should be interpreted as the positive or negative impact of a 1% percent increase of our independent variable on the increase of apparent labour productivity, our dependent variable. As an example, in the case of spatial productivity in Médio Tejo, the model suggests that a 1% increase in productivity of neighbouring regions would lead to a 1.09% increase in productivity in Médio Tejo.

Using straight equivalent speed as our transport variable, the model provides best results, although it was not possible to provide sound results for the regions of Cávado, Viseu Dão e Lafões, Beira Baixa, Alentejo Litoral, Baixo Alentejo and Algarve (p-value of F-stat is higher than the significance level of 5%).

Based on the aforementioned models, we have no proof that the inclusion of independent variables enhances the predictive power of overall regression.

The results presented in Table 66 show that productivity has a positive spillover effect across the entire country. The increase in productivity in any of these regions will lead to the increase of productivity in neighbouring ones. This was to be expected, since there was a positive spatial correlation in terms of apparent labour productivity.

Regarding the influence of spatial transport variable (straight equivalent speed), we obtained four significant coefficients in the regions of Alentejo Central, Ave, Oeste and Área Metropolitana de Lisboa. The signs of the coefficients were as expected in the regions of Oeste and Área Metropolitana de Lisboa, but were the opposite of what was expected in the regions of Alentejo Central and Ave.

Regarding the first two regions, the models prove that the investment on transport infrastructures in the neighbouring regions of Alentejo Central, Alentejo Litoral, Lezíria do Tejo and Região de Leiria has had a positive effect on their productivity, of 3.10% (Área Metropolitana de Lisboa) and 3.92% (Oeste).

Some results are more difficult to interpret, e.g. the coefficients obtained in the regions of Alentejo Central and Ave are negative and there is also a significant value of the *self_transport* variable in the model of Oeste which goes against what was expected.

We may hypothesize that the sharp difference in apparent labour productivity between Alentejo Central and Oeste to its neighbours might be one of the reasons for their unexpected coefficients. As for Ave, the fact that it is included in an LL cluster may be the reason weighing on this coefficient of spatial transport. Nevertheless, further research is required in these cases in order to gain a better understanding of this phenomenon.

Table 66 Results for regression and spatial spillover

Region	rsquared	F-stat	MSE	AIC	constant	self_transport	spatial_productivity	spatial_tranport
Alto Minho	0.519	4.669**	0.005	-64.969	0.001	4.890	1.376***	-4.552
	(0.407)****				[-0.016, 0.018]	[-8.152, 17.932]	[0.521, 2.231]	[-14.971, 5.866]
Alto Tâmega	0.572	5.792**	0.006	-65.797	-0.002	0.163	1.201***	-0.784
	(0.473)				[-0.018, 0.015]	[-0.81, 1.135]	[0.566, 1.838]	[-1.956, 0.389]
Alentejo Central	0.540	5.081**	0.008	-58.435	-0.001	3.491	0.350**	-5.794
	(0.433)				[-0.022, 0.019]	[-3.788, 10.771]	[0.028, 0.672]	[-10.504, −1.084]
Cávado	0.310	1.949	0.001	-82.680	-0.001	0.309	0.436**	-0.284
	(0.151)				[-0.011, 0.009]	[-3.225, 3.843]	[0.014, 0.86]	[-2.801, 2.233]
Ave	0.602	6.557**	0.002	-85.492	-0.001	0.349	0.742***	-1.308**
	(0.510)				[-0.01, 0.009]	[-0.811, 1.509]	[0.333, 1.151]	[-2.417, −0.201]
A.m. Porto	0.620	7.059**	0.003	-81.728	-0.001	3.997	0.724**	-3.985
	(0.531)				[-0.012, 0.009]	[-1.914, 9.909]	[0.189, 1.26]	[-8.646, 0.676]
Tâmega E Sousa	0.636	7.562**	0.003	-82.646	-0.001	0.732	1.004***	-0.283
	(0.551)				[-0.011, 0.009]	[-0.528, 1.992]	[0.54, 1.469]	[-2.043, 1.476]
Douro	0.850	24.542**	0.008	-83.853	0.003	-0.442	1.416***	1.591
	(0.815)				[-0.007, 0.013]	[-1.812, 0.927]	[0.959, 1.874]	[-0.336, 3.519]
Terras de Trás-os-Montes	0.679	9.158**	0.007	-71.478	0.000	0.595	0.798***	-0.655
	(0.604)				[-0.014, 0.014]	[-0.851, 2.041]	[0.401, 1.196]	[-2.852, 1.542]
Oeste	0.767	14.249**	0.007	-76.856	-0.005	-6.832**	1.189***	3.925***
	(0.713)				[-0.018, 0.009]	[-12.34, −1.324]	[0.772, 1.607]	[1.427, 6.424]
Região de Aveiro	0.542	5.130**	0.002	-82.289	0.000	1.500	0.634***	-0.709
	(0.436)				[-0.01, 0.011]	[-4.795, 7.794]	[0.28, 0.99]	[-4.74, 3.321]
Região de Coimbra	0.758	13.598**	0.005	-82.663	-0.001	-0.244	1.243***	0.122
	(0.703)				[-0.011, 0.009]	[-1.701, 1.213]	[0.808, 1.678]	[-1.092, 1.336]
Região de Leiria	0.753	13.176**	0.003	-89.143	-0.002	1.362	0.658***	-2.738
	(0.695)				[-0.011, 0.006]	[-0.988, 3.712]	[0.422, 0.896]	[-7.642, 2.166]

Viseu Dão Lafões	0.430	3.264*	0.002	-70.620	-0.001	-1.355	0.634**	0.178
	(0.298)				[-0.016, 0.013]	[-4.106, 1.396]	[0.011, 1.258]	[-2.63, 2.986]
Beira Baixa	0.271	1.612	0.002	-64.199	0.000	-0.049	0.487*	-0.713
	(0.103)				[-0.017, 0.017]	[-0.749, 0.651]	[-0.053, 1.027]	[-2.929, 1.503]
Médio Tejo	0.683	9.334**	0.005	-76.218	0.001	0.169	1.098***	0.950
	(0.609)				[-0.012, 0.013]	[-1.314, 1.651]	[0.636, 1.56]	[-0.334, 2.233]
Beiras e Serra da Estrela	0.614	6.894**	0.005	-71.520	-0.002	-0.020	1.005***	-0.828
	(0.524)				[-0.016, 0.012]	[-0.588, 0.549]	[0.499, 1.511]	[-2.285, 0.63]
A.m. Lisboa	0.750	13.005**	0.002	-95.916	0.000	-1.362	0.620***	3.104**
	(0.692)				[-0.006, 0.007]	[-3.775, 1.051]	[0.406, 0.836]	[0.239, 5.97]
Alentejo Litoral	0.266	1.569	0.024	-19.212	-0.003	10.643	1.277	-7.156
	(0.096)				[-0.069, 0.063]	[-5.14, 26.426]	[-0.969, 3.524]	[-20.923, 6.61]
Baixo Alentejo	0.245	1.409	0.011	-30.257	-0.012	-13.642	0.0916	4.320
	(0.071)				[-0.06, 0.037]	[-31.054, 3.77]	[-0.678, 0.861]	[-6.56, 15.2]
Lezíria do Tejo	0.702	10.218**	0.007	-71.278	0.000	-5.241*	1.078***	-0.051
	(0.633)				[-0.014, 0.014]	[-11.497, 1.014]	[0.565, 1.592]	[-2.451, 2.349]
Alto Alentejo	0.591	6.254**	0.005	-70.992	0.001	0.961	0.750***	0.460
	(0.496)				[-0.014, 0.015]	[-2.134, 4.056]	[0.372, 1.129]	[-3.727, 4.647]
Algarve	0.238	1.353	0.001	-70.361	-0.002	-0.036	0.083	1.188
	(0.062)				[-0.016, 0.013]	[-1.303, 1.232]	[-0.047, 0.214]	[-2.42, 4.796]

*p-value lesser than 10%; ** p-value lesser than 5%; *** p-value lesser than 1%; **** adjusted r-squared

Chapter 7
Conclusions

7.1. Final remarks

Despite the central role of the transportation system as an enabler of economic, social and environmental development in the country, there is a fundamental lack of data and of a monitoring & assessment strategy that provides data and analysis to enable a data-oriented policy. Taking into account the increasing complexity and interconnectivity of the different systems, it is necessary to continually evaluate the levels of performance, efficiency and impact of the transportation system.

The first part of this research provided a novel perspective on the evolution of the efficiency of the transportation systems in Portugal and, for the first time, a quantitative analysis of public policy options regarding the organization and management of the system. The ex-post evaluation of public policy options is a fundamental requisite for good public governance. Over the last 20 years and, in particular, over the last decade, the transportation system, in its various components, has experienced fundamental changes regarding ownership models, regulation, managerial and strategic decisions, etc. Unfortunately, policy decisions are made considering a number of objectives (generally qualitative) that are rarely verified and assessed. The first part of this research focuses precisely on the evaluation, from an efficiency perspective, of the system, and on the main policy changes that have occurred. It is important to mention that we have used other "lenses" apart from efficiency. An additional perspective is the impact analysis, and the authors of this study have focused on a specific aspect – productivity. Again, this could have been followed by other approaches, and we hope that this study, and the information it provides, can stimulate further studies and the development an ex-post evaluation of the main policies. Over the next few paragraphs, we present and discuss the main conclusions and policy implications of our research study.

7.1.1. Transparency

One of the most important contributions, if not the most important, of this study is to highlight the crucial importance of permanently monitoring system efficiency. This monitoring is clearly for the responsibility of regulators, in particular, AMT (Autoridade da Mobilidade e Transportes). The calculation and communication of efficiency scores and/or KPIs that would enable the tracking of resources consumed, or inputs (operating costs, staff, and investment, etc.) and outputs (passengers, vehicle-kilometres, and revenue, etc.) could stimulate the improvement of firms and of the sector as a whole. Such transparency would also provide a quantitative layer which would pave the way for truly informed decision-making processes. Similar approaches have been employed, for example, in the water sector by the regulator ERSAR.

