Decomposing generalized transport costs using index numbers: A geographical analysis of the economic and infrastructure fundamentals

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Abstract

We rely on the economic theory approach to index numbers to improve the existing definitions and decompositions of generalized transport costs, GTCs, and obtain a better understanding of their economic and infrastructure determinants. Using this approach we accurately measure the contribution that the variation of the operating costs and the accessibility variables make to GTC reductions, and discuss to what extent transportation policy in terms of market competition and infrastructure investments have been successful in reducing GTCs. To implement the optimizing behavior of transportations firms when choosing minimum cost itineraries we elaborate a new economic database on freight road transportation at a very detailed provincial level, which is embedded into a GIS presenting the digitalized road networks corresponding to five years intervals between 1980 and 2007. Average GTCs weighted by trade flows have reduced by –16.3% in Spain, with infrastructure policy leading the way with remarkable accessibility improvements in terms of lower times and distances. The contribution of infrastructure doubles that of economic cost, whose trends is mainly driven by technological and market determinants rather than specific competition and regulatory policies promoted by the administrations. We find large territorial disparities in GTCs levels and variations, but also significant clusters where the market and network effects reducing GTCs present relevant and diverse degrees of spatial association. We finally conclude that after three decades of active transportation policy, mainly aimed at intensifying investment in road infrastructure, there has been a significant increase in territorial cohesion in terms of GTCs and their components.

KEYWORDS: Generalized Transport Costs, Index number theory, Infrastructure, GIS, Territorial cohesion.

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1. Introduction

The importance of accessibility from a locational perspective both for firms and individuals is paramount. This is particularly true for macro geographical analyses relating the distribution and specialization of economic activity across space and their associated volumes of trade. Both locational and trade patterns are highly influenced by transport costs, which constitute a prime measure of accessibility to markets. Even if the importance of transport costs has been steadily declining in the past decades (Gleaser and Koolhase, 2003), the world is still quite away from being flat. Given their importance, many studies have been devoted to accurately define and measure transport costs and their determinants. Considering different transportation modes and freight cargo, we can highlight several studies measuring transportation costs: Combes and Lafourcade (2005) for the case of road transportation, Ivaldi and McCullough (2007) in train haulage, Hummels *et al.* (2007) in air delivery, and Tolofari (1986) and Hummels (2007) in maritime shipping. From a cross-section static definition, the cost engineering and accounting methodology followed by these studies is thoughtfully and competently executed—see World Bank (2009) for a summary of these studies. However, when it comes to characterize their evolution time, the approach that they should follow, based on a producer price index framework consistent with economic theory, is completely disregarded. It is like if authors interested in these issues did not want to push forward their cross-section static efforts, when projecting them in time so as to reach the expected definitions, measures and calculations within a standard index number analytical framework.

The consequences of this rather loose attitude towards the modeling of the changes in transport costs are severe: (i) studies on the same transportation mode carried out by researchers on different time and countries are not comparable because their methodological approaches are diverse, (ii) the influence of scholarly work on national statistical agencies so they would adopt a standard methodology to compile and provide price index series on transport costs on a regular basis is limited, and (iii) the lack of time-series information hampers long term evaluations of economic and infrastructure policies and the definition of guidelines associated to their strategic planning. In this context, the first contribution of this study is theoretical, and related to the improvement of the existing methodology to accurately measure the change in transport costs over time within an index number framework and, by doing this, provide a consistent decomposition of these changes that allows us to precisely determine the effects that both economic and infrastructure determinants have on transport cost variations. We accomplish this goal by adopting Fisher's (1922) formulation for each one of the price and quantity indices in which the variation of GTCs decompose. Particularly, for the price index we rely on the (normally unobservable) price aggregate corresponding to the Konüs (1924) true cost of producing index, which can be consistently used to recover its associated implicit quantity index by way of the product rule. Also we adopt a chained version of the index that allow us to calculate the cumulated change of the indices between the base period and the last year of our study, and to obtain consistent decompositions of this time series into several subperiods.

It is now accepted that a transport cost measure must meet several criteria so as to prove useful for analysis. It should be based on information reflecting the specific itinerary, the transport mode, and the nature of the commodity being transported. A measure satisfying these requirements represents a generalized transportation cost, GTC, which defines as the minimum cost of transporting a given load of a particular commodity between an specific origin and a destination, considering the economic variables related to the inputs costs necessary to produce the transportation service (*e.g.*, labor and capital costs) and the physical features of the available transport infrastructure (*e.g.*, network topology). Because the measure depends on all these elements it can be decomposed so as to identify its different economic and infrastructure determinants. As a result generalized transport cost measurement is based on multiple information related to both market and geographical aspects, and it is the result of an aggregation process that combines these elements when reflecting the optimizing behavior of the economic agents, as it is the case for firms minimizing transport costs. Taking this into consideration, and from the empirical perspective, we consistently calculate the variation of GTCs for the case of freight road transportation in Spain between 1980 and 2007, and using the proposed index number methodology, decompose it into price (economic) and quantity (infrastructure) components. Therefore, the second main contribution of this study is the calculation of the true cost of producing index and its associated quantity index. Our measurement of GTCs variations and their sources represents the first application in the transportation literature to consistently apply index number theory to calculate the true change in the cost of producing a transportation service. By doing so we avoid theoretical and measurement biases that may have relevant implications when results are normatively used to propose policy guidelines with respect to market regulation and infrastructure policy. Moreover, our empirical application goes beyond the specificity of transportation studies, since from the perspective of the index number literature we believe it is the first time that the assumption of an optimizing behavior on the part of economic agents is actually implemented to calculate Konüs indices from a producer perspective.

Finally, we choose the road transportation industry to illustrate our methodology because: (i) this mode represented about 70% of all ton-kms transported in Spain in 2009—90% of all land transportation including road, railroad and pipeline, MFOM (2010); and (ii) the tools and data that allow determining minimum costs routes by way of geographical information systems (*e.g.*, Overman, 2010) are now available, and there are some previous studies to which we can refer and compare our results. Particularly, the empirical framework defining the GTCs in trucking transportation as presented by Combes and Lafourcade (2005) or Teixeira (2006), determining transport costs savings at the aggregate national level in France and Portugal, respectively; or Martínez-Zarzoso and Nowak-Lehmann (2006) with respect to the GTC determinants along specific trade routes joining Spain with Poland and Turkey. However, with respect to these contributions, we rely on a richer database both from an economic and road network perspective. From an economic perspective we have collected data for individual operating costs at a regional (NUTS 2) and, when available, provincial (NUTS 3) level (*e.g.*, labor and fuel costs which represent over 50% of the overall costs differ at the provincial level), allowing us to determine alternative economic costs structures for firms operating in different geographical areas. From a geographical perspective, the road network database includes features that are normally overlooked, such as the degree or steepness of the road sections that comprise the arcs, which influence several variables such as actual speed and fuel consumption. This detailed description of the economic and infrastructure data allows us to study the geographical patterns of the GTCs variations and their components.

The paper structures as follows. Section 2 presents the theoretical framework based on the economic theory of index numbers by defining the volume index corresponding the GTC variation and its decomposition into the Konüs cost of producing price index and its associated quantity indices, related to transport economic costs and network infrastructure, respectively. Data description, both for the economic and the infrastructure dimensions of the analysis is presented in section 3. Section 4 shows the empirical results of the calculation of the GTCs for the Spanish freight road transportation industry since 1980 onwards. Here we present the Konüs price and quantity indices and discuss the sources of GTCs decline. Using Moran's indicator and Anselin's local indicator we explore in section 5 the existence of significant geographical clusters where the variations of GTCs and its economic and infrastructure components exhibit relevant patterns of spatial association. In this section we also calculate several inequality measures to determine whether the steady decline in all the indices has been characterized by a convergence process, thereby reducing territorial disparities in terms GTCs, economic costs, and accessibility. Finally, section 6 concludes with relevant policy implications and final remarks.

2. Index number methods and generalized transport costs

2.1. Generalized, distance and time related transport costs

Nichols (1975) introduced the concept of generalized transport cost depending on distance and time as the key accessibility variables to which economic costs (unit prices) are associated, while Combes and Lafourcade (2005) provide its most comprehensive characterization for the case of freight road transportation.[1] Here we expand their notation so as to introduce the index number methodology and deRecalling the definition of note by $GTC_{ij}^{t,t}$ the generalized transport cost between an origin *i* and a destination *j* considering the economic costs and infrastructure existing in the period *t* (first and second superscripts, respectively), corresponding to the cheapest itinerary $I_{ij}^{t,t*}$ among the set of possible itineraries $\mathbf{I}_{ij}^{t}$, and considering both the distance and time accessibility variables.[2] The itineraries are comprised of different arcs *a*, with an associated set of physical attributes in period *t*, $\mathbf{x}_a^t$. The primary physical attributes of an arc are its distance, d_a^t, road type, r_a^t, and gradient (steepness), g_a^t. From the latter two the arc speed can be determined, s_a^t (representing the actual speed—e.g. in case of congestion or very steep roads—or maximum legal speed given the road type *r*), and from there we can determine the time it takes to cover it, $t_a^t = d_a^t / s_a^t$. As a result the physical characteristics of an arc are finally summarized by its associated distance and time variables: d_a^t and t_a^t.

in time *t*, denoted by e_k^t, *i.e.*, Euro per kilometer, include the following variables, $k = 1, \ldots, 5$:[3] (i) fuel costs: $fuel_i^t$, which are associated with each arc given its road type: r_a^t, gradient: g_a^t, and speed: s_a^t (fuel costs are computed multiplying the fuel price (Euro per liter) by the fuel consumption of its particular arc); (ii)toll costs: $toll_i^t$, that result from multiplying the unit cost (Euro cents/km) by the length of the arc d_a^t; (iii)accommodation and allowance costs:

[1] For a review of GTCs and other accessibility and market potential measures see Geurs (2001).

[2] The double superscript notation for the aggregate distance and time costs: $DistC_{ij}^{t,t}$ and $TimeC_{ij}^{t,t}$, as well as all for the optimal values solving the minimum cost routes, is consistently used throughout the text for reasons that will become apparent in what follows.

[3] Subscript *i* indicates that the reference cost is available for the particular region or province where the arc *a* locates.

accom&allow^t; (iv)tire costs: *tire*^{t}, and, (v) vehicle maintenance and repairing operating costs: *rep&mant*^{t}. Taking into account these operating costs, the total distance cost is:

$$DistC_{ij}^{t,t} = \sum_{a \in I_{ij}^t} \left(\sum_k e_k^t \right) d_a^t = \sum_{a \in I_{ij}^t} \left(fuel_{i,a(r,t)}^t + toll_{i,a(r=1,t)}^t + accom\,\&\,allow^t + tire^t + rep\&mant^t \right) d_a^t \,. \quad (1)$$

he economic unit costs (prices) associated to time: denoted by e_l^t, *e.g.*, Euro per hour, include the following l = 1,…,6 variables:labor cost associated with gross salaries: lab_i^t, including social security payments; (ii)financial costs associated to the amortization: *amort*^{t}, and (iii) of the vehicle: fin_i^t, assuming that it remains operative only for a certain number of hours/year (according to its technical characteristics and other institutional issues, for example, driving and resting times); (iv)insurance costs, *ins*^{t}; (v)taxes: tax_i^t (including central, regional—state, provincial—county, and municipal—city— government taxes), and, finally (vi) indirect costs: ind_i^t, associated to other administration overhead (offices and other technical equipment), operating expenses (administrative employment) and commercial costs (outsourcing activities and marketing).

Given the driving time for an arc: $t_a^t = d_a^t / s_a^t$, the time economic costs in period *t*, and the existing road infrastructure in *t*, the overall cost associated to travel the whole length of an itinerary is: [4]

$$\begin{aligned} TimeC_{ij}^{t,t} &= \left(\sum_l e_l^t \right) \left(\sum_{a \in \mathbf{I}_{ij}^t} t_a^t \right) = \left(\sum_l e_l^t \right) \left(\sum_{a \in I_{ij}^t} \frac{d_a^t}{s_a^t} \right) = \\ &= \left(lab_i^t + amort^t + fin^t + ins^t + tax_i^t + ind_i^t \right) \left(\sum_{a \in \mathbf{I}_{ij}^t} \frac{d_a^t}{s_a^t} \right). \end{aligned} \quad (2)$$

We assume that a transport firm minimizes the cost of producing the transportation service between the origin *i* and destination *j*, subject to the existing vehicle technology. This minimum cost corresponds to the solution of the following problem that finds the least cost route $I_{ij}^{t,t*}$ among the set of itineraries joining origin *i* with destination *j*: $\mathbf{I}_{ij}^t$:

[4] One could allow for time devoted to "load and unload" the truck, which can be generally considered as the time associated to the ancillary logistics associated to a given transportation service: t^t_{log}. This would be a comprehensive variable that would capture the improvements that take place in schedule optimization techniques regarding trucks arrivals and departures (*e.g.*, by way of truck coordination centers), the physical handling of the cargo when loading and unloading the trucks, *e.g.*, containerization as a system of intermodal freight transport using standard intermodal containers as prescribed by the International Organization for Standardization (ISO), see Levinson (2006), or the real time routing of trucks accounting for congestion, incidents, traffic accidents, etc. Given the lack of reliable academic or engineering information on to what extent the time associated to these transportations logistics have reduced over the years in the Spanish case, we leave load and unload times out of the analysis.

$$GTC_{ij}^{t,t} = \min_{I_{ij}^{t,t*} \in \mathbf{I}_{ij}^{t}} \left(DistC_{ij}^{t} + TimeC_{ij}^{t} \right) =$$

$$= \sum_{a \in I_{ij}^{t}} \left(\sum_{k} e_{k}^{t} \right) d_{a}^{t,t*} + \left(\sum_{l} e_{l}^{t} \right) \left(\sum_{a \in \mathbf{I}_{ij}^{t}} t_{a}^{t,t*} \right) = \left(\sum_{l} e_{l}^{t} \right) \left(\sum_{a \in I_{ij}^{t}} \frac{d_{a}^{t,t*}}{s_{a}^{t}} \right), \qquad (3)$$

where the where the optimal distance and time variables solving (3) correspond to $d_{ij}^{t,t*} = \sum_{a \in \mathbf{I}_{ij}^{t}} d_{a}^{t,t*}$ and $t_{ij}^{t,t*} = \sum_{a \in \mathbf{I}_{ij}^{t}} t_{a}^{t,t*}$. We remark that from the economic theory approach to index numbers these optimal accessibility values depend on the economic costs, and therefore $d_{ij}^{t,t*}$ and $t_{ij}^{t,t*}$ will not normally coincide with the shortest or fastest itineraries, *i.e.*, minimum real distance and minimum real time, which are the solutions to conventional best route problems that do not account for economic costs (*e.g.*, as in the portable GPS devices).