Without transparency, there is no accountability in management or in political decisions. Unfortunately, the transportation sector has a long road ahead in terms of improving its transparency and accountability, although overall levels of efficiency have been improving, particularly after the Troika period and the financial crisis.

7.1.2. Overall efficiency evaluation

Based on observation of the main trends of the different scores in distinct companies and sectors, overall levels of efficiency have been improving. There have been several events with a positive impact in boosting efficiency. Conversely, one of the main leverages for efficiency improvement has been the financial crisis. It has had both short- and medium-term impacts on efficiency improvement, particularly from an economic perspective. The same is true of privatizations (e.g., the case of TAP), mergers and acquisitions (the case of the acquisition of Portugália and the merger of EP/Refer) and the concession of urban rail transit to private companies. The case of TAP and the concession of urban rail transit are particularly relevant from a public policy perspective, because they are both cases of increasing private sector participation in a public--dominated market. The context following the post-privatization period, in the case of TAP, also provided a favourable layer for efficiency improvement (e.g. growth in tourism and GDP).

7.1.3. Economic resilience

In general, the results also show that the economic environment affects efficiency scores. In most cases, GDP growth improves economic efficiency, which might be linked to revenue growth and, particularly, to revenue per passenger. In the case of public transport, this growth can be linked, for example, to growth in tourism that increases the use of single-day tickets, which tends to provide a higher average revenue than regular commuters using monthly passes. However, in the case of urban transport, we see a negative effect on technical efficiency that might be attributable to the strategy of increasing staff and fleets, which might, in turn, reduce overall technical efficiency. The austerity usually associated with periods of economic contraction can postpone the renewal of resources, originating a subsequent surplus of recovery periods. Another reason is related to the fact that with GDP growth, there is an increase in demand that can lead to congestion and deterioration of operating conditions. Therefore, in the technical scores that do not account for passengers but only for operational outputs (e.g., vehicle-kilometres), the levels of efficiency decrease.

7.1.4. Concessions and privatization

The impact of management models on transportation systems and utilities in general has been a recurrent topic in the academic literature, although without empirical evidence from the Portuguese context. Our research tried to fill that gap by providing an analysis of the privatization of TAP and the concessions in urban rail (light and standard) systems. Although concessions and privatization are structurally different, for the purpose of our research, they both represent a "private management" perspective on the transportation firm.

In the case of TAP, privatization appears to be the most consensual predictor for efficiency scores. Although the acquisition of Portugália also provided an important boost for efficiency, privatization was consistently the best predictor of efficiency.

In the case of urban rail transit, there is a clear pattern whereby when measuring efficiency with operational costs as an input, privately managed firms are more efficient, regardless of other financial metrics used such as inputs and outputs.

A more careful analysis of the results shows that privately managed firms are less efficient for positive GDP growth, losing their higher efficiency during GDP growth of more than 1%. On the other hand, they become increasingly efficient for negative GDP variations. Our hypothesis is that this behaviour may be related to the higher management flexibility of privately managed firms.

In the case of road concessions, toll-based contracts and availability-based contracts display distinct behaviours according to GDP changes. Toll-based contracts react positively to GDP growth, while availability-based contracts respond to it negatively. However, overall, the analysis showed that overall availability contracts are less efficient, highlighting the importance of balanced risk-sharing approaches.

The results of the controlled and uncontrolled analysis show that the Troika years had a negative effect on efficiency. This effect might be linked to a significant decrease in the overall levels of traffic. On the other hand, the financial crisis has had a positive effect. During the first few years after the financial crisis erupted, most of the traffic was unaffected, since the portion of the population who usually travels and the industries were only marginally affected at the time. In the Troika years, there were several renegotiations of road PPPs, for the purpose of decreasing capital and operational expenditures. These renegotiations occurred over a long period but were eventually finalised, allowing for significant cost savings (more clearly after the financial crisis).

7.1.5. Mergers and acquisitions

Regarding mergers and acquisitions, our research study analysed two cases: the acquisition of Portugália by TAP and the merger of EP/Refer into the new company – Infraestruturas de Portugal (IP). The results show that both strategies caused higher levels of efficiency in the companies. In these cases, "bigger is better". In the case of TAP, it provided a feeder service that fuelled the profitability of medium- to long-haul services. The case of Infraestruturas de Portugal seemed to be linked to potential synergies in joint management of the road and rail sector, thus diversifying risk. In fact, the IP's efficiency improved with GDP growth; however, in the same context, the efficiency of EP and Refer decreased.

7.1.6. Accessibility and productivity

Transportation systems and, in particular, the stock of infrastructure and the overall accessibility they allow (average accessibility, proximity to ports or airports, etc.) can play an important role in the spatial analysis of economic and social trends. The efficiency levels discussed before represent a "firm-centred" analysis, and do not provide a direct evaluation of the real spatial impact that the transportation system is having.

Therefore, this study has analysed the spatial impact on productivity. Rather than a detailed study on productivity determinants, we intended to analyse the potential (as)symmetries that the development of the transportation system has developed.

This study has the advantage of considering physical measures of accessibility, rather than investment (as many previous studies have done). The use of investment metrics (overall investment, investment growth, or even infrastructure capital stock) is based on the assumption that higher investment will enable proportionally greater accessibility and mobility. This is not necessarily the case. The average cost per kilometre of transportation infrastructure (road or railway) can change significantly based on the physical characteristics of the region. Therefore, a particular region may benefit from a high level of investment without a necessary proportional improvement in accessibility, or, put differently, the elasticity of accessibility in relation to investment may be different. Another important factor is related to the overall quality and efficiency of projects. By quality one means the fit between the infrastructure and the demand it serves.

Our results show that accessibility matters, but not just any kind of accessibility. Accessibility was measured through a number of indicators. In terms of road geographic accessibility, the 2019 analysis on Portuguese NUTS 3 indicates that the Metropolitan Area of Oporto (AM do Porto) has the best accessibility and displays the highest increase between 1986 and 2019, with an increase of 29.7. The regions with the lowest roadway geographic accessibility in 2019 were Terras de Trás-os-Montes and the Algarve. Both regions are located near Portuguese borders and, for that reason, the number of long trips between these regions to others is higher than in other regions, which results in decreased accessibility level. Although the Baixo Alentejo region is not the one ranked with the lowest accessibility, it has the smallest historical absolute variation.

On average, road travel times have decreased overall for the road system, as a result of substantial investment in road stock since the 1990s. There was a clear political priority to invest in the development of the road system, particularly in highways. Rail accessibility has displayed a different behaviour. Due to the overall decrease and disinvestment on the network, several regions exhibit an increase in rail travel times. In fact, rail-related variables offer little contribution to the understanding of productivity.

The results show that transportation variables have a high correlation with productivity, although road-related variables are predominant, as are distances to ports and seaports, these latter probably related to proximity to the coast. Railway variables are absent. The analysis showed that *sinuosidade*, *vel_reta* and *acess_viaria* are the only variables that displayed stronger correlation with apparent labour productivity. Furthermore, the analysis has shown that there are relevant spillover effects to take into account when analysing productivity, particularly in the Área Metropolitana de Lisboa.

7.2. Main limitations and future developments

These types of study have important limitations. The first concerns the use of information in annual reports. Although these are audited reports, they can still incorporate some biased interpretations of results. However, in the case of this study, we do not think that the magnitude of these errors would alter the main conclusions. The second is a recurrent criticism of the use of DEA for distinct companies and is related to the fact that each firm operates under a specific context that cannot be accurately accounted for. Thirdly, the period under analysis is relatively short, particularly when taking into account operations such as mergers and privatizations.

For future research, some areas should be more carefully considered:

- The time series considered is relatively short. It would be relevant to consider a longer time series, of 30 or 40 years. Unfortunately, for the level of granularity considered in this study, such data was unavailable;
- Another alternative is to perform analysis at a micro level, using micro data. To allow for such analysis, this study provides a detailed assessment at municipality level for the accessibility indicators that would be useful for future analysis;
- It would also be important to consider a more detailed analysis of different sectors. This study analysed the average apparent labour productivity. It would be relevant to break down the distinct potential impacts of accessibility on productivity per type of industry;
- Some future developments can also be made regarding the different types of indicators of accessibility. The indicators that have been calculated were based on physical accessibility (e.g. time and distance); an additional layer of analysis would include the generalized cost of travel, moving from physical measures of accessibility to economic measures of accessibility.

The study of the effects of transportation on productivity in Portugal faces several research challenges ahead, and we believe that this study provides a first contribution towards the use of more sophisticated measures of transport impact in this field of research.

References

Agarwal, S., Yadav, S.P., Singh, S.P. (2011). DEA based estimation of the technical efficiency of state transport undertakings in India. Opsearch 47(3), 216–230.

Agbelie, B.R.D.K. (2014). An empirical analysis of three econometric frameworks for evaluating economic impacts of transportation infrastructure expenditures across countries. Transport Policy, 35, 304-310.

Aguiar-Conraria, L., Wen, Y. (2007). Understanding the large negative impact of oil shocks. Journal of Money, Credit and Banking, 39(4), 925-944.

Ahmadvand, A., Abtahy, Z., Bashiri, M. (2011). Considering undesirable variables in PCA-DEA method: a case of road safety evaluation in Iran. Journal of Industrial Engineering International, 5(15), 43-50.

Al-Jazzaf, M.I. (1999). Impact of privatization on airlines performance: an empirical analysis. Journal of Air Transport Management, 5(1), 45-52.

Alam, I.M., Sickles, R.C. (2000). Time series analysis of deregulatory dynamics and technical efficiency: the case of the US airline industry. International Economic Review, 41(1), 203-218.

Albalate, D., Rosell, J. (2019). On the efficiency of toll motorway companies in Spain. Research in Transportation Economics, 76, 100747.

Ales, L., Maziero, P., Yared, P. (2014). A theory of political and economic cycles. Journal of Economic Theory, 153, 224-251.

Alexandridis, G., Singh, M., (2014). Mergers and acquisitions in shipping. Transport. Res. Part E, 61(1), 212-234.

Amdal, E., Bårdsen, G., Johansen, K., Welde, M. (2007). Operating costs in Norwegian toll companies: a panel data analysis. Transportation, 34(6), 681–695.

Andrade, J.S., Duarte, A.P. (2016). Crowding-in and crowding-out effects of public investments in the Portuguese economy. International Review of Applied Economics, 30(4), 488-506.

Andreou, P.C., Louca, C., Panayides, P.M., (2012). Valuation effects of mergers and acquisitions in freight transportation. Transp. Res. Part E: Logist. Transp. Rev., 48(6), 1221–1234.

Anselin, L. (1993). Local indicators of spatial autocorrelation—LISA. Geographical Analysis, 27(2), 93-115.

Aschauer, D. A. (1988) Government spending and the falling rate of profit. Economic Perspectives, 12, 11-17.

Aschauer, D. A. (1990). Highway capacity and economic growth. Economic Perspectives, 14(5), 4-24.

Aschauer, D.A. (1989a). Is government spending productive. Journal of Monetary Economics, 23, 177-300.

Aschauer, D.A. (1989b). Does public capital crowd out private capital? Journal of Monetary Economics, 24, 171-188.

Aschauer, D.A. (1989c). Public investment and productivity growth in the Group of Seven. Economic Perspectives, 13(5), 17-25.

Avenali, A., Boitani, A., Catalano, G., D'Alfonso, T., Matteucci, G. (2016). Assessing standard costs in local public bus transport: Evidence from Italy. Transport Policy, 52, 164-174.

Backx, M., Carney, M., Gedajlovic, E. (2002). Public, private and mixed ownership and the performance of international airlines. Journal of Air Transport Management, 8(4), 213-220.

Bai, X. J., Zeng, J., Chiu, Y. H. (2019). Pre-evaluating efficiency gains from potential mergers and acquisitions based on the resampling DEA approach: Evidence from China's railway sector. Transport Policy, 76, 46-56.

Banister, D., Berechman, Y. (2001). Transport investment and the promotion of economic growth. Journal of Transport Geography, 9(3), 209-218.

Banister, D., Stead, D. (2002). Reducing transport intensity. European Journal of Transport and Infrastructure Research, 2(4).

Barbot, C., Costa, Á., Sochirca, E. (2008). Airlines performance in the new market context: A comparative productivity and efficiency analysis. Journal of Air Transport Management, 14(5), 270-274.

Barnum, D.T., Karlaftis, M.G., Tandon, S. (2011). Improving the efficiency of metropolitan area transit by joint analysis of its multiple providers. Transp. Res. Part E, 47, 1160–1176

Barr, N. (2004). Economics of the Welfare State. New York: Oxford University Press.

Barros, C.P., Peypoch, N. (2009). An evaluation of European airlines' operational performance. International Journal of Production Economics, 122(2), 525-533.

Barros, C.P., Peypoch, N. (2010). Productivity changes in Portuguese bus companies. Transport Policy, 17(5), 295–302

Barros, C.P., Peypoch, N. (2010). Productivity changes in Portuguese bus companies. Transport Policy, 17(5), 295-302.

Baumont, C., Ertur, C. & Le Gallo, J., 2000. Geographic spillover and growth (a spatial econometric analysis for European regions)., s.l.: Laboratoire d'analyse et de techniques économiques (LATEC).

Bazzi, S., Chari, A.V., Nataraj, S., Rothenberg, A.D. (2017). Identifying Productivity Spillovers Using the Structure of Production Networks. Working Papers WR-1182, RAND Corporation.

Besanko, D., Gonçalves, J.T. (2017). High-speed rail in Portugal. Kellogg School of Management Cases.

Bhanot, N., Singh, H. (2014). Benchmarking the performance indicators of Indian Railway container business using data envelopment analysis. Benchmarking: An International Journal, 21(1), 101-120.

Bhattacharyya, A., Kumbhakar, S.C., Bhattacharyya, A. (1995). Ownership structure and cost efficiency: A study of publicly owned passenger-bus transportation companies in India. Journal of Productivity Analysis, 6(1), 47-61.

Bil, J. (2013). Measuring European railway efficiency using DEA approach. In Hana Vojackova. Proceedings of the 31st International Conference Mathematical Methods in Economics 2013. Jihlava: College of Polytechnics Jihlava. s. 43-48, 6 s.

Bishop, J.A., Formby, J.P., Zeager, L.A. (2001). The distributional impact of unification and the 1992–93 recession on West German households. Economics of Transition, 9(2), 515-532.

Bitzan, J.D., Wilson, W.W. (2007). Industry costs and consolidation: efficiency gains and mergers in the US railroad industry. Rev. Ind. Organ. 30(2), 81–105.

Blanchard, O. (2017). Macroeconomics, (Global Edition). Pearson.

Blanchard, O. & Perotti, R., 2002. An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output. The Quarterly Journal of Economics, Volume 117, p. 1329–1368.

Blanchard, O., Perotti, R. (2002). An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output. The Quarterly Journal of Economics, 117, 1329–1368.

Boame, A.K. (2004). The technical efficiency of Canadian urban transit systems. Transport Research, Part E 40(5), 401–416

Boardman, A.E., Laurin, C., Moore, M.A., Vining, A.R. (2013). Efficiency, profitability and welfare gains from the Canadian National Railway privatization. Research in Transportation Business & Management, 6, 19-30.

Boardman, A.E., Laurin, C., Vining, A.R. (2002). Privatization in Canada: Operating and stock price performance with international comparisons. Canadian Journal of Administrative Sciences/Revue Canadienne des Sciences de l'Administration, 19(2), 137-154.

Boardman, A.E., Vining, A.R. (1989). Ownership and performance in competitive environments: A comparison of the performance of private, mixed, and state-owned enterprises. the Journal of Law and Economics, 32(1), 1-33.

Bogart, D., Chaudhary, L. (2013). Engines of growth: the productivity advance of Indian railways, 1874–1912. The Journal of Economic History, 339-370.

Boitani, A., Nicolini, M., Scarpa, C. (2013). Do competition and ownership matter? Evidence from local public transport in Europe. Applied economics, 45(11), 1419-1434.

Boots, B., Tiefelsdorf, M. (2000). Global and local spatial autocorrelation in bounded regular tessellations. Journal of Geographical Systems, 2(4), 319-348.

Borio, C.E., Drehmann, M., Xia, F.D. (2018). The financial cycle and recession risk. BIS Quarterly Review December.

Brunner, K., Cukierman, A., Meltzer, A.H. (1980). Stagflation, persistent unemployment and the permanence of economic shocks. Journal of Monetary Economics, 6(4), 467-92.

Bruzelius, N.A. (1981). Microeconomic theory and generalised cost. Transportation, 10(3), 233–245. doi:10.1007/BF00148460.

Buehler, R., Pucher, J. (2011). Making public transport financially sustainable. Transport Policy, 18(1), 126-138.

Bueno, P.C., Vassallo, J.M., Cheung, K. (2015). Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods, Transport Reviews, 35(5), 622-649.

Button, K. (2010). Transport economics. Edward Elgar Publishing.

Button, K., Costa, A. (1999). Economic efficiency gains from urban public transport regulatory reform: Two case studies of changes in Europe. The Annals of Regional Science, 33(4), 425-438.

Campa, J.M., Hernando, I. (2004). Shareholder value creation in European M&As. European financial management, 10(1), 47-81.

Carreira, C., Teixeira, P. (2016). Entry and exit in severe recessions: lessons from the 2008–2013 Portuguese economic crisis. Small Business Economics, 46(4), 591-617.

Catalão, F.P., Cruz, C.O., & Sarmento, J.M. (2019b). The determinants of cost deviations and overruns in transport projects, an endogenous models approach. Transport Policy, 74, 224-238.

Catalão, F.P., Cruz, C.O., Miranda Sarmento, J. (2019a). Exogenous determinants of cost deviations and overruns in local infrastructure projects. Construction Management and Economics, 37(12), 697-711.

Catalão, F.P., Cruz, C.O., Sarmento, J.M. (2020). Public management and cost overruns in public projects. International Public Management Journal, 1-27.

Cavaignac, L., Petiot, R. (2017). A quarter century of Data Envelopment Analysis applied to the transport sector: A bibliometric analysis. Socio--Economic Planning Sciences, 57, 84-96.

Chang, K.P., Kao, P.H. (1992). The relative efficiency of public versus private municipal bus firms: An application of data envelopment analysis. In International Applications of Productivity and Efficiency Analysis, 63-80. Dordrecht: Springer.

Chang, Y.C., Yu, M.M. (2014). Measuring production and consumption efficiencies using the slack-based measure network data envelopment analysis approach: the case of low-cost carriers. Journal of advanced transportation, 48(1), 15-31.

Chapin, A., Schmidt, S. (1999). Do mergers improve efficiency? Evidence from deregulated rail freight. J. Transp. Econ. Policy, 147–162.

Charnes, A., Cooper, W.W., Rhodes, E. (1978). Measuring the efficiency of decision-making units. *European journal of operational research*, *2*(6), 429-444.

Chen, C.C. (2014). The efficiency of freeway bus service industry as facing the entrance of High-Speed Rail: Taiwan's case. Economic Research Guardian, 4(2), 18.

Chen, X., Gao, Y., An, Q., Wang, Z., Neralić, L. (2018). Energy efficiency measurement of Chinese Yangtze River Delta's cities transportation: a DEA window analysis approach. Energy Efficiency, 11(8), 1941-1953.

Chen, Y., Gayle, P.G. (2019). Mergers and product quality: evidence from the airline industry. Int. J. Ind. Organ., 62, 96-135.

Chow, C.K.W. (2010). Measuring the productivity changes of Chinese airlines: the impact of the entries of non-state-owned carriers. Journal of Air Transport Management, 16(6), 320-324.

Chu, X., Fielding, G.J., Lamar, B.W. (1992). Measuring transit performance using data envelopment analysis. Transportation Research Part A: Policy and Practice, 26(3), 223-230.