2.2. Generalized transport cost variation and its decomposition

Since $GTC_{ij}^{t,t}$ is the outcome of an optimizing behavior on the part of firms minimizing the transport cost between *i* and *j*, it is natural to resort to the economic theory of index numbers (Diewert, 1993; Fisher and Shell, 1998) when defining the variation of the $GTC_{ij}^{t,t}$ between a base period $t = 0$ and the current period $t = 1$. This approach assumes that given the unit prices related to distance and time that the transportation firm faces in period *t*, the choice of the optimal itinerary involving the optimal distance and time quantities is the solution to the cost minimizing problem. From this perspective the firm demands the specific arcs comprised in the optimal itinerary, and the road network can be thought of as the available infrastructure—technology—to produce the transportation service. As a result, when dealing with GTCs, we assume that the set of economic unit prices (e_{k}^{t}, e_{l}^{t}) and accessibility quantity variables (t_{a}^{t}, d_{a}^{t}) in the base and current periods are *interdependent*, since the firm demands the optimal itinerary given those prices (as opposed to the axiomatic approach to index numbers that assumes that both sets of variables are independent). With this in mind, the variation of the $GTC_{ij}^{t,t}$ between two consecutive periods is defined through the following value aggregate index that compares the costs of the transportation service in both periods: [5]

$$\Delta GTC_{ij}^{0,1} = \frac{GTC_{ij}^{1,1}}{GTC_{ij}^{0,0}} = \frac{\min_{I_{ij}^{1,1*} \in \mathbf{I}_{ij}^{1}} \left(DistC_{ij}^{1,1} + TimeC_{ij}^{1,1} \right)}{\min_{I_{ij}^{0,0*} \in \mathbf{I}_{ij}^{0}} \left(DistC_{ij}^{0,0} + TimeC_{ij}^{0,0} \right)}, \qquad (4)$$

this index incorporates information related to the change in both cost (economic) and physical (infrastructure) fundamentals, the problem is how to decompose it in a sensible manner, so as to identify the contribution that each one of these elements make to the variation of the GTC. This will result into a *price index* which summarizes the change in the distance e_{k}^{t}, and time e_{l}^{t}, economic unit prices, and its counterpart *quantity index* representing the change in

[5] See also IMF (2004) for a presentation of the index numbers in a production−cost function context. Diewert (2004) reviews the present and future perspectives of research on index numbers.

the optimal time $t_a^{t,t*}$, and distance $d_a^{t,t*}$, accessibility variables corresponding to the minimum cost itinerary.

2.2.1 Price and quantity indices

To reveal the sources that give origin to these variations we resort to the Konüs (1924) true cost of producing index, that in our current setting allows the comparison between the minimum cost of joining the origin *i* and destination *j* considering the unit prices corresponding to the base and current periods, *but* using the same network infrastructure. Considering the network infrastructure existing in the base period $t = 0$, the *Laspeyres–Konüs cost of producing price index* capturing the change in the economic variables corresponds to:

$$EC_{ij}^{0} = \frac{GTC_{ij}^{1,0}}{GTC_{ij}^{0,0}} = \frac{\min\limits_{I_{ij}^{1,0*} \in \mathbf{I}_{ij}^{0}} \left(DistC_{ij}^{1,0} + TimeC_{ij}^{1,0} \right)}{\min\limits_{I_{ij}^{0,0*} \in \mathbf{I}_{ij}^{0}} \left(DistC_{ij}^{0,0} + TimeC_{ij}^{0,0} \right)}, \tag{5}$$

where the denominator corresponds to (3), but the numerator represents a hypothetical generalized transport cost: $GTC_{ij}^{1,0}$, involving the calculation the cost in which the transportation firm would incur given the distance and time unit prices in the current period: e_k^1 and e_l^1, and the network infrastructure existing in the base period, *i.e.*,

$$DistC_{ij}^{1,0} = \sum_{a \in I_{ij}^{0}} \left(\sum_{l} e_l^1 \right) d_a^0 = \sum_{a \in I_{ij}^{0}} \left(fuel_{i,a(r)}^1 + toll_{i,a(r=1)}^1 + accom^1 + tire^1 + rep\&mant^1 \right) d_a^0 \text{, and} \tag{6}$$

$$\begin{aligned} TimeC_{ij}^{1,0} &= \left(\sum_{k} e_k^1 \right) \left(\sum_{a \in \mathbf{I}_{ij}^{0}} t_a^0 \right) = \left(\sum_{k} e_k^1 \right) \left(\sum_{a \in I_{ij}^{0}} \frac{d_a^0}{s_{a(r)}^0} \right) = \\ &= \left(lab_i^1 + amort^1 + fin^1 + ins^1 + tax_i^1 + ind_i^1 \right) \left(\sum_{a \in \mathbf{I}_{ij}^{0}} \frac{d_a^0}{s_{a(r)}^0} \right). \end{aligned} \tag{7}$$

and, tTherefore,

$$\begin{aligned} GTC_{ij}^{1,0} &= \min_{I_{ij}^{1,0*} \in \mathbf{I}_{ij}^{0}} \left(DistC_{ij}^{1,0} + TimeC_{ij}^{1,0} \right) = \\ &= \sum_{a \in I_{ij}^{0}} \left(\sum_{k} e_k^1 \right) d_a^{1,0*} + \left(\sum_{l} e_l^1 \right) \left(\sum_{a \in \mathbf{I}_{ij}^{0}} t_a^{1,0*} \right) = \left(\sum_{l} e_l^1 \right) \left(\sum_{a \in I_{ij}^{t}} \frac{d_a^{1,0*}}{s_a^0} \right). \end{aligned} \tag{8}$$

If EC_{ij}^{0} < 1 there is a deflationary process. On the contrary, EC_{ij}^{0} > 1 indicates an increase in economic costs, whereas if EC_{ij}^{0} = 1 signals that there is no variation in the aggregate costs between the base and current periods. We note on the one hand that the optimal distances and times corresponding to the cheapest itineraries may not coincide in both periods. In that case $I_{ij}^{0,0*} \neq I_{ij}^{1,0*}$ with $d_{ij}^{0,0*} = \sum_{a \in \mathbf{I}_{ij}^{t}} d_a^{0,0*} \neq d_{ij}^{1,0*} = \sum_{a \in \mathbf{I}_{ij}^{t}} d_a^{1,0*}$ and $t_{ij}^{0,0*} = \sum_{a \in \mathbf{I}_{ij}^{t}} t_a^{0,0*} \neq$

$t_{ij}^{1,0*} = \sum_{a \in \mathbf{I}_{ij}^{t}} t_{a}^{1,0*}$. It is clear that a change in the unit prices could result in a change in the optimal itinerary by the firm, which could decide for an alternative route, *e.g.*, if the price of toll highways in the current period reduces with respect to the remaining unit prices, the firm may demand a toll arc that was not demanded with the base period prices. On the other hand, if the minimum cost itinerary does not change from the base to the current period: $I_{ij}^{0,0*} = I_{ij}^{1,0*}$, then the distance and time quantities do not change, and the price index (5) precisely corresponds to the familiar Laspeyres (1871) formulation that uses the base period quantities as reference for the price change: $EC_{ij}^{0} = EC_{ij}^{L}$.

Since our goal is to decompose the variation of the generalized transport costs $\Delta GTC_{ij}^{0,1}$ into a price index and a quantity index, once we have EC_{ij}^{0} we can recover its associated *Paasche-Konüs implicit quantity index* because it is completely determined by way of the product rule. Denoting by IC_{ij}^{1} such infrastructure change index, we have:

$$\Delta GTC_{ij}^{0,1} = \frac{GTC_{ij}^{1,1}}{GTC_{ij}^{0,0}} = EC_{ij}^{0} \cdot IC_{ij}^{1} = \frac{GTC_{ij}^{1,0}}{GTC_{ij}^{0,0}} \cdot IC_{ij}^{1} , \tag{9}$$

and therefore:

$$IC_{ij}^{1} = \Delta GTC_{ij}^{0,1} / EC_{ij}^{0} = \frac{GTC_{ij}^{1,1}}{GTC_{ij}^{0,0}} / \frac{GTC_{ij}^{1,0}}{GTC_{ij}^{0,0}} = \frac{GTC_{ij}^{1,1}}{GTC_{ij}^{1,0}} = \frac{\min\limits_{I_{ij}^{1,1*} \in \mathbf{I}_{ij}^{1}} \left(DistC_{ij}^{1,1} + TimeC_{ij}^{1,1} \right)}{\min\limits_{I_{ij}^{1,0*} \in \mathbf{I}_{ij}^{0}} \left(DistC_{ij}^{1,0} + TimeC_{ij}^{1,0} \right)} . \tag{10}$$

The IC_{ij}^{1} index reflects the change in the aggregate quantity variables using the current period unit prices as reference by updating the infrastructure network. As the counterpart to EC_{ij}^{0}, (10) can be regarded as the associated (input oriented) quantity index measuring productivity growth as the aggregate reduction in the distance and time accessibility variables brought about by changes in the infrastructure network. It is normally expected that $IC_{ij}^{1} < 1$ showing that this term contributes to a reduction in the GTC as a result of improvements in the transportation network, thereby reducing both the optimal distance and time between *i* and *j* from the base to the current period. On the contrary, $IC_{ij}^{1} > 1$ would indicate an increase in transport costs, caused by a worsening in the infrastructures (as would be expected in countries where infrastructure deteriorates due to lack of maintenance). Finally, a value of $IC_{ij}^{1} = 1$, would be obtained when changes in the infrastructure network do not bring any change in the minimum cost itinerary and its associated optimal distance and time variables, *i.e.*, $I_{ij}^{1,1*} = I_{ij}^{1,0*}$, and therefore $EC_{ij}^{0} = \Delta GTC_{ij}^{0,1}$.

We can now recall the departure point in our previous analysis corresponding to the price index (5) and define the analogous *Paasche–Konüs cost of producing price index* that considers as the reference network infrastructure that existing in the current period $t = 1$. In that case, we define the index EC_{ij}^{1} = $GTC_{ij}^{1,1}$ / $GTC_{ij}^{0,1}$ = $\min_{I_{ij}^{1,1*} \in \mathbf{I}_{ij}^{1}} \left(DistC_{ij}^{1,1} + TimeC_{ij}^{1,1} \right)$ / $\min_{I_{ij}^{0,1*} \in \mathbf{I}_{ij}^{1}} \left(DistC_{ij}^{0,1} + TimeC_{ij}^{0,1} \right)$, with the same structure, interpretation, and values than (5), but where the associated distance and time costs: $DistC_{ij}^{0,1}$ and $TimeC_{ij}^{0,1}$, reverse the reference periods for the economic unit prices and the accessibility quantity variables associated to the network infrastructure. On this occasion, if the optimal itinerary within the current period network remains constant once the change in unit prices is taken into account, then $I_{ij}^{1,1*} = I_{ij}^{0,1*}$ and EC_{ij}^{1} adopts the form of the Paasche (1874) price index: EC_{ij}^{1} = EC_{ij}^{P}.[6] Given this price index the counterpart decomposition to (9) is $\Delta GTC_{ij}^{0,1} = GTC_{ij}^{1,1} / GTC_{ij}^{0,0}$ = $EC_{ij}^{1} \cdot IC_{ij}^{0}$ = $\left(GTC_{ij}^{1,1} / GTC_{ij}^{0,1} \right) \cdot IC_{ij}^{0}$, which allows us to recover its counterpart *Laspeyres-Konüs implicit quantity index* that uses the base period prices as reference, thereby obtaining IC_{ij}^{0} = $\left(GTC_{ij}^{1,1} / GTC_{ij}^{0,0} \right)$ / $\left(GTC_{ij}^{1,1} / GTC_{ij}^{0,1} \right)$ = $GTC_{ij}^{0,1} / GTC_{ij}^{0,0}$ = $\min_{I_{ij}^{0,1*} \in \mathbf{I}_{ij}^{1}} \left(DistC_{ij}^{0,1} + TimeC_{ij}^{0,1} \right)$ / $\min_{I_{ij}^{0,0*} \in \mathbf{I}_{ij}^{0}} \left(DistC_{ij}^{0,0} + TimeC_{ij}^{0,0} \right)$. As in the previous IC_{ij}^{1} case, when the changes in the infrastructure network do not alter the choice of optimal itinerary, *i.e.*, $I_{ij}^{0,1*} = I_{ij}^{0,0*}$, IC_{ij}^{0} = 1, and EC_{ij}^{1} = $\Delta GTC_{ij}^{0,1}$.

Finally, we remark that instead of departing from the definition of the Laspeyres–Konüs or Paasche–Konüs true price indices EC_{ij}^{0} and EC_{ij}^{1}, and calculate their implicit quantity indices IC_{ij}^{1} and IC_{ij}^{0}, it also possible to start out defining these quantity indices and, from there on, recover their associated price indices by way of the following expressions: $EC_{ij}^{0} = \Delta GTC_{ij}^{0,1} / IC_{ij}^{1}$ and $EC_{ij}^{1} = \Delta GTC_{ij}^{0,1} / IC_{ij}^{0}$. From an operational perspective, this reverse approach or alternative sequence for calculating the price and quantity indices yields the same results to those already introduced, but represent an alternative way to obtain the economic and infrastructure components in which generalized transport cost variations can be decomposed.