Cliff, A., Ord, J. (1981). Spatial processes. Models and applications. London: Pion.

Cohen, J.P. (2010). The broader effects of transportation infrastructure: Spatial econometrics and productivity approaches. Transportation Research Part E, 46, 317-326.

Cooper, W., Seiford, L. & Tone, K. (2007). Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software (Second Edition). New York: Springer.

Cooper, W., Seiford, L., Zhu, J. (2011). Handbook on Data Envelopment Analysis. New York: Springer Science & Business Media.

Cordera, R., Canales, C., dell'Olio, L., Ibeas, A. (2015). Public transport demand elasticities during the recessionary phases of economic cycles. Transport Policy, 42, 173-179.

Costa, A. (1998). Public transport efficiency and effectiveness: Metro de Madrid. Transport networks in Europe: Concepts, analysis, and policies. Cheltenham: Elgar, pp.248-264.

Costa, Á., Markellos, R.N. (1997). Evaluating public transport efficiency with neural network models. Transportation Research Part C: Emerging Technologies, 5(5), 301-312.

Coto-Millán, P., Fernández, X.L., Hidalgo, S., Pesquera, M.Á. (2016). Public regulation and technical efficiency in the Spanish Port Authorities: 1986–2012. Transport Policy, 47, 139-148.

Couto, A., Graham, D.J. (2008). The contributions of technical and allocative efficiency to the economic performance of European railways. Portuguese Economic Journal, 7(2), 125-153.

Cowie, J. (2002). Acquisition, efficiency and scale economies: an analysis of the British bus industry. Transport Revision 22(2), 147–157.

Cowie, J. (2009). The British passenger rail privatisation: conclusions on subsidy and efficiency from the first round of franchises. Journal of Transport Economics and Policy (JTEP), 43(1), 85-104.

Cowie, J., Asenova, D. (1999). Organisation form, scale effects and efficiency in the British bus industry. Transportation, 26(3), 231-248.

Crafts, N., Leunig, T., Mulatu, A. (2008). Were British railway companies well managed in the early twentieth century? The Economic History Review, 61(4), 842-866.

Crafts, N., Mills, T.C., Mulatu, A. (2007). Total factor productivity growth on Britain's railways, 1852–1912: A reappraisal of the evidence. Explorations in Economic History, 44(4), 608-634.

Cruz, C.O. Marques, R.C. (2012). Using probabilistic methods to estimate the public sector comparator. Computer-Aided Civil and Infrastructure Engineering, 27, 782–800.

Cruz, C.O., Marques, R.C. (2011). Revisiting the Portuguese experience with public-private partnerships. African Journal of Business Management, 5(11), 4023-4032.

Cruz, C.O., Marques, R.C. (2013). Risk-sharing in highway concessions: contractual diversity in Portugal. Journal of professional issues in engineering education and practice, 139(2), 99-108.

Cruz, C.O., Marques, R.C., Pereira, I. (2015). Alternative contractual arrangements for urban light rail systems: lessons from two case studies. Journal of Construction Engineering and Management, 141(3), 05014017.

Cruz, C.O., Sarmento, J.M. (2017). Airport privatization with public finances under stress: An analysis of government and investor's motivations. Journal of Air Transport Management, 62, 197-203.

Daito, N., Gifford, J. (2014). US highway public private partnerships: Are they more expensive or efficient than the traditional model? Managerial Finance, 40, 1131-1151.

Daraio, C., Diana, M., Di Costa, F., Leporelli, C., Matteucci, G., Nastasi, A. (2016). Efficiency and effectiveness in the urban public transport sector: A critical review with directions for future research. European Journal of Operational Research, 248(1), 1-20.

de Bok, M., Costa, Á., Melo, S., Palma, V., Frias, R. D. (2010). Estimation of a mode choice model for long distance travel in Portugal. In Proceedings from Word Conference of Transport Research, Lisbon.

De Borger, B., Kerstens, K., Staat, M. (2008). Transit costs and cost efficiency: bootstrapping non-parametric frontiers. Res Transp Econ, 23(1), 53–64.

De Haas, R., Van Horen, N. (2012). International shock transmission after the Lehman Brothers collapse: Evidence from syndicated lending. American Economic Review, 102(3), 231-37.

Deller, S., Halstead, J. (1994). Efficiency in the production of rural road services: The case of New England towns. Land Economics, 70, 247–259.

Desmarais-Tremblay, M. (2014). On the Definition of Public Goods. Assessing Richard A. Musgrave's contribution. Documents de travail du Centre d'Economie de la Sorbonne 2014.05 – ISSN: 1955-611X. 2014.

Dnes, A.W. (1996). The economic analysis of franchise contracts. Journal of Institutional and Theoretical Economics (JITE)/Zeitschrift für die gesamte Staatswissenschaft, 297-324.

Dodgson, J. (2011). New, disaggregated, British railway total factor productivity growth estimates, 1875 to 1912 The Economic History Review, 64(2), 621-643.

Doi, N., Ohashi, H. (2019). Market structure and product quality: a study of the 2002 Japanese airline merger. Int. J. Ind. Organ., 62, 158-1939.

Doomernik, J.E. (2015). Performance and efficiency of high-speed rail systems. Transportation Research Procedia, 8, 136-144.

Drezner, D. W. (2014). The system worked: Global economic governance during the Great Recession. World Pol., 66, 123.

Eckel, C., Eckel, D., Singal, V. (1997). Privatization and efficiency: Industry effects of the sale of British Airways. Journal of Financial Economics, 43(2), 275-298.

Efthymiou, D., Antoniou, C. (2017). Understanding the effects of economic crisis on public transport users' satisfaction and demand. Transport Policy, 53, 89-97.

Egilmez, G., McAvoy, D. (2013). Benchmarking road safety of US states: A DEA-based Malmquist productivity index approach. Accident Analysis & Prevention, 53, 55-64.

Emrouznejad, A., Yang, G.L. (2018). A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. Socio-Economic Planning Sciences, 61, 4-8.

Fageda, X., Gonzalez-Aregall, M. (2017). Do all transport modes impact on industrial employment? Empirical evidence from the Spanish regions. Transport Policy, 55, 70-78.

Färe, R., Grosskopf, S., Sickles, R.C. (2007). Productivity? of US airlines after deregulation. Journal of Transport Economics and Policy (JTEP), 41(1), 93-112.

Farsi, M., Fetz, A., Filippini, M. (2007). Economies of scale and scope in local public transportation. Journal of Transport Economics and Policy (JTEP), 41(3), 345-361.

Fernandes, C., Ferreira, M., Moura, F. (2015) PPPs—true financial costs and hidden returns. Transport Reviews, 36(2), 1–21.

Fernandes, C., Oliveira Cruz, C., Moura, F. (2019). Ex post evaluation of PPP government-led renegotiations: Impacts on the financing of road infrastructure. The Engineering Economist, 64(2), 116-141.

Fethi, M.D., Jackson, P.M., Weyman-Jones, T.G. (2000). Measuring the efficiency of European airlines: an application of DEA and Tobit Analysis. European Public Choice Society: Siena, Italy, 2000, 26-29.

Flyvbjerg, B., Holm, M.K.S., Buhl, S.L., 2003. How common and how large are cost overruns in transport infrastructure projects? Transport Reviews, 23(1), 71-88.

Gagnepain, P., Ivaldi, M. (2002). Incentive regulatory policies: the case of public transit systems in France. RAND Journal of Economics, 605-629.

Garcia-Mila, T., McGuire, T.J. (1992). The contribution of publicly provided inputs to states' economies. Regional science and urban economics, 22(2), 229-241.

Gathon, H.J. (1989). Indicators of partial productivity and technical efficiency in the European urban transit sector. Annals of Public and Cooperative Economics, 60(1), 43-60.

Geary, R. C., 1954. The Contiguity Ratio and Statistical Mapping. The Incorporated Statistician, 5(3), pp. 115-127+129-146.

George, S. A., Rangaraj, N. (2008). A performance benchmarking study of Indian Railway zones. Benchmarking: An International Journal, 15(5), 599-617.

Geurs K., Eck R. (2001). Accessibility measures: review and applications. Evaluation of accessibility impacts of land-use transport scenarios, and related social and economic impacts, National Institute of Public Health and Environment, RIVM report 408505 006.

Geurs, K., Eck, J. (2001). Accessibility Measures: Review and Applications (No. 408505006). Retrieved from Utrecht: link

Geurs, K.T., van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. Journal of Transport Geography, 12(2), 127–140.

Gherghina, Ş.C., Onofrei, M., Vintilă, G., Armeanu, D.Ş. (2018). Empirical evidence from EU-28 countries on resilient transport infrastructure systems and sustainable economic growth. Sustainability, 10(8), 2900.

Gillen, D.W., Oum, T.H., Tretheway, M.W. (1989). Privatization of Air Canada: Why it is necessary in a deregulated environment. Canadian Public Policy/Analyse de politiques, 15(3), 285-299.

Godsell, J., Masi, D., Karatzas, A., Brady, T.M. (2018). Using project demand profiling to improve the effectiveness and efficiency of infrastructure projects. International Journal of Operations & Production Management, 38(6), 1422-1442.

Graham, D.J. (2007). Variable returns to urbanization and the effect of road traffic congestion. Journal of Urban Economics, 62, 103–120.

Graham, D.J. (2008). Productivity and efficiency in urban railways: Parametric and non-parametric estimates. Transportation Research Part E: Logistics and Transportation Review, 44(1), 84-99.

Granger, C. (1969). Investigating Causal Relations by Econometric Models and Cross-spectral Methods. Econometrica, 37(3), 424-438.

Granger, C. & Newbold, P., 1974. Spurious regression in econometrics. Journal of Econometrics, Volume 2, pp. 111-120.

Granger, C., 1969. Investigating Causal Relations by Econometric Models and Cross-spectral Methods. Econometrica, 37(3), pp. 424-438.

Gutiérrez, J., Condeço-Melhorado, A., Martin, J.C. (2010) Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment. Journal of Transport Geography, 18, 141-152.