2.2.2 The Fisher version of the GTC variation and the transitivity property

These results show that there are two alternative ways of decomposing the variation of the GTC depending on the choice of the price and its associated quantity indices, *i.e.* $\Delta GTC_{ij}^{0,1} = GTC_{ij}^{1,1} / GTC_{ij}^{0,0} = EC_{ij}^{0} \cdot IC_{ij}^{1} = EC_{ij}^{1} \cdot IC_{ij}^{0}$. As a result, depending on the alternative reference periods for the economic and infrastructure indices, we would generally obtain two different values for the contribution of economic prices and accessibility quantities. This suggests the following geometric mean decomposition of $\Delta GTC_{ij}^{0,1}$ that does not settle for one particular period, but takes them both into account in a symmetric way:

[6] Konüs (2004; 20-21) shows that the Laspeyres and Paasche price indices respectively represent a lower and upper bound to the true index.

$$\Delta GTC_{ij}^{0,1} = GTC_{ij}^{1,1} / GTC_{ij}^{0,0} = \left[\left(EC_{ij}^{0} \cdot IC_{ij}^{1} \right) \cdot \left(EC_{ij}^{1} \cdot IC_{ij}^{0} \right) \right]^{1/2} \\ = \left(EC_{ij}^{0} \cdot EC_{ij}^{1} \right)^{1/2} \left(IC_{ij}^{0} \cdot IC_{ij}^{1} \right)^{1/2} = EC_{ij}^{0,1} \cdot IC_{ij}^{0,1}. \tag{11}$$

end this theoretical section by recalling the axiomatic approach to index numbers and highlight one relevant property of these indices that proves useful in a time series context like the one we undertake in the empirical section. An index is said to verify the transitivity property (or circularity test) if it is possible to consistently decompose its time variations from an initial to a final period into consecutive subperiods, thereby allowing for specific time analyses. For example, time periods when there have been important investment efforts resulting in improvements of the transportation network, which should translate in larger GTCs reductions, or price inflationary periods that would have the opposite effect through an increase in the price index. All previous indices satisfy the transitivity property and, therefore, given a sequence of periods: t = 0, 1, 2, it is verified that $\Delta CGT_{ij}^{0,2} = \Delta CGT_{ij}^{0,1} \cdot \Delta CGT_{ij}^{1,2}$. Focusing on the initial definition (4) and the decomposition presented in (11) we have that given a sequence of T periods, $t = 0,\ldots T$, it is possible to decompose the variation of the GTC between the first and last periods into any subperiods using any of the available alternatives:

$$\Delta CGT_{ij}^{0,T} = \frac{CGT_{ij}^{T,T}}{CGT_{ij}^{0,0}} = \Delta CGT_{ij}^{0,t} \cdot \Delta CGT_{ij}^{t,T} = \frac{CGT_{ij}^{t,t}}{CGT_{ij}^{0,0}} \cdot \frac{CGT_{ij}^{T,T}}{CGT_{ij}^{t,t}} = \\ = \left(EC_{ij}^{0} \cdot IC_{ij}^{t} \right) \left(EC_{ij}^{t} \cdot IC_{ij}^{T} \right) = \left(EC_{ij}^{t} \cdot IC_{ij}^{0} \right) \left(EC_{ij}^{T} \cdot IC_{ij}^{t} \right) = \\ = \left[\left(EC_{ij}^{0} \cdot EC_{ij}^{t} \right)^{1/2} \left(IC_{ij}^{0} \cdot IC_{ij}^{t} \right)^{1/2} \right] \left[\left(EC_{ij}^{t} \cdot EC_{ij}^{T} \right)^{1/2} \left(IC_{ij}^{t} \cdot IC_{ij}^{T} \right)^{1/2} \right] \\ = \left(EC_{ij}^{0,t} \cdot IC_{ij}^{0,t} \right) \left(EC_{ij}^{t,T} \cdot IC_{ij}^{t,t} \right). \tag{12}$$

From this expression we can recover any change in the generalized transport cost between an intermediate period and the final year by diving the fixed base indices corresponding to those periods, *i.e.*,

$$\Delta CGT_{ij}^{t,T} = \frac{CGT_{ij}^{T,T}}{CGT_{ij}^{t,t}} = \frac{CGT_{ij}^{T,T} \,/\, CGT_{ij}^{0,0}}{CGT_{ij}^{t,t} \,/\, CGT_{ij}^{0,0}} = \left[\left(EC_{ij}^{t} \cdot IC_{ij}^{T} \right) \left(EC_{ij}^{T} \cdot IC_{ij}^{t} \right) \right]^{1/2} = \\ = \left(EC_{ij}^{t} \cdot EC_{ij}^{T} \right)^{1/2} \left(IC_{ij}^{t} \cdot IC_{ij}^{T} \right)^{1/2} = EC_{ij}^{t,T} \cdot IC_{ij}^{t,T}. \tag{13}$$

That is, we can recover the chain component $\Delta CGT_{ij}^{t,T}$ of the GTC variation verifying the transitivity property for the whole period: $\Delta CGT_{ij}^{0,T} = \Delta CGT_{ij}^{0,t} \cdot \Delta CGT_{ij}^{t,T}$. Moreover, as these expressions can be generalized to any two particular subperiods, we can also calculate the cumulative variation—chained components—of the generalized transport costs between period t and $t+n$, whose particular definition is (with n = 1 we would obtain year to year variations):

$$\Delta CGT_{ij}^{t,t+n} = \frac{CGT_{ij}^{t+n,t+n}}{CGT_{ij}^{t,t}} = \frac{CGT_{ij}^{t+n,t+n} / CGT_{ij}^{0,0}}{CGT_{ij}^{t,t} / CGT_{ij}^{0,0}} = \left[\left(EC_{ij}^{t} \cdot IC_{ij}^{t+n}\right)\left(EC_{ij}^{t+n} \cdot IC_{ij}^{t}\right)\right]^{1/2} = \\ = \left(EC_{ij}^{t} \cdot EC_{ij}^{t+n}\right)^{1/2} \left(IC_{ij}^{t} \cdot IC_{ij}^{t+n}\right)^{1/2} = EC_{ij}^{t,t+n} \cdot IC_{ij}^{t,t+n}. \tag{14}$$

The definition of the above decompositions based on the economic theory of index numbers greatly improves previous proposals from a methodological perspective, constituting a substantial advance with respect to other studies on the sources of transport costs variation, which did not rely on index number theory and its potential when decomposing them, so as to consistently identify its sources. Applying the proposed methodology to previous studies in a consistent way would result in a sound identification of the sources of transport cost variations, *e.g.*, the already cited studies and, particularly, Combes and Lafourcade (2005), Texeira (2006), and Martínez-Zarzoso and Nowak-Lehmann (2006), on road transportation. Thus, the analytical potential of index numbers, both theoretical and empirical, allows establishing a reference framework to analyze the change in any GTC pertaining to any transportation industry.

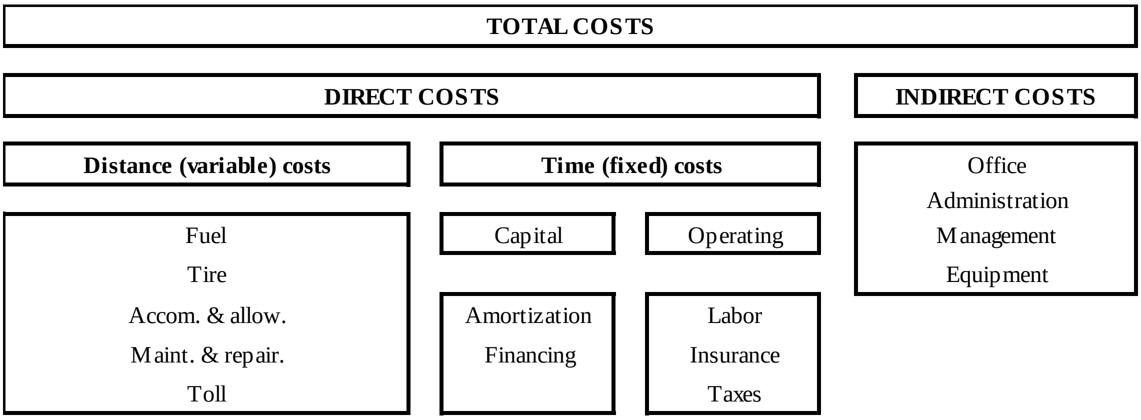
3. Calculating GTCs: The case of freight road transportation in Spain (1980-2007)

3.1 The economic (unit-price) costs database

The reference economic costs used to calculate the GTC are obtained using the engineering approach that is based on the operating expenses of a representative transportation mean. In long distance road freight transportation the most common type of vehicle is the 40 tons articulated truck. For this particular vehicle several economic analyses, based on a detailed scrutiny of the accountancy of transport frims, are available. In the Spanish case the Directorate General of Road Transportation collects monthly statistics on transport costs carried out within the 'Observatory of Road Freight Transportation' (MF, 2010). Our methodology, based on these indicators, differentiates between direct and indirect costs. Among the first ones, fixed costs (related to the annual driven distance) and variable costs (related to the annual hours worked) are considered.[7] Figure 1 illustrates the typology of costs corresponding those considered in the methodological section: eqs. (1) and (2).

[7] Private companies can check their cost structure using the ACOTRAM 2.2.1 software developed by the Spanish Ministry of Transportation as an aid to determine the fares for road freight transportation.

Figure 1: Economic costs of freight road transportation



Source: Observatory of Road Freight Transportation, MF (2010).

The compilation of the economic database is an intricate task due to its complexity, the variety of potential alternatives and the lack of data in many components that define the overall and unit costs. All the different economic and technological hypotheses concerning the reference vehicle that are used in this study are reported in detail in the technical annexes. They also show the ancillary issues necessary to compute the economic costs during the period 1980-2007 (*i.e.*, the criteria to update the costs are presented in annex 1.2). All the formulae (annex 1.1) and technical assumptions (annex 1.3) apply for all regions and provinces in Spain, but their specific values may differ among them for numerous reasons (*e.g.*, in Spain collective bargaining takes places at the provincial level, which result in wage differentials st this geographical level). Finally, current economic variables have been expressed in real terms using the regional GDP deflator in order to obtain real costs. We remark that these reference costs are influenced by institutional, regulatory and legal issues (taxes on fuel, driving and resting times, minimum wages...). Also, the industrial structure (relationship between efficiency and competition, firm size...) plays also an important role in their behavior thru time.[8] Therefore, the different components which result in the individual unit-price economic costs depend on multiple factors that are taken into account in our analysis, but whose detailed discussion exceeds the available space of this section. Nevertheless, their most important features are described in what follows.

onsidering the mentioned technical-economic hypotheses and the available information, unit price data for all economic costs have been systematically collected for all Spanish provinces. Focusing first on the aggregate information at the national level, Table 1 presents information on unit costs variations between 1980 and 2007 for the above categories (column (5)). Data reveals that only three price categories have increased in real terms during this period. Firstly, fuel costs—accounting for almost one third of the total costs—experienced an accumulated growth up to 33.3%. The high inflation experienced in recent years has counterbalanced the technological and efficiency improvements made by vehicle manufacturers after the oil crisis—particularly, new engines consuming as much as a 25.5% less, see annex 1.3. Secondly, labor costs—accounting for 13% of the total costs—have increased by a contained 13.9% during these years. This is result of the strong liberalization and deregulation

[8] For example, the freight road transportation sector is atomized in Spain, where 87 per 100 of the firms are small (with less than five vehicles). This turns out in high competitive pressures and higher cost efficiency.

processes as well as the competitive pressures that have characterized the Spanish road freight transport industry during recent years, keeping salary increases moderate.[9] Finally, taxes have also suffered an upward trend although its weight over total costs is negligible, and therefore have a limited impact on the overall cost. DDespite the increase in these three economic costs, the downward behavior of the rest of the categories has resulted in a –16.1% reduction of total unit costs at constant prices from 1980 to 2007. For example, the entry of Spain into the European Monetary Union resulted in a sharp downturn of the interest rates that reduced capital costs significantly, thereby counterbalancing the opposite effect brought about by shorter useful years in the vehicle life-cycle and longer financing years—eq. (A.1) in the appendix. Other unit costs which have experienced a significant decrease over these years are the accommodation and allowance costs— representing about 10% of total costs, insurances, tires and tolls. Factors such as the modernization and consolidation of insurance markets, technological advances in retreading and tire manufacturing, as well as negotiations between toll highway concessionaires and governmental agents have played a role in this cost reduction.

Table 1: Levels and variations of the unit economic transport costs, 1980-2007 [a]

	Levels (Euros)		Share in total costs (%)		Unweighted variation (%)	Weighted variation (%) [b]	
	1980 (1)	2007 (2)	1980 (3)	2007 (4)	∆ 07/80 (5)	∆ 07/80 [c] (6)=(3)·(4)	(7)
DIRECT COSTS (km)	**1.13**	**0.94**	**91.84**	**91.69**	**-16.25**	**-14.92**	**92.62**
Distance Costs (km)	**0.51**	**0.52**	**41.48**	**50.48**	**2.09**	**0.87**	**-5.38**
Fuel	0.22	0.30	18.28	29.04	33.25	6.08	-37.74
Accom. & allow.	0.13	0.11	10.50	10.87	-13.16	-1.38	8.58
Tire	0.08	0.05	7.12	4.92	-42.07	-3.00	18.60
Maint. & repair.	0.04	0.04	3.59	4.24	-1.02	-0.04	0.23
Toll[d]	0.02	0.01	1.98	1.41	-40.36	-0.80	4.95
Time Costs (hr)	**29.28**	**26.80**	**50.36**	**41.22**	**-8.46**	**-15.79**	**98.00**
Capital	10.34	8.56	17.78	13.16	-17.22	-6.74	41.85
Amortization	7.19	7.13	12.36	10.96	-0.81	-3.17	19.65
Financing	3.15	1.43	5.42	2.20	-54.64	-3.58	22.20
Operating	18.94	18.25	32.58	28.06	-3.68	-9.04	56.14
Labor	12.61	14.36	21.69	22.09	13.90	-3.16	19.62
Insurance	5.92	3.41	10.18	5.24	-42.39	-5.78	35.89
Taxes	0.41	0.47	0.71	0.73	14.28	-0.10	0.63
INDIRECT COST (km)	**0.10**	**0.08**	**8.16**	**8.31**	**-14.57**	**-1.19**	**7.38**
ECONOMIC COSTS (km) [b]	**1.23**	**1.03**	**100.00**	**100.00**	**-16.11**	**-16.11**	**100.00**

[a] Variation of unit economic costs in constant 2007 Euros.
[b] Economic costs per unit distance (km.), once time costs (per hour) are converted to distance costs dividing by the average speed: Economic costs / km. = Distance costs / km. + Time costs / hr. ÷ speed (km./hr.).
[c] Shift-Share variation. Unit costs variation weighted by their 1980 cost shares in total economic costs.
[d] The toll cost is an average cost for the reference vehicle assuming that 10% of the annual distance is corresponds to this category. However, GTC calculations considerer actual tolls of the arcs really used.
Note: Annual driven distance of the representative 40t. articulated truck has risen from 90.000 km in 1980 to 120.000 km in 2007, while the number of total annual hours driven has remained stable at 1.906 over the whole period.
Source: Own elaboration

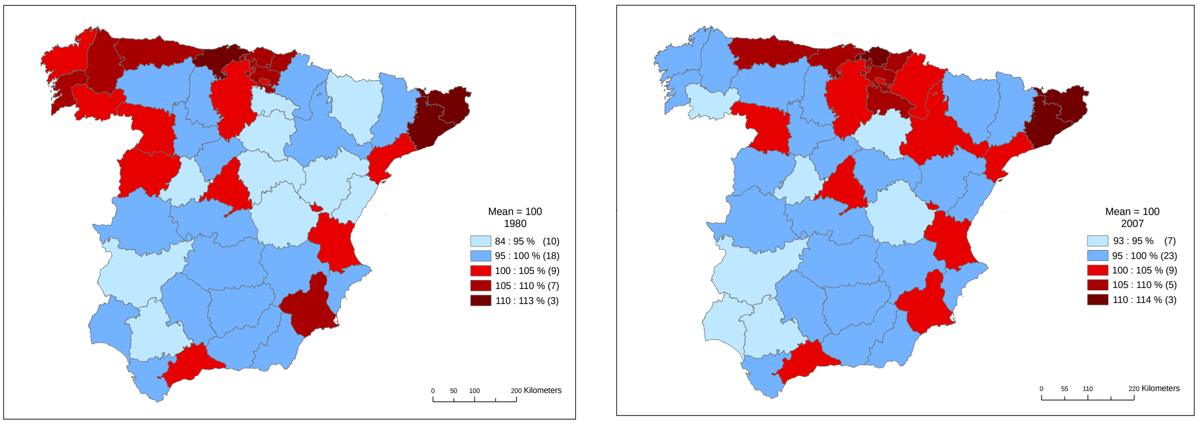
Behind this –16.1% overall reduction in total unit costs per kilometer there is not only the relative reduction of the majority of the categories above mentioned, but also the technological

[9] It is important to notice that wages have been recorded from the industry collective agreements (between trade unions and firms associations) and therefore they are not approximated by the mark-ups of the self-employed drivers. Thus, labor costs normally follow the same trend than the overall prices in the economy (and, more particularly, the Consumer Price Index upon which salaries updating is based on).

improvements incorporated into the vehicles which have allowed to increase driven annual distance by one third from 90,000 km to 120,000 km. On the contrary, total unit costs per hour, which have remained constant at 1.906 hours/year, have increased due to the upward pressure of fuel and labor costs. The last two columns in Table 1 (weighted variation) show a shift-share analysis of the unit economic costs refereed to the distance covered by the reference vehicle in kilometers—column (5), and the weight of each particular costs category in the overall -16.1% reduction—column (7). For this purpose, time costs per hour have been converted in km taking in to account the annual distance covered by the reference vehicle. As a result, since the distance covered by the reference vehicle has increased over the years, time units cost expressed in km have declined. This explains why in the last two columns presenting, respectively, the shift-share analysis of the economic costs variation and the percentage contribution of each cost to the -16.1% overall change, the costs of labor and taxes reverse their signs with respect to their unweighted variation, implying that they contribute to the overall reduction in unit economic costs per km (and the remaining costs decrease in a larger value). In the last column, a positive value reflects that the particular cost has declined over the years thereby contributing to the overall reduction in the associated percentage. On the contrary, the only exception are fuel costs, whose negative value shows that their contribution has increased, thereby counterbalancing the overall reduction. From an index number methodological perspective, we remark that the shift-share analysis presented in the last two columns would correspond to the standard decomposition of a Laspeyres producer price index that weights each unit price variation, *i.e.*, e_k^{07}/e_k^{80} and e_l^{07}/e_l^{80} by their corresponding shares in the total economic costs, but does not take into account the network infrastructure. Even if this decomposition is useful to examine the sources of the changes in overall economic costs, it fails to meet the network criteria that should characterize the notion of generalized transport costs.

Detailing now the information at the provincial (NUTS 3) level, Figure 2 shows the individual aggregate economic costs in Spain for 1980 and 2007 (Euros per km). Our calculations unveil a large heterogeneity showing that the higher cost levels are observed in those regions located on the northern and eastern Spain. In particular, those regions located on the Bay of Biscay area, the Ebro valley, Valencia and Catalonia, together with Madrid, are those where transport costs are higher. The opposite is observed in the western and southern Spanish provinces where costs are about 10% lower. The individual costs behind these differentials are mainly labor, fuel, and taxes, which tend to be more expensive in high income regions.

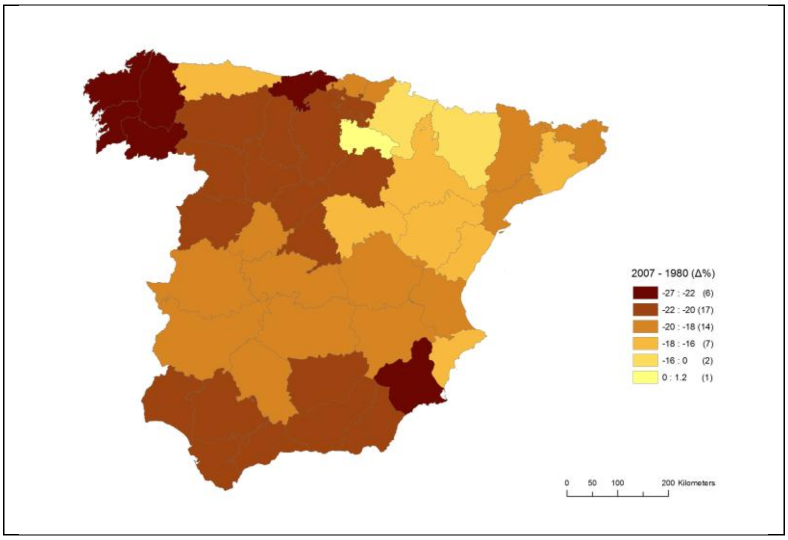
Figure 2: Economic road freight transport costs in Spain 1980-2007 (Euros per km).
(Euros per total annually driven distance by the reference vehicle: 120.000 kms.)



Source: Own elaboration

If the regional heterogeneity and distribution of the transport economic costs in 2007 is remarkable—a result normally overlooked in aggregate national studies, it seems even more important to analyze their dynamics since the base year of 1980. Generally speaking the relative positions are not drastically altered throughout the considered time span. A downward trend in the reference economic costs has been experienced in most regions, with the exception of La Rioja (a result that contributes to make the latter the only province where GTCs increase). Those regions presenting higher costs at the beginning of the 80s, although experiencing deeper decreasing trends during the following three decades, kept on leading the economic costs ranking, being the most expensive ones also in 2007. We find some exceptions such as Murcia (–24.8%), Galicia (–23%), Cantabria (–22.9%) and Andalusia (–20.5%), whose provinces have reduced their costs well below the –16.1% national average. Finally, those provinces whose reference economic costs were close to the Spanish average at 1980 have reduced their costs below that average at the end of the analyzed period thereby improving their relative position in the ranking (Navarra, Madrid, Aragón, Castilla y León and Valencia). Figure 3 shows the percentage variation of the annual transport costs during 1980–2007.

Figure 3: Variation in the provincial reference economic costs in Spain, 1980 *v.* 2007 (%)



Source: Own elaboration

3.2. The GIS database of the infrastructure network

Geographic Information System (GIS) techniques have been used to compute minimum cost routes using the shortest path algorithm of Dijkstra (1959).[10] Seven digital road networks have been created corresponding to the following years: 1980, 1985, 1990, 2000, 2005 and 2007. The networks (see Figure 4) include all toll and free highways (2x2/3 lanes), national roads (2x1 lanes), as well as the main ones belonging to regional governments (2x1 lanes) and local municipalities (secondary and urban). In general, the length of national 2x1 roads has decreased in favor of high capacity 2x2/3 highways (Table 2). Highways accounted 335 km. in

[10] The analysis has been performed using the network analyst toolbox of the ArcGIS software.

1980 and 9,557 km. in 2007, which represents a remarkable increase of 2,752% in 27 years. Tolled roads have grown by 77% since 1980. National roads have decreased their length mainly in the first two decades due to a common practice of doubling the existent national roads to upgrade the infrastructure to highways.

Each one of these networks has a cartographic base and a related database. As anticipated in the second section, each link of the network is one arc, *a* with its corresponding set of attributes in period *t*, $\mathbf{x}_a^t$. The database assigns to each arc not only the physical characteristic already discussed in the empirical section: distance, d_a^t (meters), road type: r =1,…6, the gradient (degrees), and speed: $s_{a(r,t)}^t$, from which the associated travel time t_a^t is obtained, but also its particular economic costs. These costs are calculated by multiplying the unit distance costs associated to distance and time by the length of the arc and the time it takes to cover it, and allowing for above mentioned provincial differences. With regard to the resolution of the origins and destinations of the minimal economic cost routes—including internal travel costs, 678 transport zones were considered. [11] In this stage of the GIS implementation, other ancillary costs were added in the calculation of the routes. [12]

Table 2. Variation in the number and length of arcs (1980–2007).

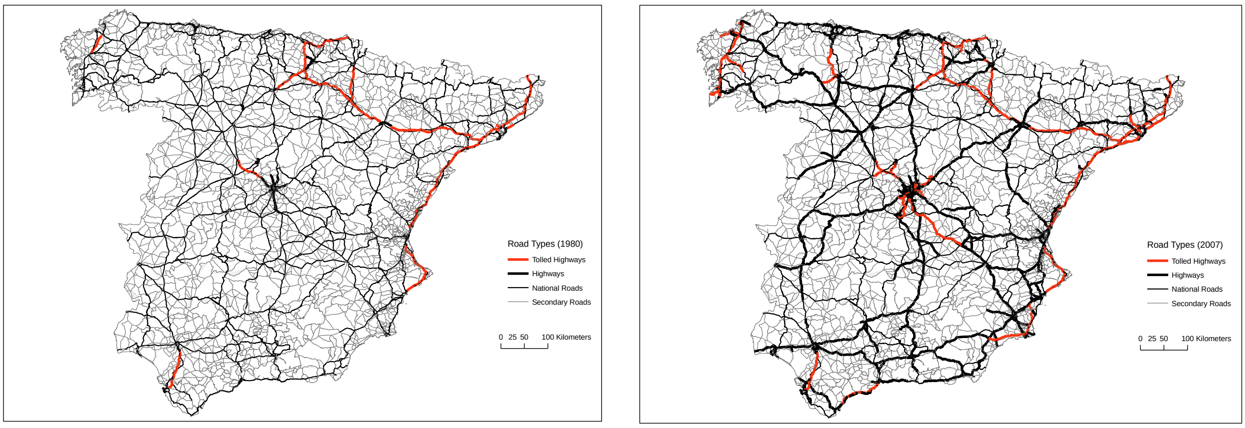
							National roads			**1st order regional**		
	1980	2007	Δ%	1980	2007	Δ%	1980	2007	Δ%	1980	2007	Δ%
Number	386	675	74,9	134	2,430	1,713.4	5287	3946	-25.4	1842	1608	-12.7
Dis. (km)	1,630	2,883	76.9	335	9,557	2,752.8	21,456	16,372	-23.7	11,703	10,714	-8.5
	2nd order regional											
	1980	2007	Δ%	1980	2007	Δ%	1980	2007	Δ%	1980	2007	Δ%
Number	3792	3648	-3,8	1,973	1940	-1.7	761	742	-2.5	14,175	14,989	5.7
Dis. (km)	27,597	27,161	-1,6	19,059	18,943	-0.6	1,274	1217	-4.5	83,055	86,849	4.6

Source: Own elaboration

[11] Internal travel cost depends on the size of transport zone as well as on its development level (urban or rural), which determines the mean speed of each zone. Internal speeds were linearly fitted assigning 20 km/h to the zone with the highest population density and 80 Km/h to the one with less population density. Then, internal km. and travel times were converted to economic values given the correspondent provincial costs. Finally, to estimate the internal km. (D_{ii}) of zone *i* we use the method proposed by Rich (1975): $D_{ii} = 1/2\sqrt{area/\pi}$.

[12] E.g. regulated stops for drivers were set by the European Parliament and Council on 15th March, 2006 ((CE) nº 561/2006). The regulation states that the driver must rest 45 minutes after 4 hours driving and 11 hours after 9 hours.