Guzmán, I., Montoya, J.L. (2011). Eficiencia técnica y cambio productivo en el sector ferroviario español de vía ancha (1910-1922). Innovar, 21(40), 219-234.

Handy, S.L., Niemeier, D.A. (1997). Measuring accessibility: An exploration of issues and alternatives. Environment and Planning A, 29(7), 1175–1194.

Hansen, W.G. (1959). How Accessibility Shapes Land Use. Journal of the American Planning Association, 25(2), 73–76.

Hardiman, N., Spanou, C., Araújo, J.F., MacCarthaigh, M. (2019). Tangling with the Troika: “domestic ownership” as political and administrative engagement in Greece, Ireland, and Portugal. Public Management Review, 21(9), 1265-1286.

Harris, R.G., Winston, C. (1983). Potential benefits of rail mergers: an econometric analysis of network effects on service quality. Rev. Econ. Stat., 65(1), 32–40.

Hicks, J.R. (1966) The Theory of Wages. St. Martins Press. ISBN 0-333-02764-7.

Hill, E., Clair, T.S., Wial, H., Wolman, H., Atkins, P., Blumenthal, P., Ficenec, S., Friedhoff, A. (2012). Economic shocks and regional economic resilience. In Urban and regional policy and its effects: Building resilient regions (pp. 193-274). Brookings Institution Press.

Hilmola, O.P. (2007). European railway freight transportation and adaptation to demand decline. International Journal of Productivity and Performance Management, 56(3), 205-225.

Hilmola, O.P. (2011). Benchmarking efficiency of public passenger transport in larger cities. Benchmarking: An International Journal, 18(1), 23-41.

Holvad, T., Hougaard, J.L., Kronborg, D., Kvist, H.K. (2004). Measuring inefficiency in the Norwegian bus industry using multi-directional efficiency analysis. Transportation, 31(3), 349–369.

Jara-Diaz, S.R., Basso, L.J. (2003). Transport cost functions, network expansion and economies of scope. Transportation Research Part E: Logistics and Transportation Review, 39(4), 271-288.

Jarboui, S., Forget, P., Boujelben, Y. (2015). Efficiency evaluation in public road transport: a stochastic frontier analysis. Transport, 30(1), 1-14.

Jarboui, S., Forget, P., Boujelbene, Y. (2012). Public road transport efficiency: a literature review via the classification scheme. Public Transport, 4(2), 101-128.

Jiang, J.L., Song, R., Li, J., Liu, J. (2011). Evaluating of urban roads congestion based on data envelopment analysis. Journal of Transport Information and Safety, 29(3), 10-14.

Jitsuzumi, T., Nakamura, A. (2010). Causes of inefficiency in Japanese railways: Application of DEA for managers and policymakers. Socio-Economic Planning Sciences, 44(3), 161-173.

Kabasakal, A., Kutlar, A., Sarikaya, M. (2013). Efficiency determinations of the worldwide railway companies via DEA and contributions of the outputs to the efficiency and TFP by panel regression. Central European Journal of Operations Research, 23(1), 69-88.

Kabasakal, A., Kutlar, A., Sarikaya, M. (2015). Efficiency determinations of the worldwide railway companies via DEA and contributions of the outputs to the efficiency and TFP by panel regression. Central European Journal of Operations Research, 23(1), 69-88.

Karlaftis, M.G. (2004). A DEA approach for evaluating the efficiency and effectiveness of urban transit systems. European Journal of Operational Research, 152(2), 354-364.

Kerstens, K. (1996). Technical efficiency measurement and explanation of French urban transit companies. Transportation Research Part A: Policy and Practice, 30(6), 431-452.

Kerstens, K. (1999). Decomposing technical efficiency and effectiveness of French urban transport. Annales d'économie et de statistique, 129-155.

Krugman, P. (1979) Increasing returns, monopolistic competition, and international trade. Journal of International Economics, 9, 950-959.

Krugman, P. (1995) Development, Geography, and Economic Theory. Cambridge, MA. The MIT Press.

Kumar S (2011) State road transport undertakings in India: technical efficiency and its determinants. Benchmarking 18(5), 616–643.

Kumbhakar, S.C., Orea, L., Rodríguez-Álvarez, A., Tsionas, E.G. (2007). Do we estimate an input or an output distance function? An application of the mixture approach to European railways. Journal of Productivity Analysis, 27(2), 87-100.

Kutlar, A., Kabasakal, A., Sarikaya, M. (2013). Determination of the efficiency of the world railway companies by method of DEA and comparison of their efficiency by Tobit analysis. Quality & Quantity, 47(6), 3575-3602.

Lai, P.L., Potter, A., Beynon, M., Beresford, A. (2015). Evaluating the efficiency performance of airports using an integrated AHP/DEA-AR technique. Transport Policy, 42, 75-85.

Lambrecht, B.M. (2004). The timing and terms of mergers motivated by economies of scale. Journal of Financial Economics, 72(1), 41-62.

Larson, P.D. (2013). Deregulation of and mergers among American and Canadian railroads: a study of four decades. Res. Transp. Bus. Manag. 6, 11–18.

Le Gallo J. (2014) Cross-Section Spatial Regression Models. In: Fischer M., Nijkamp P. (eds) Handbook of Regional Science. Berlin, Heidelberg: Springer.

Le Gallo, J., 2014. Cross-Section Spatial Regression Models. Berlin, Heidelberg: Springer.

Le Néchet, F., Melo, P.C., Graham, D.J. (2012). The role of transport induced agglomeration effects on firm productivity in mega-city regions: Evidence for Bassin Parisien. Transportation Research Record: Journal of the Transportation Research Board, 2307, 21–30.

Levaggi, R. (1994). Parametric and non-parametric approach to efficiency: the case of urban transport in Italy. Studi Economici, 49, 67-88.

Levin, R.C., Weinberg, D.H. (1979). Alternatives for restructuring the rail-roads: End-to end or parallel mergers? Econ. Inq. 17 (3), 371–388.

Levine, J. (1998). Rethinking accessibility and jobs-housing balance. Journal of the American Planning Association, 64(2), 133-149.

Levinson, D.M. (1998). Accessibility and the journey to work. Journal of Transport Geography, 6(1), 11–21.

Li, Y., Wang., Y.-Z., Cui, Q. (2016). Has airline efficiency affected by the inclusion of aviation into European Union Emission Trading Scheme? Evidences from 22 airlines during 2008–2012. Energy, 96, 8-22.

Linneker, B.J., Spence N.A. (1992). An Accessibility Analysis of the Impact of the M25 London Orbital Motorway on Britain, Regional Studies, 26(1), 31-47.

Lobo, A., Couto, A. (2016). Technical efficiency of European metro systems: the effects of operational management and socioeconomic environment. Networks and Spatial Economics, 16(3), 723-742.

Loizides, I., Giahalis, B. (1995). The performance of public enterprises: a case study of the Greek railway organisation. International Journal of Transport Economics/Rivista internazionale di economia dei trasporti, 283-306.

Loizides, J., Tsionas, E.G. (2002). Productivity growth in European railways: a new approach. Transportation Research Part A: Policy and Practice, 36(7), 633-644.

López, F.J.R., Cacheda, J.M.C. (2018). An approximation to technical efficiency in Spanish toll roads through a DEA approach. Transportation research procedia, 33, 386-393.

Mallikarjun, S. (2014). Efficiency of US airlines: A strategic operating model. Journal of Air Transport Management, 43, 46-56.

Manuela Jr., W.S., Rhoades, D.L., Curtis, T. (2016). The U.S. airways group: a post-merger analysis. J. Air Transport. Manag., 56, 138-150.

Marchetti, D., Wanke, P. (2017). Brazil's rail freight transport: Efficiency analysis using two-stage DEA and cluster-driven public policies. Socio--Economic Planning Sciences, 59, 26-42.

Margari, B., Erbetta, F., Petraglia, C., Piacenza, M. (2007). Regulatory and environmental effects on public transit efficiency: a mixed DEA-SFA approach. Journal of Regulatory Economics 32(2):131–151.

Maroto, A., Zofío, J.L. (2016). Accessibility gains and road transport infrastructure in Spain: A productivity approach based on the Malmquist index. Journal of Transport Geography, 52, 143-152.

Martín, J.C., Roman, C. (2001). An application of DEA to measure the efficiency of Spanish airports prior to privatization. Journal of Air Transport Management, 7(3), 149-157.

Martynova, M., Renneboog, L. (2008). A century of corporate takeovers: what have we learned and where do we stand? J. Bank. Financ. 32, 2148–2177.

Mathieu, G. (2003). The reform of UK railways--privatization and its results. Japan Railway & Transport Review, (34).

McCartney, S., Stittle, J. (2008). "Taken for a Ride": The Privatization of the UK Railway Rolling Stock Industry. Public Money and Management, 28(2), 93-100.

Megginson, W.L., Netter, J.M. (2001). From state to market: A survey of empirical studies on privatization. Journal of economic literature, 39(2), 321-389.

Melo, P.C., Graham, D.J., Brage-Ardao, R. (2013). The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. Regional Science and Urban Economics, 43, 695-706.

Mendiluce, M., Schipper, L. (2011). Trends in passenger transport and freight energy use in Spain. Energy Policy, 39(10), 6466-6475.

Michaelides, P.G., Belegri-Roboli, A., Marinos, T. (2009). International air transportation carriers: evidence from SFA and DEA technical efficiency results (1991-2000). European Journal of Transport and Infrastructure Research, 9(4), 347-362.

Mink, M., de Haan, J. (2013). Contagion during the Greek sovereign debt crisis. Journal of International Money and Finance, 34, 102-113.

Mizutani, F., Nakamura, K. (1996). Effects of Japan national railways' privatization on labor productivity. Papers in Regional Science, 75(2), 177-199.

Mohring, H. (1972). Optimization and scale economies in urban bus transportation. The American Economic Review, 62(4), 591-604.