Figure 4: Spanish road network, 1980 *v.* 2007



Source: Own elaboration

4. GTCs of freight road transportation in Spain (1980-2007): Results

4.1. Averaging GTCs using trade data

In this section we present the calculations of the GTCs and their variation between 1980 and 2007, as well as their decomposition into the infrastructure and economic components as presented in expression (11) for consecutive periods, and expression (12) for cumulative variations. To average the generalized transport costs of a particular zone *i* against the remaining *j* zones, we depart from the common practice relying on the arithmetic mean: $\overline{GTC}_{ij}^{t,t} = 1/(N-1)\sum_{j=1}^{N-1} GTC_{ij,z}^{t,t}$, that does not take into account actual trade between zones, and adopt a weighted approach that multiplies the individual *i*, *j* transportation cost by the share of zone *j* on zone *i*'s total exports. As a result our aggregate allows for the trade patterns between regions, *i.e.*, the GTC between region *i* and *j* will be irrelevant in the weighted average cost if these regions do not trade with each other. Here we use the interregional trade database C−intereg that provides information of the exported and imported goods between provinces in Spain. The data we use corresponds to the volume of the exported goods (tons) in year 2005 classified at the divisional level (NACE Rev.1.1 classification), which are mainly distributed by road freight transportation. The exports at provincial level have been allocated to the transport zones within a province using as weights the distribution of income—a proxy of the distribution of economic activity driving the exports (see Llano *et al.*, 2010, for a thoughtful discussion of this database and the interregional trade data). Denoting by X_i the total volume of road shipping from zone *i* and by x_{ij} that reaching zone *j*, the trade weighted average of the GTCs corresponds to:

$$GTC_{ij}^{t,t} = \sum_{j=1}^{N-1} s_{ij}^{05} GTC_{ij,z}^{t,t} = \sum_{j=1}^{N-1} (x_{ij}^{05} / X_i^{05}) GTC_{ij,z}^{t,t} \, . \qquad (15)$$

4.2. GTCs levels and variations

Table 3 presents the arithmetic average and trade weighted average of the GTCs in Spain aggregated at regional (NUTS 2) level. The first remarkable feature of our results is that weighting the GTC by trade data results in a drastic reduction of GTCs since most of the exports are done to nearby locations whose bilateral GTCs are much lower. In 1980 and 2007 the trade weighted GTCs (152.9€ and 128.0€, respectively) represent about 20% of their unweighted GTCs counterparts (698.9€ and 559.6€). This is consistent with the reduction in trade as result of increasing distance reported in Hilberry and Hummels (2008), who using U.S. trade data determine that the volume (tons) component of the total value shipped from one region to another drastically drops by more than 50% when the shipping distance exceeds 200 miles. Both the mean of the unweighted and trade weighted GTCs have decreased during these three decades dropping by −19.9 and −16.3%, respectively. This descend has been generalized in all the Spanish provinces except La Rioja. In 2007, the percentage difference between the lowest Madrid's value of 74.9€ and the highest value of 162.8€ in Asturias amounts as much as 117.4% (131.9% for the unweights arithmetic mean). The three costliest regions: Asturias (162.8€), Aragón (157.5€) and Galicia (148,4€) locate in the geographical periphery, presenting GTCs well over the 128.0€ Spanish average. This situation was already observed in 1980 since these same regions also displayed the highest GTCs. Since the relative drop in the GTCs of the regions presenting the highest GTCs has been larger than the national average, one wonders if there has been a significant change in the ranking of regions. In fact, the interesting question of whether there has been a convergence process in GTCs resulting in larger territorial cohesion is studied in depth in section five, where we calculate several inequality indicators of the individual GTCs and their components.

Table 3: GTCs in the Spanish regions, 1980-2007.

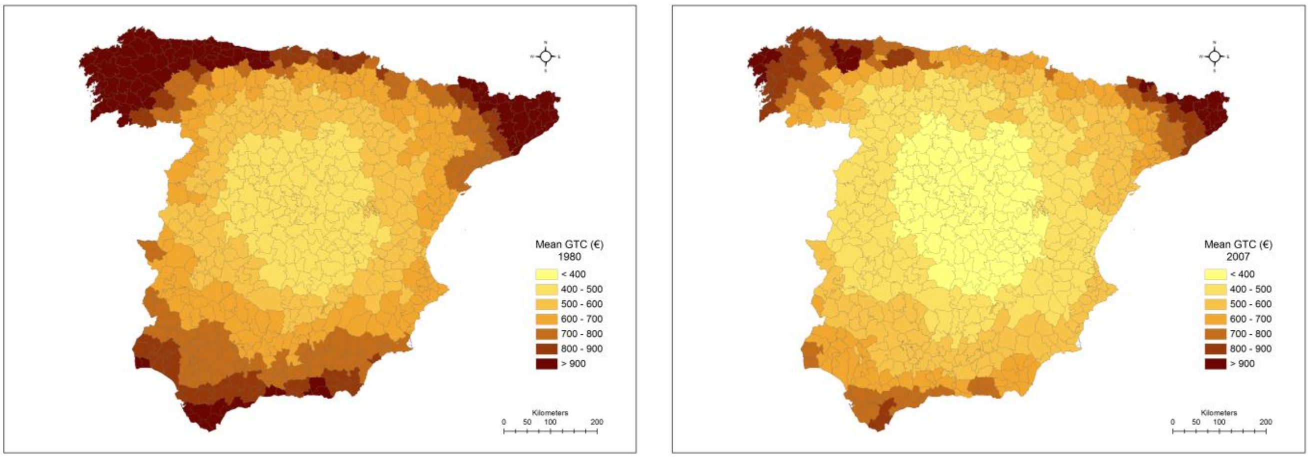
	Arithmetic average: $\overline{GTC}_{ij}^{t,t}$			**Trade weighted average: $GTC_{ij}^{t,t}$**		
	Levels (Euros)		**Variation Δ 07/80**	**Levels (Euros)**		**Variation Δ 07/80**
	1980	**2007**		**1980**	**2007**	
Andalusia	786.8	630.5	-19.9	146.01	120.17	-17.70
Aragón	610.4	514.6	-15.7	176.38	157.49	-10.71
Asturias	1007.2	808.8	-19.7	199.00	162.84	-18.17
Cantabria	836.4	639.9	-23.5	185.96	139.02	-25.24
Castilla y León	543.6	422.8	-22.2	146.41	121.25	-17.18
Castilla-La Mancha	470.3	378.6	-19.5	156.09	133.41	-14.53
Catalonia	918.3	780.1	-15.0	143.99	126.75	-11.98
Com. Valenciana	621.1	500.3	-19.4	114.05	97.92	-14.15
Extremadura	614.6	480.1	-21.9	173.20	144.35	-16.65
Galicia	1052.6	791.4	-24.8	190.56	148.41	-22.12
Madrid	433.7	348.7	-19.6	89.81	74.94	-16.56
Murcia	712.9	532.9	-25.2	142.31	113.48	-20.26
Navarra	654.4	552.6	-15.6	142.39	123.48	-13.28
Basque Country	780.2	626.9	-19.6	159.65	132.70	-16.88
La Rioja	518.2	503.2	-2.9	126.99	129.08	1.64

Mean	698.9	559.6	-19.9	152.93	128.00	-16.30
Maximum	1,052.6 Galicia	808.8 Asturias	-25.2 Murcia	199.0 Asturias	162.8 Asturias	-25.2 Cantabria
Minimum	433.7 Madrid	348.7 Madrid	-2.9 La Rioja	89.8 Madrid	74.9 Madrid	1.6 La Rioja

Source: Own elaboration

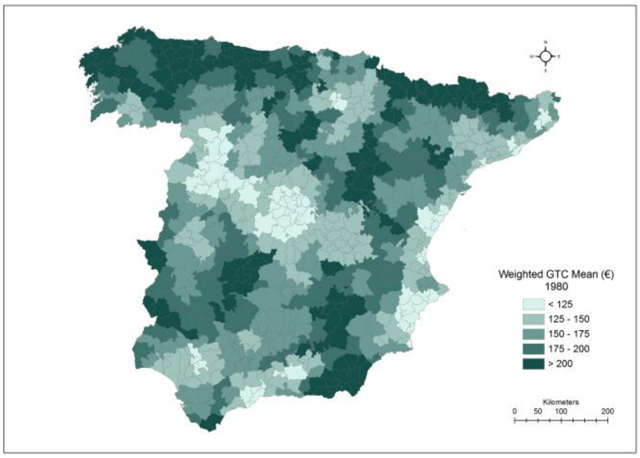
Figures 5a and 5b summarize the results of the GTC for the 678 transport zones considering the arithmetic and trade weighted average of the GTCs. In the former case one observes a clear center- periphery pattern, with the lowest GTCs locating in the center of Spain and the highest GTCs in the farthest coastal areas. This confirms long established ideas in the literature on transport accessibility, and reproduces the results obtained for other countries, such as France (Combes and Lafourcade, 2005), as well as at European level (Spiekermann and Neubauer, 2002). Zones situating in central regions, especially Madrid, have the lowest GTCs due to their location and the network configuration of the Iberian peninsula. By being located in a privileged geographical central place, and as the administrative and economic capital of the country, Madrid has benefited from a very inclusive and thick transport and communications network. For these reasons, a high proportion of the optimal freight road transport itineraries cross over the Madrilenian region. On the other hand the highest CGTs (darker colors) are located in peripheral regions, especially in Galicia, Asturias and Catalonia.A more fuzzy picture is revealed in the two lower maps portraying the trade weighted average of GTCs. In this case GTCs are strongly influenced by the scope of the commercial flows with peripheral regions exhibiting low GTCs as well, due to the short logistic range of their commercial flows. The issue of whether there are systematic geographical clustering in trade weighted GTCs remain open and, once again, in the next section we test several hypotheses of alternative spatial clustering in the GTCs variations and their economic and infrastructure components.

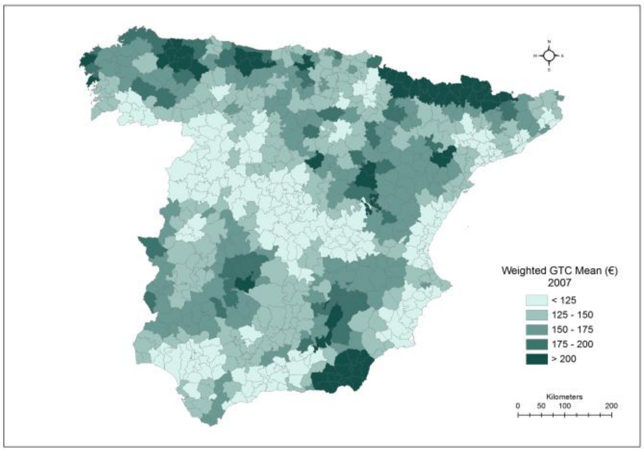
Figure 5a. Arithmetic average: $\overline{GTC}_{ij}^{t,t}$, 1980 *versus* 2007 (€).



Source: Own elaboration

Figure 5b.Trade weighted average: $GTC_{ij}^{t,t}$, 1980 *versus* 2007 (€).





Source: Own elaboration

As previously mentioned, the trade weighted mean GTC has experienced a significant fall in the last years to the aggregate tune of −16.3%. However, as with the reference economic costs, the fall in GTCs has not been equal across regions and provinces. Cantabria (−25.2%), Galicia (−22.1%) or Murcia (−20.3%) have undergone even a larger reduction. In the opposite side, La Rioja is the only region experiencing an increase in its GTC. Other regions such as Aragon (−10.7%), Catalonia (−12.0%) and Navarra (−13.3%) have also experienced lower reductions in their GTCs. At a provincial level, the reduction in the GTCs also present large differences, even among those belonging to the same region (particularly when a region includes provinces that are far apart from each other and separated by geographical barriers). Provinces located at the northeast zone, and most of the Andalusian provinces have experienced lower lessening. On the contrary, provinces located at the north-northwest (Cantabria, Galician and from Castilla y Leon), and the center (Madrid and those from Castilla-La Mancha) have displayed the higher GTCs drops.

4.3. A shift-share economic decomposition of the sources of GTCs decline

In this section wWe perform a shift-share analysis of the GTC variation that allows us to determine the joint contribution that all economical and infrastructure factors make to the −16.3% reduction in the GTCs, through the changes in each individual cost component. Columns (1) and (2) in Table 4 present the direct distance and time costs as well as the indirect costs resulting in the overall reduction in GTCs. The shift-share analysis yields the contribution that each cost makes to the overall GTC decline by weighting their individual shift (column 3) by their base 1980 share (column 4), which can be expressed as a percentage of the overall change (last two columns (6) and (7)). The reasons behind these figures closely follow the patterns and explanations behind each individual trend of the reference unit economic costs already discussed in section 3.1—Table 1. We observe that it is the time costs those driving the fall in GTCs by contributing with a 75.3% in the overall reduction (−12.2% out of −16.3%). Both capital and operating costs contribute with a similar extent (−5.1% and −7.2%, respectively); while it is the insurance costs, followed by the financing costs, those specific components that reduce the most. Distance costs contribute with a mere 17.5% to the overall reduction (−2.8% out of −16.3%) with fuel cost counterbalancing the GTCs decline by 20.0% (3.3% increase versus the −16.3% CGT reduction). These are sensible results since the improvement in the road networks mainly results in larger time savings rather than distance savings, and therefore, it is the costs associated to the former what drives GTCs reductions. This is confirmed by the observed reductions in the optimal distances and times associated to the minimum costs itineraries: $\Delta d_{ij}^{t,t*}$ and $\Delta t_{ij}^{t,t*}$. From 1985 to 2005 optimal time has reduced by −14.9% while optimal distance has reduced by −0.3%.

Table 4: $\Delta GTC_{ij}^{t,t}$ **:** Shift-share analysis, 1980-2007

	Levels (Euros)			**Share in total costs (%)**		$\Delta GTC_{ij}^{80,07}$	
	1980 (1)	**2007 (2)**	**Δ 07/80 (3)**	**1980 (4)**	**2007 (5)**	**% (6)=(3)·(4)**	**(7)**
DIRECT COSTS	**140,97**	**117,84**	**-16,41**	**0,92**	**0,92**	**-15,12**	**92,80**
Distance costs	**70,61**	**66,25**	**-6,18**	**0,46**	**0,52**	**-2,85**	**17,50**
Fuel	33,66	38,66	14,86	0,22	0,30	3,27	-20,04
Accom. & allow.	19,47	14,41	-26,00	0,13	0,11	-3,32	20.31
Tire	11,38	6,75	-40,68	0,07	0,05	-3,05	-18.75
Maint. & repair.	5,74	5,82	1,35	0,04	0,05	0,05	-0.31
Toll	0,35	0,60	71,53	0,00	0,00	0,17	-1.01
Time Costs	**70,36**	**51,59**	**-26,67**	**0,46**	**0,40**	**-12,27**	**75,30**
Capital	24,99	17,24	-31,00	0,16	0,13	-5,06	31,08
Amortization	17,37	14,36	-17,32	0,11	0,11	-1,97	12,06
Financing	7,62	2,88	-62,19	0,05	0,02	-3,10	19,00
Operating	45,37	34,35	-24,29	0,30	0,27	-7,21	44,22
Labor	31,02	26,73	-13,83	0,20	0,21	-2,80	17,17
Insurance	13,45	6,68	-50,35	0,09	0,05	-4,42	27,15
Taxes	0,90	0,94	4,39	0,01	0,01	0,03	-0,16
INDIRECT COSTS	**11,96**	**10,16**	**-15,00**	**0,08**	**0,08**	**-1,17**	**7,17**
ECONOMIC COSTS	**152,93**	**128,00**	**-16,30**	**1,00**	**1,00**	**-16,30**	**100,00**

Source: Own elaboration

4.4. Decomposing GTCs using index numbers: economic and infrastructure components.

We now decompose the variation of the trade weighted average of the generalized transport costs $\Delta GTC_{ij}^{0,t}$ to identify the individual sources behind its reduction in terms of transport economic costs and the infrastructure accessibility variables. We recall the decomposition introduced in the methodological section regarding the Laspeyres-Konüs and Paasche-Konüs cost of producing price indices and their corresponding implicit quantity indices, their geometric mean—Fisher-type—decomposition given in eq. (11), as well as their fixed base and interperiodical cumulative versions: eqs. (12), (13) and (14), respectively. Table 5 shows these results regarding the relative contribution that the change in economic costs $EC_{ij}^{0,t}$, and the infrastructure accessibility variables $IC_{ij}^{0,t}$, make to the reduction in GTCs.

For the overall period between 1980 and 2007, about two thirds of the reduction in GTCs are the result of improvements in the network infrastructure as described in section 3.2 (with a cumulated percentage reduction of –10.0%), which have resulted in shorter distances and transport times. The remaining 7.0% corresponds to the relative deflation of constant economic costs which we have analyzed discussed in section 3.1. Thus, the role of infrastructure on GTCs reduction is much larger than the one played by the reduction of economic costs. This result is not surprising for the Spanish case since it was in this period when the central and regional administrations, making use of major European development programs such as the structural and cohesion funds (*e.g.*, ERDF), more heavily invested in the enlargement and improvement of the high capacity road network. [13] We can also consistently study the cumulated change in the GTCs and its economic and infrastructure components in periods of five years. Table 5 shows that the reduction in GTCs driven by infrastructure reductions is monotonic as it constantly reduces in a cumulative way. However, the inflationary trends affecting fuel and labor costs as a result of the oil crisis and the indexation of salaries to the consumer price index (increasing on average about 10% yearly in the 1980's)[14], explain why the increase of the price economic index compensates the reduction of the quantity infrastructure index, resulting in a 3.0% increase of the GTCs between 1980 and 1985. While in the following five years the economic index still signals an inflationary process of 0.8% with respect to the base year, the fall in its infrastructure counterpart (–3.5%) compensates that increment, thereby resulting in a –2.7% reduction in the GTC. From 1990 onwards both the economic and infrastructure indices follow the same reducing trends (for the 1990/1980 period the situation even reverses and the cumulated economic index falls by a greater percentage that the infrastructure index (–6.4% *v.* –5.0%).

Table 5: Decomposition of the fixed base $\Delta GTC_{ij}^{0,t}$ into economic and infrastructure components.

	Fixed based indices			Percentage variation (%)		
	$\Delta GTC_{ij}^{80,t}$	$EC_{ij}^{80,t}$	$IC_{ij}^{80,t}$	$\Delta GTC_{ij}^{80,t}$	$EC_{ij}^{80,t}$	$IC_{ij}^{80,t}$
85/80	1.0296	1.0387	0.9912	2.96	3.87	–0.88

[13] The approach followed by Combes and Lafourcade (2005) to identify the sources of GTCs reduction relies on the calculation of the Laspeyres (producer) price index for transport costs EC_{ij}^{L} that assumes that the optimal itineraries do not change over the whole period (*i.e.*, average optimal distance and time remain constant). Expressing in percentage the variation of the arithmetic mean of the generalized transport costs $\Delta\overline{GTC}_{ij}^{0,T}(\%)$ and that of the economic costs $\overline{EC}_{ij}^{L}(\%)$, they calculate the contribution of infrastructure as a residual: $\overline{IC}_{ij}(\%) = \Delta\overline{GTC}_{ij}^{0,T}(\%) - \overline{EC}_{ij}^{L}(\%)$. We have performed equivalent calculations to determine the bias that this simplification causes on the economic index and, by extension, the associated infrastructure index. Particularly, we calculate the standard Laspeyres price index EC_{ij}^{L} and compare it to the true Laspeyres-Konüs price index EC_{ij}^{0} —eq. (5). For the whole period the bias in economic costs is $BE_{ij} = EC_{ij}^{0} - EC_{ij}^{L}$ = 0.9299 – 0.9336 = – 0.0037 or –0.37 percentage points. As a result the contribution of economic costs to GTCs decline using the Laspeyres formulation is lower than the true one by an amount that can be related to the true index: BE_{ij} (%) / EC_{ij}^{0} (%) = – 0.37 / – 7.01 = 5.3%. Also, using (9) we can determine the corresponding bias in the Paasche-Konüs implicit quantity index resulting in an overstatement of the contribution of infrastructure by $BI_{ij} = IC_{ij}^{1} - IC_{ij}$ = 0.9901–0.8966 = 0.0036 = 0.36 percentage points, or 3.5% of the true IC_{ij}^{1} (%). At a NUTS 3 provincial level, the maximum observed economic bias corresponds to Castellón (Comunidad Valenciana) with –1.53 percentage points, resulting in a overestimation of the true contribution of infrastructure to GTC decline by 1.42 percentage points.

[14] The annual change rate of the CPI over the previous year was –15.6% in 1980 and –6.7% in 1990.

90/80	0.9729	1.0084	0.9648	−2.71	0.84	−3.52
95/80	0.8896	0.9363	0.9501	−11.04	−6.37	−4.99
00/80	0.8921	0.9597	0.9295	−10.79	−4.03	−7.05
05/80	0.8462	0.9339	0.9062	-15.38	−6.61	−9.38
	$\Delta GTC_{ij}^{80,07}$	$EC_{ij}^{80,07}$	$IC_{ij}^{80,07}$	$\Delta GTC_{ij}^{80,07}$	$EC_{ij}^{80,07}$	$IC_{ij}^{80,07}$
07/80	**0.8370**	**0.9304**	**0.8996**	**−16.30**	**−6.96**	**−10.04**

Source: Own elaboration

, resorting to the index number methodology and the transitivity property we can complete our study of the reduction in GTCs by calculating their periodical changes—eq. (14). Table 6 shows the change that takes place as the base period is updated every five years. While the first row coincides with that of Table 5 since the base year corresponds to 1980, this is not the case for the rest. Here we can identify the third period between 1990 and 1995 as the one where the contribution of the economic index is the largest (−7.15%). In this period the price of fuel exhibited mild increases and inflation levels sharply reduced thereby containing salaries. Additionally the reduction in interest rates resulted in lower capital costs increases, while the rest of the categories followed a similar pattern. Nonetheless, in the following five years period the situation reversed and economic costs increased by 2.5%. As anticipated, this uneven evolution of the economic index is not observed in the periodical infrastructure index that presents a steady decline over the years. As a result we conclude that the successive investments in high capacity roads have contributed steadily to the reduction of GTCs in all periods except the first five years when the modernization of Spanish roads was taking off.

Table 6: Decomposition of interannual $\Delta GTC_{ij}^{t,t+1}$ into economic and infrastructure components.

	Interannual indices			**Percentage variation (%)**		
	$\Delta GTC_{ij}^{t,t+n}$	$EC_{ij}^{t,t+n}$	$IC_{ij}^{t,t+n}$	$\Delta GTC_{ij}^{t,t+n}$	$EC_{ij}^{t,t+n}$	$IC_{ij}^{t,t+n}$
85/80	1.0296	1.0387	0.9912	2.96	3.87	−0.88
90/85	0.9449	0.9709	0.9733	−5.51	−2.91	−2.67
95/90	0.9143	0.9285	0.9847	−8.57	−7.15	−1.53
00/95	1.0028	1.0250	0.9783	0.28	2.50	−2.17
05/00	0.9486	0.9730	0.9749	−5.14	−2.70	−2.51
07/05	0.9891	0.9963	0.9928	−1.09	−0.37	−0.72

Source: Own elaboration

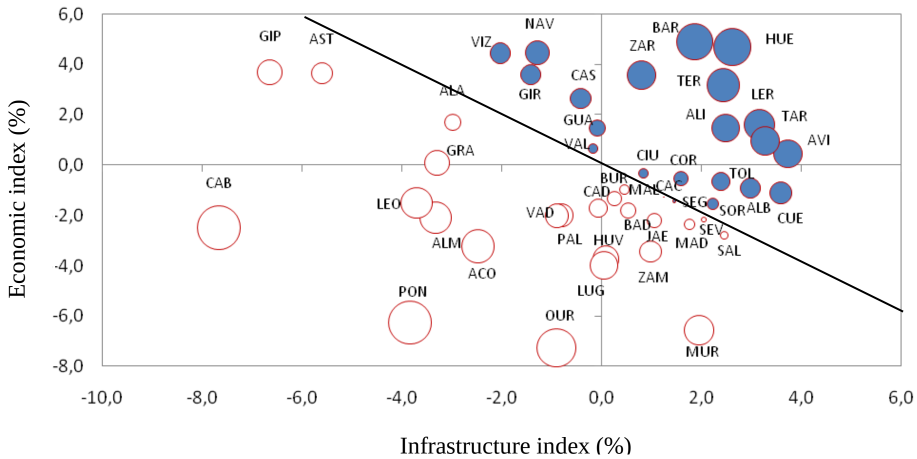
4.5. Geographical analyses of GTCs variation: spatial association and territorial cohesion

5.1. Geographical clusters of GTCs variation: the market and network effects

The GTCs and their economic and infrastructures indices present large territorial disparities. Examining variation values at the NUTS 3 level, we find that in 31 out of the 47 provinces the reduction in the infrastructure index is larger than that of the economic index. This suggests that the expansion and improvement of the high capacity road network have played the leading role in the reduction of the GTCs over the last three decades in Spain. But, as expected, this effect has not been geographically homogeneous. The contribution of infrastructure has been larger within those peripheral regions whose accessibility to the Iberian peninsula was the lowest as a result of physical barriers, particularly the provinces situated by the Bay of Biscay (Galicia, Asturias, Cantabria, and The Basque Country), as well as some Andalusian provinces situating in the southeast of the peninsula (Almeria and Granada). On the contrary, those provinces situating in the center have profited relatively less from the new infrastructure; particularly Madrid and the surrounding provinces.

Before we determine whether there are significant clusters in their variations by way of the Moran global and local indicators of spatial association, we analyze particular trends of the economic and infrastructure indices following the methodological approach proposed by Camagni and Capellin (1985). The central idea consists of studying the evolution of the variation of GTCs by plotting their economic and infrastructure components with respect to the national average. This makes it possible to differentiate four categories of regions: leading provinces where both indices fall more the national average, lagging provinces where they fall less, economic driven regions where this component falls more but the infrastructure component does not, and infrastructure (accessibility) driven regions where the opposite is observed. In Figure 6 all four categories are present. Provinces in shaded circles lag behind in both the economic and infrastructure indices, or just one of them, but still presenting lower GTCs reductions that the national average (represented by the 45º degree bisecting line). Contrarily, clear circles portrait leading provinces where both indices fall below the average, or at least one of the two, but resulting in this case in larger GTCs reductions than the average. We find a differential of eight percentage points between the regions with the largest and smallest cumulative infrastructure decrease. Among those regions most benefited by the improvements in the infrastructure network, we find Cantabria (CAB), where its contribution to the fall of the GTCs presents a remarkable –17.5% (7.5 percentage points more than the Spanish average situating at –10.0%), twice the reduction in its economic index to the tune of –9.3% (2.3% percentage points below the –7.0% average). On the other hand the region where the contribution of infrastructure is larger in relative terms with respect to the economic costs is Asturias (AST), where the former is five times larger than the latter (–15.5% and –3.2%, *i.e.*, –5.5 and 3.8 percentage points below and above the average respectively). Even with this simple analysis we observe emerging patterns of spatial association, with the four Galician provinces situating in the northwest of Spain (PON, ACO, OUR, LUG) leading GTCs reductions, while all four northeast Catalonian provinces (GIR, BAR, LER, TAR) present the lowest GTCs reductions.