Moran, P. A. P., 1950. Notes on Continuous Stochastic Phenomena. Biometrika, 37(1/2), pp. 17-23.

Morrison, J.M., Dumple, P.L., Wigan, M.R. (1979). Accessibility indicators for transport planning. Transportation Research Part A, 13A(2), 91–109.

Musgrave, R.A. (1959). The theory of public finance: a study in public economy. New York: McHraw-Hill.

Musgrave, R.A. (1969). Provision for social goods. In: Margolis J., Guitton H. (eds) Public economics. London: Palgrave MacMillan, pp. 124-144.

Mwangi, F.K. (2013). The effect of macroeconomic variables on financial performance of aviation industry in Kenya (Doctoral dissertation, University of Nairobi).

Nasreen, S., Saidi, S., Ozturk, I. (2018). Assessing links between energy consumption, freight transport, and economic growth: evidence from dynamic simultaneous equation models. Environmental Science and Pollution Research, 25(17), 16825-16841.

Nguyen, H.O., Nguyen, H.V., Chang, Y.T., Chin, A.T., Tongzon, J. (2016). Measuring port efficiency using bootstrapped DEA: the case of Vietnamese ports. Maritime Policy & Management, 43(5), 644-659.

Nicholls, S. (2001). Measuring the accessibility and equity of public parks: A case study using GIS. Managing Leisure, 6(4), 201–219.

Nolan, J.F. (1996). Determinants of productive efficiency in urban transit. Logistics and Transportation Review, 32(3), 319.

Nolan, J.F., Ritchie, P.C., Rowcroft, J.E. (2002). Identifying and measuring public policy goals: ISTEA and the US bus transit industry. Journal of Economic Behavior & Organization, 48(3), 291-304.

Nollet, Â.C., Thiry, B., Tulkens, H. (1988). Mesure de l'efficacité productive: applications a la société de transports intercommunaux de Bruxelles. In B.Thirty and H.Tulkens (eds) La Performance Economique des Sociétés Belges de Transport Urbains (Charlerloi: CIRIEC), pp. 137-170.

Nordhaus, W.D. (2002). The mildest recession: Output, profits, and stock prices as the US emerges from the 2001 recession (No. w8938). National Bureau of Economic Research.

North, D. C., 1955. Location Theory and Regional Economic Growth. Journal of Political Economy, 63(3), pp. 243-258.

Obeng, K. (1994). The economic cost of subsidy-induced technical inefficiency. International Journal of Transport Economics/Rivista internazionale di economia dei trasporti, 3-20.

Ochieng, M.D., Ahmed, A.H. (2014). The effects of privatization on the financial performance of Kenya Airways. International Journal of Business and Commerce, 3(5), 10-26.

Odeck, J. (2003). Ownership, scale effects and efficiency of Norwegian bus operators: empirical evidence. International Journal of Transport Economics/ Rivista internazionale di economia dei trasporti, 30(3), 305-325.

Odeck, J. (2006). Identifying traffic safety best practice: an application of DEA and Malmquist indices. Omega, 34(1), 28-40.

Odeck, J. (2008). How efficient and productive are road toll companies?: Evidence from Norway. Transport Policy, 15(4), 232-241.

Odeck, J. (2008a). The effect of mergers on efficiency and productivity of public transport services. Transport Research, Part A 42(4), 696–708.

Odeck, J. (2008b). The effect of mergers on efficiency and productivity of public transport services Transport. Res. Part A Policy & Practice, 42 (4), 696-708.

Odeck, J., Alkadi, A. (2003) The performance of subsidized urban and rural public bus operators: empirical evidence from Norway. The Annals of Regional Science 38(3), 413–431.

Odeck., J., Alkadi, A. (2001). Evaluating efficiency in the Norwegian bus industry using data envelopment analysis. Transportation, 28, 211–232.

Örkcü, H.H., Balıkçı, C., Dogan, M.I., Genç, A. (2016). An evaluation of the operational efficiency of Turkish airports using data envelopment analysis and the Malmquist productivity index: 2009–2014 case. Transport Policy, 48, 92-104.

Ottoz, E., Fornengo, G., Di Giacomo, M. (2009). The impact of ownership on the cost of bus service provision: an example from Italy. Applied Economics, 41(3), 337-349.

Oum, T.H., Pathomsiri, S., Yoshida, Y. (2013). Limitations of DEA-based approach and alternative methods in the measurement and comparison of social efficiency across firms in different transport modes: An empirical study in Japan. Transportation Research Part E: Logistics and Transportation Review, 57, 16-26.

Ozbek, M., de la Garza, J., Triantis, K. (2010). Data and modeling issues faced during the efficiency measurement of road maintenance using data envelopment analysis. Journal of Infrastructure Systems, 16(1), 21–30.

Pereira, A. M. & Pereira, R. M., 2015. Infrastructures Investment in Portugal. Lisboa: Fundação Francisco Manuel dos Santos.

Pereira, A.M., Andraz, J.M. (2005). Public investment in transportation infrastructure and economic performance in Portugal. Review of Development Economics, 9(2), 177-196.

Pereira, A.M., Pereira, R.M. (2017). Infrastructure Investment, Labor Productivity, and International Competitiveness: The Case of Portugal (No. 0071). Gabinete de Estratégia e Estudos, Ministério da Economia.

Pereira, P.T., Wemans, L. (2015). Portugal and the global financial crisis: short-sighted politics, deteriorating public finances and the bailout imperative. In The Global Financial Crisis and its Budget Impacts in OECD Nations. Edward Elgar Publishing.

Pereira, R., Pereira, A., Hausman, W.J. (2017). Rail road infrastructure investments and economic development in the antebellum United states. Journal of Economic Development, 42(3), 1-16.

Piacenza, M. (2006). Regulatory contracts and cost efficiency: Stochastic frontier evidence from the Italian local public transport. Journal of Productivity Analysis, 25(3), 257-277.

Pina, V., Torres, L. (2001). Analysis of the efficiency of local government services delivery: an application to urban public transport. Transport Research, Part A 35(10), 929–944.

Pina, V., Torres, L. (2001). Analysis of the efficiency of local government services delivery. An application to urban public transport. Transportation Research Part A: Policy and Practice, 35(10), 929-944.

Plakandaras, V., Papadimitriou, T., Gogas, P. (2019). Forecasting transportation demand for the US market. Transportation Research Part A: Policy and Practice, 126, 195-214.

Pollitt, M. G., Smith, A. S. (2002). The restructuring and privatisation of British Rail: was it really that bad? Fiscal Studies, 23(4), 463-502.

Porter, M. E., 2000. Location, Competition, and Economic Development: Local Clusters in a Global Economy. Economic Development Quarterly, 14(1), pp. 15-34.

Redman, L., Friman, M., Gärling, T., Hartig, T. (2013). Quality attributes of public transport that attract car users: A research review. Transport policy, 25, 119-127.

Reis, R. (2015). Looking for a success in the euro crisis adjustment programs: the case of Portugal. Brookings Papers on Economic Activity, 2015(2), 433-458.

Reis, R. (2017). QE in the future: the central bank's balance sheet in a fiscal crisis. IMF Economic Review, 65(1), 71-112.

Reis, R.F., Sarmento, J.M. (2019). "Cutting costs to the bone": the Portuguese experience in renegotiating public private partnerships highways during the financial crisis. Transportation, 46(1), 285-302.

Rice, P., Venables, A.J., Patacchini, E. (2006). Spatial determinants of productivity: Analysis for the regions of Great Britain. Regional Science and Urban Economics 36, 727–752.

Rouse, P., Chiu, T. (2009). Towards optimal life cycle management in a road maintenance setting using DEA. European Journal of Operational Research, 196(2), 672-681.

Roy, W., Yvrande-Billon, A. (2007). Ownership, contractual practices and technical efficiency: The case of urban public transport in France. Journal of Transport Economics and Policy (JTEP), 41(2), 257-282.

Sampaio, B.R., Neto, O.L., Sampaio, Y. (2008). Efficiency analysis of public transport systems: lessons for institutional planning. Transport Research, Part A, Policy Practice 42(3), 445–454.

Samuelson, P.A. (2010). Economics. Tata McGraw-Hill Education.

Sarmento, J., Renneboog, L., Matos, P.V. (2017). Measuring highway efficiency by a DEA approach and the Malmquist index. European Journal of Transport and Infrastructure Research, 17(4), 530-551.

Sarmento, J.M. (2018). Public Finance and National Accounts in the European Context. Springer International Publishing.

Sarmento, J.M., Renneboog, L. (2015). Portugal's experience with Public Private Partnerships. Public private partnerships: A global review, 266.

Saxena P., Saxena, R.R. (2011). Measuring efficiencies in Indian public road transit: a data envelopment analysis approach. Opsearch, 47(3), 195–204.

Schefczyk, M. (1993). Operational performance of airlines: an extension of traditional measurement paradigms. Strategic Management Journal, 14(4), 301-317.

Scheraga, C.A. (2004). Operational efficiency versus financial mobility in the global airline industry: a data envelopment and Tobit analysis. Transportation Research Part A: Policy and Practice, 38(5), 383-404.

Sean, A. (1993). Markets and freedom: Achievements and limitations of the market mechanism in promoting individual freedoms. Oxford Economic Papers, 45(4), 519-541.

Sengupta, J.K. (1999). A dynamic efficiency model using data envelopment analysis. International Journal of Production Economics, 62(3), 209-218.

Sentence, A. (2009). Developing transport infrastructure for the Low Carbon Society. Oxford Review of Economic Policy, 25(3), 391–410.

Sheth, C., Triantis, K., Teodorovic, D. (2007). Performance evaluation of bus routes: a provider and passenger perspective. Transport Research, Part E: Logistic Transport Review 43(4), 453–478.

Shi, F.X., Lim, S.H., Chi, J. (2011). Railroad productivity analysis: case of the American Class I railroads. International Journal of Productivity and Performance Management, 60(4), 372-386.

Shires, J.D., Preston, J.M., Nash, C.A., Wardman, M. (1994) Rail Privatisation: The Economic Theory.Discussion Paper. Institute of Transport Studies, University of Leeds, Leeds, UK.