Figure 6. Economic $EC_{ij}^{80,07}$ and infrastructure $IC_{ij}^{80,07}$ indices, (%)



ing of the economic and infrastructure indices should be expected as long as neighboring provinces present similar evolution in their costs structures and infrastructure endowments. For example, regarding the economic costs of transportation services, labor expenses will exhibit similar trends in those areas comprised in a single geographical market, and where changes in the industry structure and regulations take place simultaneously. The same would apply to other elements such as accommodation and allowances, maintenance and repairing, tires, etc., where the degree of competition will result in similar pricing rules (*e.g.*, mark-ups) as long as there is an effective competition between firms within a geographical range. In fact, we have shown that economic costs in levels and change rates largely differ across Spanish regions as a result of all these factors, and since the likelihood of similar trends in economic costs depends on how the specific input markets are integrated across neighboring regions, as well as on how effective competition and market performance shape similar pricing rules, we associate the presence of spatial clustering in cost trends to the degree of market integration, *i.e.*, the existence of a geographical *market effect*. In the case of changes in the infrastructure endowments, similar contributions of infrastructure investment to GTCs decline in neighboring areas would take place as long as improving a given arc of a road network also benefits the remaining elements. In general, this would be the case in radial networks (also referred to as “star” or “hub and spoke”) as the one existing in Spain in the eighties, where the peripheral and central regions connected by corridors jointly benefited from the improvements of the radial arcs. Here we can remark two questions concerning this issue. Firstly, the benefits are normally asymmetrical since for an outer node the development of its radial connection is critical when increasing its accessibility to the whole network, while for the center, that particular connection is only one of its multiple radial links. This is further reinforced when trade weighted GTCs variations and their components are taken into account since all exports from an outer node must travel the radial arc, and therefore fully benefit from its improvements, while the percentage of exports from the center toward that node is only a share in its total exports. For the Spanish case we observe this result, by which reductions in GTCs driven by infrastructure improvements are larger in peripheral regions that central regions—particularly until 1995 when the radial network of high capacity roads was completed. Secondly, it is normally the case that in radial networks the outer nodes are further conformed of clusters of provinces presenting a subnetwork structure (*e.g.*, in the Spanish case, Galicia, the Basque country or Catalonia are good examples), while the center corresponds to a single territory (*e.g.*, the Madrid region itself). Given this network topology, improving a spoke benefits all provinces conforming an outer node, and when this takes place it is natural to observe contemporary improvements in their accessibility variables. These patterns of asymmetrical and contemporary shared benefits from infrastructure improvements are the result of what is termed in the accessibility literature as transportation *network effects* (van Excel *et al.*, 2002).

To determine whether exists spatial autocorrelation at the aggregate level in the variation of the GTCs, as well as its economic and infrastructure components associated to the market and network effects, we have calculated Para medir si existe autocorrelación espacial en la variación de los GTCs y de sus componentes (EC, IC) se ha calculado el MMoran's indicator for all these indices (see Anselin, 1995). This measure allows us to evaluate whether the spatial pattern of the variations is clustered, dispersed, or random. An statistically significant value of the indicator in the proximity of 1.0 indicates clustering, while a value near –1.0 indicates dispersion. The results reported in Table 7 show positive and significant statistically values, confirming the spatial clustering of the variations. Even if the values corresponding to the variation in economic variables and infrastructure are similar, the larger value of the latter suggests that the network effect predominates over market effect when favoring the spatial clustering.

Table 7. Spatial autocorrelation of variations: Moran's index

	Moran indicator	*p*-value
$\Delta GTC_{ij}^{80,07}$	0,2346	0,0000
$EC_{ij}^{80,07}$	0,2378	0,0000
$IC_{ij}^{80,07}$	0,2740	0,0000

Source: Own elaboration

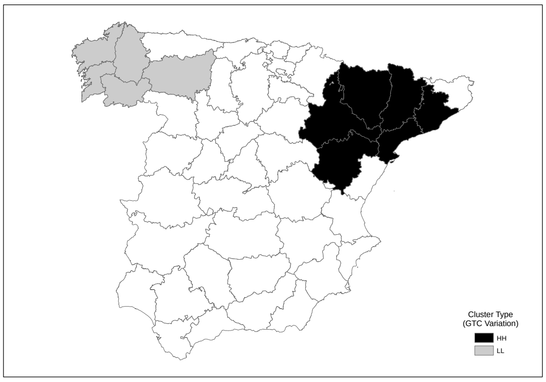
Las f

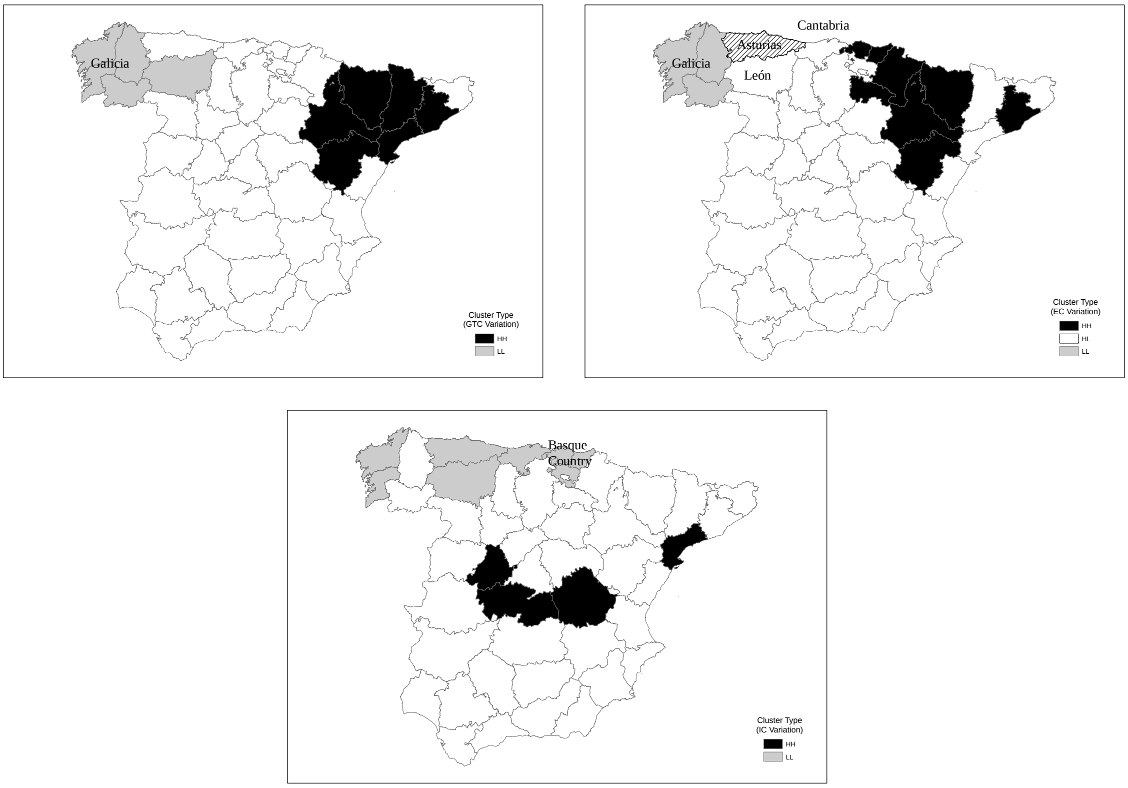
This is further corroborated in Figures 7a, 7b and 7c where the values of the local Moran's indicator (Anselin's Local Moran Indicator) are portrayed. This indicator allows identifying areas where the spatial clustering is more intense—as suggested in Figure 6. At a NUTS 3 level, when a province presents a high value of the variation in GTCs, economic costs or infrastructure costs, and it is surrounded by other provinces with similar values, they conform a high-high (HH) spatial cluster. In our case, this implies a lower reduction in the GTC and its components, since the higher the value of the indices, the lower their reduction from the base year. Contrarily, low-low (LL) pairings signal the existence of significant clusters where GTCs and their components have decreased most. The remaining combinations: HL and LH, would be observed when a province of one of the two types is surrounded by regions of the other type. A situation that is not likely to emerge since it would be indicative of separate geographical markets for the input factors regarding economic costs, and from an infrastructure perspective, the case of isolated provinces that do not profit from network effects because of geographical barriers.

As regards La variación de los generalized transport costs variations, $\Delta GTC_{ij}^{80,07}$, there is a cluster of provinces exhibiting larger reductions (LL) in the northeast: Galicia and León, whose sources are both reductions in economic costs $EC_{ij}^{80,07}$, as well as in the distance and time infrastructure variables of accessibility $IC_{ij}^{80,07}$. Contrarily, in the northeast: Catalonia and Aragon, we find a significant cluster of provinces where the GTCs variation is below the average, presenting an HH profile. The source of this latter clustering is the jointly significant increase in economic costs in these neighboring provinces that prevents a larger decline in the generalized transportations costs (Figure 7b). Interestingly, in Catalonia and Aragon there does not exist an HH pattern for infrastructure, a situation signaling that the benefits from larger accessibilities can be found in some of the provinces within these regions, and therefore there is not a significant spatial cluster of relatively low declines (HH) in the $IC_{ij}^{80,07}$ indices for these provinces (Figure 7c).

We identify two interesting cases that show the potentiality of the spatial association analysis when identifying clusters in terms of the generalized, economic and infrastructure transport costs. The case of the Basque Country provinces is noteworthy because we identify two opposite clustering in terms of economic costs and infrastructure costs. This region conforms an HH cluster in terms in economic costs $EC_{ij}^{80,07}$, meaning that they decrease below the Spanish average, while it has benefited from accessibility gains since they also conform a significant cluster of LL infrastructure costs $IC_{ij}^{80,07}$ as result of the decrease in distance and time. Consequently, both trends compensate each other and we do not observe any clustering in terms of $\Delta GTC_{ij}^{80,07}$. The second case corresponds to the Asturias province, situating in the northwest where we identify a significant HL cluster regarding economic costs. This situation emerges because economic costs have decrease to a lesser extent in this region than in those surrounding it. This disparity is the result of the specific market determinants. Comparing the evolution in key economic costs representing the highest shares in the reference transport costs, we find that fuel, salaries, and capital costs in Asturias varied by 6.1%, 38.3% and −17.4%, respectively, while in Lugo, laying east from Asturias, these three costs varied by −10.8, 26.5% and −21.4%; and similarly for the provinces of Cantabria and León laying west and south, respectively.

ure 7. Spatial clustering: Anselin’s Local Moran indicator: a) $\Delta GTC_{ij}^{80,07}$, b) $EC_{ij}^{80,07}$ and c) $IC_{ij}^{80,07}$





ource: Own elaboration.

5.2. Effects of GTCs variation on territorial cohesion

conclude our geographical analyses studying the effects of the variation of GTCs on territorial cohesion using their relative concentration or dispersion around the mean over the different periods. This concept is related with regional convergence or integration and it is gaining more relevance in European Union countries, mainly after the introduction of the goal of territorial cohesion in the EU agenda as a main policy objective (CEC, 2004). The EU defines territorial cohesion as a balanced development, with less regional disparities, and deems transport policy as one of the main instruments to improve it. TParticularly, as a way to increase the accessibility of peripheral regions with central markets. Considering that the equal access to markets is one of the main indicators reflecting whether territorial cohesion has been achieved, in this section we analyze the convergence–divergence of GTCs as a proxy of changes in regional disparities. In order to do so, we use a set of indicators frequently used in the literature (*e.g.*, Ramjerdi 2006, López *et al.*, 2008). Particularly, the Gini coefficient, the variation coefficient and Theil's index. If the variation in GTCs and their components show a convergence tendency, then territorial cohesion in terms of accessibility levels has increased.

Table 8 reports these measures of dispersion for the generalized transport costs variation and the reference economic costs and network infrastructure. Particularly, we measure the relative dispersion at the NUTS 3 provincial level using: (i) the trade weighted version of eq. (3) $GTC_{ij}^{t,t}$, which allows us to determine whether GTCs themselves have converged over the years; (ii) eq. (8): $GTC_{ij}^{t,80}$ measuring the convergence of the GTCs driven by the equalization of the reference unit economic costs since the infrastructure network is kept constant in the base year, and therefore it plays no role in GTCs variations; and, finally, (iii) the counterpart to eq. (8):

$GTC_{ij}^{80,t}$, measuring whether GTCs have converged due to the equalization of the accessibility variables of distance and time—brought about by the improvements in the road infrastructure, since the unit economic costs are kept constant in the same base year. All three measures indicate an overall reduction in regional disparities in terms of accessibility to markets and therefore an increase of territorial cohesion. The Gini coefficient shows a cumulated reduction in dispersion by −7.1% for $GTC_{ij}^{t,t}$, situating between those corresponding to the variation coefficient and Theil's index. Considering the reductions in the disparities regarding the reference unit economic costs $GTC_{ij}^{t,80}$, and the accessibility variables associated to the infrastructure $GTC_{ij}^{80,t}$, the latter presents a larger convergence with a reduction in disparities of −4.1% in the Gini coefficient, while the former reduces by −1.5%. This result is quite robust since it holds independently of the dispersion measure that is used. Consequently, this analysis confirms that the main driver behind the reduction in territorial disparities in terms of GTCs is the infrastructure investment policy implemented by the Spanish central and regional administrations, particularly in the 1995-2007 period. The fact that the larger reduction in disparities took place in this period instead of 1980-1995 is due to the fact that in this earlier period all major road investments projects were devoted to improve the radial connections between the periphery and the center of the Peninsula, while in the later period investments reinforced the grid nature of the transport network, which benefits peripheral areas more than central areas. Also, it is not surprising that economic costs were less relevant when driving transport cost down, since besides the drastic technological improvements (in the reference vehicle, logistics, etc.), other political actions determining market conditions such as those aimed at liberalize and deregulate labor and capital markets have not been as successful as their infrastructure counterparts. In this sense all factors already discussed in section 3.1 presenting the evolution of the reference unit economic transport costs, and falling in the realm of market dynamics that cannot be steered by governments, finally result in economic cost variations that present lower reductions in regional disparities.

We can therefore conclude that transport infrastructure as a regional policy instrument has proved successful in reducing accessibility disparities in the Spanish provinces, and that this reduction in the distance and time variables have brought less GTCs disparities as well. It is beyond the scope of this paper to study what are the consequences of this reduction of the GTCs in terms of the location of economic activity, but it is a well-known fact that *within* countries regional disparities of GDP per capita have not decrease in Europe throughout this period, including Spain, see Duro (2004). Therefore, the generally accepted notion of higher road infrastructure investment bringing larger regional cohesion would not be supported in the Spanish case—as studied for the Italian case by Faini (1983), which in turn corroborates the main proposition emanating from new economic geography models that reducing transport costs may favor core-periphery patterns, and warning against indiscriminate infrastructure investments that could result in larger disparities, Ottaviano (2008).

Table 8 – Variation of territorial cohesion: $GTC_{ij}^{t,t}$, $GTC_{ij}^{t,80}$ and $GTC_{ij}^{80,t}$.