Siabato, W., Guzmán-Manrique, J. (2019). Spatial autocorrelation and the development of quantitative geography. Cuadernos de Geografía: Revista Colombiana de Geografía, 28(1), 1-22.

Simões do Paço, A., Varela, R. (2015). The "Memorandum of Understanding" in Portugal and the Portuguese Left. Socialism and Democracy, 29(3), 104-114.

Smith, A.S. (2006). Are Britain's railways costing too much? Perspectives based on TFP comparisons with British Rail 1963–2002. Journal of Transport Economics and Policy (JTEP), 40(1), 1-44.

Stehmann, O., Zenger, H. (2011). The competitive effects of rail freight mergers in the context of European liberalization. J. Compét. Law Econ., 7(2), 455–479.

Sullivan, D. O., Morrison, A., Shearer, J. (2000). Using desktop GIS for the investigation of accessibility by public transport : an isochrone approach. Geographical Information Science, 14(1), 85–104.

Sun, H.L., Tang, A.P. (2000). The sources of railroad merger gains: Evidence from stock price reaction and operating performance. Transp. J., 39(4), 14–26.

Sweet, R.J. (1997). An aggregate measure of travel utility. Transportation Research Part B: Methodological, 31(5), 403-416.

Thompson, L. (2003). Changing railway structure and ownership: is anything working? Transport Reviews, 23(3), 311-355.

Tillman, R. (1997) Shadow tolls and public–private partnerships for transportation projects. The Journal of Structured Finance, 3, 30–37.

Tofallis, C. (1997). Input efficiency profiling: an application to airlines. Computers & Operations Research, 24(3), 253-258.

Tone, K., Sawada, T. (1990). An efficiency analysis of public vs. private bus transportation enterprises. Operational research, 90, 357-365.

Tovar, B., Wall, A. (2015). Can ports increase traffic while reducing inputs? Technical efficiency of Spanish Port Authorities using a directional distance function approach. Transportation Research Part A: Policy and Practice, 71, 128-140.

Tulkens, H. (2006). On FDH efficiency analysis: some methodological issues and applications to retail banking, courts and urban transit. In Public goods, environmental externalities and fiscal competition (pp. 311-342).Boston, MA: Springer.

Tulkens, H., Eeckaut, P.V. (1995). Non-frontier measures of efficiency, progress and regress for time series data. International Journal of Production Economics, 39, 83-97.

Tulkens, H., Thiry, B., Palm, A. (1988). Mesure de l'efficacité productive: methodologies et applications aux sociétés de transports intercommunaux de Liége, Charleroi et Verviers. In B.Thiry and H.Tulkens (eds), La Performace Economique des Sociétés Belges de Transport Urbains (Cherlerloi:CIRIEC), pp.81-136.

Tulkens, H., Wunsch, P. (1994). Les performances économiques de la STIB au mois le mois.Revue Suisse d'Économie Politique et de Statistique, 130, 627-646.

Venkatesh, A., Kushwaha, S. (2018). Short and long-run cost efficiency in Indian public bus companies using Data Envelopment Analysis. Socio--Economic Planning Sciences, 61, 29-36.

Vickers, J., Yarrow, G.K. (1988). Privatization: An economic analysis (Vol. 18). MIT press.

Viton, P.A. (1997). Technical efficiency in multi-mode bus transit: A production frontier analysis. Transportation Research Part B: Methodological, 31(1), 23-39.

Viton, P.A. (1998). Changes in multi-mode bus transit efficiency, 1988–1992. Transportation, 25(1), 1-21.

Von Hirschhausen, C., Cullmann, A. (2010). A nonparametric efficiency analysis of German public transport companies. Transport Research, Part E, Logist Transp Rev, 46(3), 436–445.

Wang, L.C., Tsai, H.Y. (2009). Evaluation of highway maintenance performance using Data Envelopment Analysis (DEA) in Taiwan. Journal of Marine Science and Technology, 17(2), 145-155.

Wang, L.F., Chen, T.L. (2010). Do cost efficiency gap and foreign competitors matter concerning optimal privatization policy at the free entry market? Journal of Economics, 100(1), 33-49.

Wanke, P., Barros, C.P., Nwaogbe, O.R. (2016). Assessing productive efficiency in Nigerian airports using Fuzzy-DEA. Transport Policy, 49, 9-19.

Wanke, P.F. (2012). Efficiency of Brazil's airports: Evidences from bootstrapped DEA and FDH estimates. Journal of Air Transport Management, 23, 47-53.

Wanke, P.F. (2013). Physical infrastructure and flight consolidation efficiency drivers in Brazilian airports: A two-stage network-DEA approach. Journal of Air Transport Management, 31, 1-5.

Weber, J. (2003). Individual accessibility and distance from major employment centers: An examination using space-time measures. Journal of Geographical Systems, 5(1), 51–70.

Welde, M., Odeck, J. (2011). The efficiency of Norwegian road toll companies. Utilities Policy, 19(3), 162–171.

Wilson, A.G. (1971). A family of spatial interaction models, and associated developments, Environment and Planning, 3, 1-21.

Winston, C., Maheshri, V., Dennis, S.M. (2011). Long-run effects of mergers: the case of US western railroads. J. Law Econ. 54(2), 275–304.

Winston, C., Shirley, C. (2010). Alternate route: Toward efficient urban transportation. Brookings Institution Press.

Wunsch, P. (1994). Costing busses: back to the basics. Brussels: FUSL (SMASH Cahier 9405).

Yan, J., Xiaowen, F.U., Oum, T.H., Wang, K. (2019). Airline horizontal mergers and productivity: empirical evidence from a quasi-natural experiment in China. Int. J. Ind. Organ., 62, 358-376.

Yu, H., Zhang, Y., Zhang, A., Wang, K., Cui, Q. (2019). A comparative study of airline efficiency in China and India: A dynamic network DEA approach. Research in Transportation Economics, 76, 100746.

Yu, M.M. (2008). Assessing the technical efficiency, service effectiveness, and technical effectiveness of the world's railways through NDEA analysis. Transportation Research Part A: Policy and Practice, 42(10), 1283-1294.

Yu, M.M., Fan, C.K. (2009). Measuring the performance of multimode bus transit: a mixed structure network DEA model. Transport Research, Part E: Logistic Transport Review 45(3), 501–515.

Yu, M.M., Lin, E.T. (2008). Efficiency and effectiveness in railway performance using a multi-activity network DEA model. Omega, 36(6), 1005-1017.

Yuen, A.C.L., Zhang, A., Cheung, W. (2013). Foreign participation and competition: A way to improve the container port efficiency in China? Transportation Research Part A: Policy and Practice, 49, 220-231.

Zegras, C., Srinivasan, S. (2007). Household Income, Travel Behavior, Location and Accessibility: Sketches from Two Different Developing Context. Transportation Research Record, 2038(1), 128–138.

Notes

< **1.** The efficiency evaluation was carried out using the DEA SolverPro™ software developed by SAITECH.

< **2.** Available at link.

< **3.** The generalized cost of transport corresponds to the sum of all monetary and non-monetary costs associated with a certain journey from A to B. It can be expressed though the following formula:

$g = \sum_i m_i + \sum_j n_j$,

where m_i are the various monetary costs (fuel, insurance, maintenance, etc.) and nj are the non-monetary costs (e.g., time, CO_2 emissions, noise, etc.). See more in Bruzelius (1981) or Button (2010).

< **4.** Based on the indicators developed by Infraestruturas de Portugal. We have calculated, for each year and municipality, the corresponding value, using a GIS based analysis, with the physical network evolution. These were later aggregated into NUTS 3, for the purpose of the productivity analysis.

< **5.** The current Nomenclature of Territorial Units for Statistics 2016 classification (NUTS 2016) is valid from 1 January 2018 until 1 January 2021 among European member states and lists NUTS 1, NUTS 2 and NUTS 3. NUTS 3 are usually used within small regions for specific diagnoses. In Portugal, the last changes took place in 2013.

< **6.** The first would be to verify the stationarity of the time series, thus verifying that the statistical properties of a process generating a time series does not change over time. This is important since several time series models are based on the assumption of stationarity. In order to assess the stationarity of our time series, we have conducted Augmented Dickey-Fuller (ADF) tests. The next step would be to verify causality between processes, which we have conducted using Granger-causality tests. The last step to verify consists of the cointegration of time series, ensuring the statistical strength of their relationship and the yield of non-spurious results from our regressions (Granger & Newbold, 1974).

< **7.** A high Pearson correlation is an indicator of the relation between pairs of variables.

< **8.** The LISA procedure enables the creation of a local spatial statistic, one for each location, a comparison between it and the global statistic. The sum of LISA is proportional to a corresponding global statistic.

< **9.** Therefore, there are as many statistics as original observations.

< **10.** We formulated two hypotheses to be tested:

1. The influence of productivity in neighbouring regions decays linearly with distance.
2. The influence of productivity in neighbouring regions decays quadratically with distance.

In order to test these hypotheses, we had followed a set of assumptions:

- If the value of *linear_reg* converges to a single number, the relationship between *prod_apar* in a given region and its neighbours is linear;
- If th e value of *quadratic_reg* converges to a single number, the relationship between *prod_apar* in a given region and its neighbours is quadratic;
- We can use the coefficient of variance (CoV) as a measure of "convergence" for the value;
- The smaller the CoV, the better the region is described by the linear/quadratic relationship;
- NUTS with smaller CoV for *linear_reg* are better described by a linear relationship and hence the proximity matrix should be calculated as $\frac{1}{d_{ij}}$
- NUTS with smaller CoV for *quadratic_reg* are better described by a quadratic relationship and hence the proximity matrix should be calculated as $\frac{1}{d_{ij}^2}$

< **11.** If a variable, or group of variables (x) is found to be helpful for predicting another variable, or group of variables, y then x is said to Granger-cause y; otherwise, it is said to fail to Granger-cause y (Granger, 1969; Blanchard & Perotti, 2002). Granger's causality tests the null hypothesis that the coefficients of past values in the regression equation is zero.