		Inequality measures			Variation 1980-2007 (%)		
		GINI coefficient	Variation coefficient (%)	Theil's index	GINI coefficient	Variation coefficient (%)	Theil's index
$GTC_{ij}^{t,t}$	**1980**	0,0703	18,38	0,0075	–	–	–
	1985	0,0699	18,27	0,0074	–0,58	–0,61	–1,86
	1990	0,0680	17,75	0,0071	–3,28	–3,40	–6,27
	1995	0,0705	18,49	0,0075	0,28	0,63	–0,03
	2000	0,0676	17,62	0,0070	–3,80	–4,12	–6,98
	2005	0,0658	17,48	0,0069	–6,38	–4,88	–8,47
	2007	0,0653	17,35	0,0068	–7,06	–5,58	–9,72
$GTC_{ij}^{t,80}$	**1985**	0,0705	18,44	0,0075	0,27	0,32	–0,21
	1990	0,0683	17,79	0,0071	–2,77	–3,20	–5,80
	1995	0,0698	18,12	0,0073	–0,75	–1,43	–2,33
	2000	0,0700	18,19	0,0074	–0,45	–1,02	–1,06
	2005	0,0698	18,32	0,0076	–0,71	–0,33	0,37
	2007	0,0692	18,14	0,0074	–1,55	–1,29	–1,07
$GTC_{ij}^{80,t}$	**1985**	0,0695	18,19	0,0074	–1,04	–1,03	–1,80
	1990	0,0699	18,32	0,0075	–0,53	–0,31	–0,77
	1995	0,0711	18,90	0,0078	1,21	2,81	3,31
	2000	0,0680	17,82	0,0071	–3,24	–3,02	–5,89
	2005	0,0672	17,57	0,0069	–4,40	–4,38	–8,35
	2007	0,0674	17,56	0,0069	–4,11	–4,45	–8,70

Source: Own elaboration

6. Conclusions

costs and their economic (price) and infrastructure (quantity) determinants. The former is related to the reference unit operating costs, while the latter corresponds to the distance and time accessibility determinants. Given its desirable axiomatic and theoretical properties, we decide for a fixed-based version of GTCs variations satisfying the transitivity property or circularity test, and where each one of the two mutually exclusive economic and infrastructure components corresponds to the Fisher formulation. We believe that the existing studies of the variation of GTCs can benefit from the proposed analytical framework so as to improve their methods and accurately measure and compute the contribution that these elements make to GTCs reductions.

From an empirical perspective we illustrate our proposed methodology calculating the GTCs in freight road transportation in Spain for five years periods between 1980 and 2007. For this purpose we construct a very detailed economic database of the operating costs of the reference vehicle at the NUTS 3 provincial level, and embed into a GIS containing the actual road transport network. For the GIS implementation we also rely on a very detailed geographical representation consisting of 678 transport zones. We make use of the cheapest path routing algorithms to calculate optimal itineraries associated to the minimum GTCs, which are later on grouped into the 47 provinces for which individual economic costs exist, and averaged arithmetically or by way of trade flows so as to take into account the actual patterns of trade. Our results show that trade weighted GTCs declined by 16.3% from 1980 to 2007, and relaying on a consistent index number decomposition of this value index we learn that the main driver behind this fall is the contribution made by the infrastructure improvements in the form of time and distance reductions. In terms of variation rates, the reduction in GTCs associated to infrastructure amounts about two thirds of the overall GTC decline, –10.0%, with the reduction in economic costs accounting for the rest. From a time perspective GTCs reductions are more intense in the 1990-1995 and 2000-2005 periods. In these years the steady improvements in road infrastructure, generally observed throughout the whole period, are reinforced with the fall in the reference economic costs, both sources contributing to the largest GTCs reductions.

We find a large geographical heterogeneity in both GTCs levels and their variations, particularly for the arithmetically averaged GTCs. In this case, the usual center-periphery pattern favoring Madrid as the region with the lowest GTCs thanks to its central location and high capacity road network. The picture is not so clear when trade weighted GTCs are considered since commercial flows are clearly constrained by many factors such as transport costs themselves, but also the economic specialization of regions in sectors producing goods with high weight to value ratios and prone to trade by road transportation (*e.g.*, manufactures)—as studied by Duranton *et al.* (2011). However, using different global and local indicators of spatial correlation we are able to identify relevant clusters where GTCs variation and their components exhibit a significant geographical association. Particularly, the values of the local Moran index do not only indicate significant clustering of GTCs variations in the northeast and northwest of Spain—with GTCs falling below and above the national average, respectively, but also relevant market effects where the trends in economic costs correlate in neighboring regions, as well as relevant network effects where the improvements in the road infrastructure translate into distance and time reductions that also correlate in space.

Finally, we study whether GTCs and their components converge or diverge through time, so as to draw relevant implications from the perspective of transportation policy. Using several measures of dispersion we find a robust convergence process in the GTCs accompanying their –16.3% decrease. This leads to the conclusion that the transportation policies implemented in Spain between 1980 and 2007 have contributed to the overall reduction in regional disparities in terms of accessibility to markets, and therefore an increase of territorial cohesion. In this sense we can differentiate between (i) those *economic policy* measures resulting in lower operating costs—*i.e.*, deregulation initiatives bringing more flexible and competitive labor and capital markets (*e.g.*, reforming labor contracts or the adoption of the Euro, respectively)—, and (ii) those project-specific investment decisions conforming the *infrastructure policy*, aimed at the improvement of the road network. It could be argued that both types of policies have resulted in a reduction in regional disparities, but since the evolution of economic costs does not only depend on the actions undertaken by the governing administrations but mainly on global market forces (*e.g.*, fuel costs depending on oil prices), while investment decisions are taken almost exclusively at a political level, we confirm that infrastructure policies have had a larger effect on GTCs than economic policies. In the light of these results we conclude that transportation policy both at the economic and infrastructure levels, whose effects on the GTCs can be associated precisely to the changes in these particular components, have proved successful in Spain in driving the cost of transportation down. Since the departure point of Spain in the base year of

1980 corresponded to a country where the transport market was still subject to intense regulation, and where networks were relatively underdeveloped in terms of high capacity roads and connections between peripheral regions, we believe that the Spanish experience can serve as an useful benchmark to plan and design similar policies in other developing countries in the same situation.

Appendix 1. Formulae and technical-economic hypotheses for the estimation of the reference economic costs (*<u>ONLY FOR REFEREEING UNLESS OTHERWISE DIRECTED</u>*).

1.1 Formulae for the estimation of economic costs

A) *Fixed costs*: *Capital*

A.1) *Amortization:* The constant amortization criterion has been applied to estimate the annual amortization charge of each component (tractor truck and trailer). The sum of both charges yields the amortization cost:

$$A_T = A_C + A_S = \frac{V_C - R_C}{N_C} + \frac{V_S - R_S}{N_S}, \tag{A.1}$$

where C represents the tractor truck and S the trailer. A_i is the annual amortization charge, V_i the gross purchase price (excluding VAT and once the cost of tires has been discounted), R_i is the residual value (% of the purchase price), and N_i is the useful life of each element (in years).

A.2) *Financing*:

$$F_T = F_C + F_S = \frac{\left(t \cdot \dfrac{P_C ij}{j-1}\right) - P_C}{N_C} + \frac{\left(t \cdot \dfrac{P_S ij}{j-1}\right) - P_S}{N_S}, \tag{A.2}$$

where F_i is the annual financing cost, t the number of years for financing, P_i is the gross loan (in % of the net purchase price), i is the interest rate, and j is the capitalization rate: $j = (1+i)^t$. The interest rate applied was the one-year Euribor plus a 1.5% differential.

B) *Fixed costs: Operating*

B.1) *Labor*: Annual labor costs are approximated by the annual gross salary of a heavy vehicle driver, which are fixed in the regional freight road transport collective agreements. This proxy includes seniority, distance, assistance and extraordinary bonuses (Christmas, July and profits). Other spending related to Social Security are also included. These expenses accounts for the 37,2% of the reference salary.

B.2) *Insurance*: Annual insurance costs include fully comprehensive insurance on the vehicle, civil Responsibility, insurances on freight losses, driving license withdrawal and other insurances related to the driver and the people travelling with the vehicle.

B.3) *Taxes*: Annual fiscal costs include taxes on the company (for instance, the Tax on Economic Activities) and other charges on the vehicle (Technical Inspection of Vehicles, Inspection of Mechanical Traction Vehicles, authorization visa…)

C) *Variable costs:*

C.1) *Fuel*:

$$G = \frac{P_G \cdot C_G \cdot k}{100} , \tag{A.3}$$

where G is the annual fuel cost, P_G is the net purchase price (excluding VAT but including fuel discounts), C_G is the average fuel consumption (in liters for every 100 km), and k the annual distance travelled by the vehicle (kms).

C.2) *Accommodation and allowance*: Annual accommodation and allowance costs include spending on lunch (half day allowance), dinner, bed and breakfast (whole day allowance). The activity bonus (0,0488 Euros per km according to the Spanish Ministry of Public Works) is also included in this category.

C.3) *Tires*:

$$N = \frac{P_n \cdot n \cdot k}{D_n} , \tag{A.4}$$

where P_n is the gross purchase price of every tire (excluding VAT), n is the number of tires, k is the annual distance travelled (kms), and D_n is the average life of each tire (in kms).

C.4) *Maintenance and repairing*:

Within tThis category includes expenses related to both routine replacement of original auto parts (e.g. filters), other preventive processes (*maintenance*), as well as those costs related to unexpected breakdowns (*repairing*). Both are accounted per kilometer.

C.5) *Tolls*: An average toll is estimated weighting net prices (excluding VAT) by the distance over toll highways and the average daily intensities of traffic flows.

D) *Indirect costs:*

Three firm sizes have been analyzed (from 1 to 5 vehicles, from 6 to 19, and more than 19) and then a weighted average indirect cost has been estimated. They included office (real state, supplies, cleaning …), labor (management, administrative, commercial), equipment and facilities, and other financial costs related to the cash flow.

1.2 Price indices and variables used to update the reference economic costs:

When yearly data on a particular variable is not been available, its value has been calculated using the available prices indices. These indices accurately show the price evolution of each cost category with enough accuracy and periodicity. In the following lines, the price indices that have been used for each cost category are explained:

A.1) *Amortization*: To extrapolate the purchase prices for the tractor trucks and trailers the label 'motor vehicles and trailers manufacturing' of the Industrial Prices Index, as published by the Spanish Statistical Institute, has been used.

A.2) *Financing*: Interest rates available from the Bank of Spain have been used.

B.1) *Labor*: To extrapolate labor costs the overall Consumer Prices Index, as published by the Spanish Statistical Institute, plus a 0.75% differential, is used.

B.2) *Insurance*: To extrapolate insurance costs the label 'automobile insurances' within the Consumer Prices Index, elaborated by the Spanish Statistical Institute, is used. When this label is not available, labels 'other spending related to automobiles' (1985-2002) or 'personal travel' (1980-1985) were used.

B.3) *Taxes*: Same criterion as for labor costs.

C.1) *Fuel*: Petrol prices available in the Ministry of Economy, Ministry of Industry, Tourism and Commerce, and companies such as CAMPSA or Repsol, have been used.

C.2) *Accommodation and allowance*: Same criterion as for labor costs.

.3) *Tires:* To extrapolate tires, maintenance and repairing costs the label 'maintenance and repairing services' within the Consumer Prices Index, as published by the Spanish Statistical Institute, has been used.

C.4) *Maintenance and repairing*: Same criterion as for tire costs.

D) *Indirect costs*: Same criterion as for labor costs (as labor indirect costs account for more than 75% of the overall indirect costs of the freight road transport companies in Spain).

1.3 Technical-economic hypotheses for the reference vehicle (40-ton articulated truck)

Table A.1: Economic and technical hypothesis for the reference vehicle, 1980–2007.

	1980	1985	1990	1995	2000	2005	2007
Characteristics of the vehicle							
Power (HP)	225	300	375	400	420	420	420
Maximum authorized load (Tn)	32	36	36	40	40	40	40
Useful load (Tn)	20	23,5	23.5	25	25	25	25
Number of axis	4	5	5	5	5	5	5
Number of tires	10	12	12	12	12	12	12
Labor hypothesis							
Worked days per year	225	225	225	225	225	225	225
Worked hours per year	1,906	1,906	1,906	1,906	1,906	1,906	1,906
Worked hours with load per year	1,620	1,620	1,620	1,620	1,620	1,620	1,620
Worked hours with load per year	8,5	8,5	8,5	8,5	8,5	8,5	8.5
Distance							
Kms. per year	90,000	94,925	100,119	105,597	111,375	117,470	120,000
Kms. with load per year	76,500	80,686	85,101	89,757	94,669	99,849	102,000
Fixed costs:							
Tractor truck price (without VAT)(1)	25.267,5	44.658,6	57.072,1	67.431,6	77.791,2	85.292,4	96.577,0
Tractor truck life (years)	8	8	8	6	6	6	6
Tractor truck residual value	20%	20%	20%	20%	20%	20%	20%
Trailer price (exc. VAT)	6,371.3	11,260.8	14,390.9	21,770.0	29,149.1	31,959.6	32,569.5
Trailer life (years)	10	10	10	8	8	8	8
Trailer residual value	15%	15%	15%	15%	15%	15%	15%
Total to finance	70%	70%	70%	70%	70%	70%	70%
Financing time (years)	4	4	4	5	5	5	5
Interest rate (Euribor + 1.5%)	19.25%	9.38%	9.75%	7%	7.8%	6.02%	6.70%
Logistics (hrs.)	2:30	2:07	1:47	1:30	1:16	1:04	1:00
Variable costs:							
Fuel consumption (l /100 km.)	49	45	42	40	38.5	38.5	36.5
Fuel discounts	0%	0%	1%	2%	3%	4%	5%
Tires life (km.)	100,000	100,000	100,000	135,000	135,000	135,000	135000

NOTE: **(1)** Net price including a common discount of 10 per 100.
Source: Own elaboration.

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