Index of figures

Index of tables

Research Team

CRUZ, Carlos Oliveira
(Instituto Superior Técnico)
Associate Professor with Habilitation at Instituto Superior Técnico and Invited Professor at the Getúlio Vargas Foundation (Rio de Janeiro). Researcher at CERIS – Civil Engineering Research and Innovation for Sustainability.

COSTA, Álvaro
(Faculdade de Engenharia da Universidade do Porto)
Associate Professor with Habilitation at the Faculty of Engineering, University of Porto. CEO of TRENMO. Researcher at CITTA – Research Centre for Territory, Transport and Environment.

SARMENTO, Joaquim Miranda
(Instituto Superior de Economia e Gestão)
Assistant Professor with Habilitation at the ISEG – Lisbon School of Economics and Management. Invited Professor at the Getúlio Vargas Foundation (Rio de Janeiro). Researcher at ADVANCE.

SOUSA, Vítor Faria e
(Instituto Superior Técnico)
Assistant Professor at Instituto Superior Técnico. Researcher at CERIS – Civil Engineering Research and Innovation for Sustainability.

JANUÁRIO, João Fragoso
(Instituto Superior Técnico)
PhD student at Instituto Superior Técnico. Researcher at CERIS – Civil Engineering Research and Innovation for Sustainability.

Published studies

Economics

O Cadastro e a Propriedade Rústica em Portugal
Coordenado por Rodrigo Sarmento de Beires; 2013.

Custos e Preços na Saúde: Passado, presente e futuro
Coordenado por Carlos Costa; 2013.

25 anos de Portugal Europeu: A economia, a sociedade e os fundos estruturais
Coordenado por Augusto Mateus; 2013.

Que economia queremos?
Coordenado por João Ferrão; 2014.

A Economia do Futuro: A visão de cidadãos, empresários e autarcas
Coordenado por João Ferrão; 2014.

Três Décadas de Portugal Europeu: Balanço e perspectivas
Coordenado por Augusto Mateus; 2015.

Empresas Privadas e Municípios: Dinâmicas e desempenhos
Coordenado por José Tavares; 2016.

Investimento em Infra-Estruturas em Portugal
Coordenado por Alfredo Marvão Pereira; 2016.

Benefícios do Ensino Superior
Coordenado por Hugo Figueiredo e Miguel Portela; 2017.

Diversificação e Crescimento da Economia Portuguesa
Coordenado por Leonor Sopas; 2018.

Dinâmica Empresarial e Desigualdade
Coordenado por Rui Baptista; 2018.

Encerramento de Multinacionais: O capital que fica
Coordenado por Pedro de Faria; 2018.

GDP-linked bonds in the Portuguese Economy
Coordenado por Gonçalo Pina, 2020.

Features of Portuguese International Trade: a Firm-level Perspective
Coordenado por João Amador; 2020.

Financial Constraints and Business Dynamics: Lessons from the 2008--2013 Recession
Coordenado por Carlos Carreira, Paulino Teixeira, Ernesto Nieto--Carrillo e João Eira; 2021.

Transport systems in Portugal Analysis of efficiency and regional impact
Carlos Oliveira Cruz, Álvaro Costa, Joaquim Miranda Sarmento, Vítor Faria e Sousa e João Fragoso Januário, 2021.

Institutions

Droga e Propinas: Avaliações de impacto legislativo
Coordenado por Ricardo Gonçalves; 2012.

Justiça Económica em Portugal: A citação do réu no processo civil
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Justiça Económica em Portugal: Factos e números
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Justiça Económica em Portugal: Gestão processual e oralidade
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Justiça Económica em Portugal: Meios de resolução alternativa de litígios
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Justiça Económica em Portugal: Novo modelo processual
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Justiça Económica em Portugal: O sistema judiciário
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Justiça Económica em Portugal: Produção de prova
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Justiça Económica em Portugal: Recuperação do IVA
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Justiça Económica em Portugal: Síntese e propostas
Coordenado por Mariana França Gouveia, Nuno Garoupa, Pedro Magalhães; 2012.

Segredo de Justiça
Coordenado por Fernando Gascón Inchausti; 2013.

Feitura das Leis: Portugal e a Europa
Coordenado por João Caupers, Marta Tavares de Almeida e Pierre Guibentif; 2014.

Portugal nas Decisões Europeias
Coordenado por Alexander Trechsel, Richard Rose; 2014.

Valores, Qualidade Institucional e Desenvolvimento em Portugal
Coordenado por Alejandro Portes e M. Margarida Marques; 2015.

O Ministério Público na Europa
Coordenado por José Martín Pastor, Pedro Garcia Marques e Luís Eloy Azevedo; 2015.

Juízes na Europa: Formação, selecção, promoção e avaliação
Coordenado por Carlos Gómez Ligüerre; 2015.

Limitação de Mandatos: O impacto nas finanças locais e na participação eleitoral
Coordenado por Francisco Veiga e Linda Veiga; 2017.

O Estado por Dentro: Uma etnografia do poder e da administração pública em Portugal
Coordenado por Daniel Seabra Lopes; 2017.

O Impacto Económico dos Fundos Europeus: A experiência dos municípios portugueses
Coordenado por José Tavares; 2017.

Orçamento, Economia e Democracia: Uma proposta de arquitetura institucional
Coordenado por Abel M. Mateus; 2018.

Instituições e Qualidade da Democracia: Cultura política na Europa do Sul
Coordenado por Tiago Fernandes; 2019.

Os Tribunais e a Crise Económica e Financeira: Uma análise ao processo decisório em contexto de crise económico-financeira
Patrícia André, Teresa Violante e Maria Inês Gameiro; 2019.

Society

Como se aprende a ler?
Coordenado por Isabel Leite; 2010.

Fazer contas ensina a pensar?
Coordenado por António Bivar; 2010.

Desigualdade Económica em Portugal
Coordenado por Carlos Farinha Rodrigues; 2012.

Projecções 2030 e o Futuro
Coordenado por Maria Filomena Mendes e Maria João Valente Rosa; 2012.

Envelhecimento Activo em Portugal: Trabalho, reforma, lazer e redes sociais
Coordenado por Manuel Villaverde Cabral; 2013.

Escolas para o Século XXI: Liberdade e autonomia na educação
Coordenado por Alexandre Homem Cristo; 2013.

Informação e Saúde
Coordenado por Rita Espanha; 2013.

Literatura e Ensino do Português
Coordenado por José Cardoso Bernardes e Rui Afonso Mateus; 2013.

Processos de Envelhecimento em Portugal: Usos do tempo, redes sociais e condições de vida
Coordenado por Manuel Villaverde Cabral; 2013.

Que ciência se aprende na escola?
Coordenado por Margarida Afonso; 2013.

Inquérito à Fecundidade 2013
INE e FFMS; 2014.

A Ciência na Educação Pré-Escolar
Coordenado por Maria Lúcia Santos, Maria Filomena Gaspar, Sofia Saraiva Santos; 2014.

Dinâmicas Demográficas e Envelhecimento da População Portuguesa (1950–2011): Evolução e perspectivas
Coordenado por Mário Leston Bandeira; 2014.

Ensino da Leitura no 1.º Ciclo do Ensino Básico: Crenças, conhecimentos e formação dos professores
Coordenado por João A. Lopes; 2014.

Ciência e Tecnologia em Portugal: Métricas e impacto (1995–2012)
Coordenado por Armando Vieira e Carlos Fiolhais; 2014.

Mortalidade Infantil em Portugal: Evolução dos indicadores e factores associados de 1988 a 2008
Coordenado por Xavier Barreto e José Pedro Correia; 2014.

Os Tempos na Escola: Estudo comparativo da carga horária em Portugal e noutros países
Coordenado por Maria Isabel Festas; 2014.

Cultura Científica em Portugal
Coordenado por António Granado e José Vítor Malheiros; 2015.

O Multimédia no Ensino das Ciências
Coordenado por João Paiva; 2015.

O Quinto Compromisso: Desenvolvimento de um sistema de garantia de desempenho educativo em Portugal
Coordenado por Margaret E. Raymond; 2015.

Desigualdade do Rendimento e Pobreza em Portugal: As consequências sociais do programa de ajustamento
Coordenado por Carlos Farinha Rodrigues; 2016.

Determinantes da Fecundidade em Portugal
Coordenado por Maria Filomena Mendes; 2016.

Será a repetição de ano benéfica para os alunos?
Coordenado por Luís Catela Nunes; 2016.

Justiça entre Gerações: Perspectivas interdisciplinares
Coordenado por Jorge Pereira da Silva e Gonçalo Almeida Ribeiro; 2017.

Migrações e Sustentabilidade Demográfica: Perspectivas de evolução da sociedade e economia portuguesas
Coordenado por João Peixoto; 2017.

Mobilidade Social em Portugal
Coordenado por Teresa Bago d'Uva; 2017.

Porque melhoraram os resultados do PISA em Portugal? Estudo longitudinal e comparado (2000–2015)
Coordenado por Anália Torres; 2018.

Igualdade de Género ao Longo da Vida: Portugal no contexto europeu
Coordenado por Anália Torres; 2018.

As mulheres em Portugal, Hoje: Quem são, o que pensam e como se sentem
Coordenado por Laura Sagnier e Alex Morell; 2019.

Financial and Social Sustainability of the Portuguese Pension System
Coordenado por Amílcar Moreira; 2019.

Identidades Religiosas e Dinâmica Social na Área Metropolitana de Lisboa
Coordenado por Alfredo Teixeira; 2019.

A evolução da ciência em Portugal (1987-2016)
Elizabeth Vieira, João Mesquita, Jorge Silva, Raquel Vasconcelos, Joana Torres, Sylwia Bugla, Fernando Silva, Ester Serrão e Nuno Ferrand; 2019.

A pobreza em Portugal: Trajetos e quotidianos
Coordenado por Fernando Diogo, 2021.

FUNDAÇÃO
FRANCISCO MANUEL DOS SANTOS