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A geographical analysis of economic and infrastructure
fundamentals

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

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Abstract

We use the economic theory approach to index numbers in order to improve the existing definitions and decompositions of generalized transport costs (GTCs), and thus to obtain a better understanding of their economic and infrastructure determinants. Using this approach we accurately measure the contribution made to reducing GTCs by the variation in operating costs and accessibility variables, and discuss to what extent transportation policy has been successful in reducing GTCs in terms of market competition and infrastructure investments. To implement the optimizing behaviour of transportation firms when choosing minimum cost itineraries, we compile a new economic database on road freight transportation at a highly detailed provincial level, which is then embedded into a GIS to show the digitalized road networks corresponding to five-year intervals between 1980 and 2007. Average GTCs weighted by trade flows have decreased by −16.3% in Spain, with infrastructure policy leading the way in providing notable accessibility improvements in terms of lower times and distances. The contribution of infrastructure is double that of economic cost, whose trends are mainly driven by technological and market determinants rather than by specific competition and regulatory policies promoted by the administrations. We find large territorial disparities in GTC levels and variations, but also significant clusters where the market and network effects on GTC reduction show relevant and diverse degrees of spatial association. We finally conclude that after three decades of active transportation policy aimed mainly 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.

JEL CODES: C43, H54, L92, R58

1. Introduction

The importance of accessibility from a locational perspective both for firms and individuals is paramount. This is particularly true both for micro and macro geographical analyses regarding 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. Although the importance of transport costs has been steadily declining in the past decades (Gleaser and Koolhase, 2003), the world is still quite far from being flat. Given their importance, many studies have been devoted to accurately defining and measuring 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 the point of view of a static cross-section 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 characterizing 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 as though the authors interested in these issues were reluctant to take their static cross-section efforts when studying transport costs to their logical extension to time-series analysis, in order to obtain consistent definitions, measures and calculations within the standard analytical framework represented by index numbers theory.

This somewhat lax attitude towards modelling changes in transport costs has serious consequences: (i) studies on the same transportation mode carried out by researchers at different times and in different countries are not comparable as they use different methodological approaches; (ii) scholarly work has a limited influence in encouraging national statistical agencies to adopt a standard methodology for the compilation and provision of price index series on transport costs on a regular basis; and (iii) the lack of time-series information hampers long term assessments 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 involves improving the existing methodology to accurately measure the change in transport costs over time within an index number framework and, by doing so, to provide a consistent decomposition of these changes that allows us to determine precisely 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 of the price and quantity indices into which the GTC variation decomposes. Specifically, 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 means of the product rule. We also adopt a chained version of the index that allows us to calculate the accumulated 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 in order to prove useful for analysis. It must 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, or GTC, which is defined as the minimum cost of transporting a given load of a particular commodity between a specific origin

and a destination, considering the economic variables related to the input costs necessary to produce the transportation service (*e.g.*, labour 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 data related to both market and geographical aspects, and is the result of an aggregation process that combines these elements when reflecting the optimizing behaviour of the economic agents, as is the case of firms seeking to minimize their transport costs. Taking this into consideration, and from the empirical perspective, we consistently calculate the variation in GTCs for the case of road freight 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 GTC 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 important 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 this to be the first time that the assumption of an optimizing behaviour on the part of economic agents is actually implemented to calculate Konüs indices from a producer perspective.

Finally, we have selected 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 minimum cost routes to be determined using 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 GTC in trucking transportation as presented by Combes and Lafourcade (2005) or Teixeira (2006), determining transport cost savings at the aggregate national level in France and Portugal, respectively; or the work by Martínez-Zarzoso and Nowak-Lehmann (2006) on GTC determinants along specific trade routes joining Spain with Poland and Turkey. However, with due respect to these contributions, we work with a richer database from both an economic and road network perspective. We have collected economic data for individual operating costs at a regional (NUTS 2) and –when available– provincial (NUTS 3) level (*e.g.*, labour and fuel costs, which represent over 50% of the overall costs, differ at the provincial level), allowing us to determine alternative economic cost 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 comprising 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 GTC variations and their components.

The paper is structured as follows. Section 2 presents the theoretical framework based on the economic theory of index numbers by defining the volume index corresponding to GTC variation and its decomposition into the Konüs cost of producing price index and its associated quantity index, related to transport economic costs and network infrastructure respectively. Data

description, both for the economic and infrastructure dimensions of the analysis, is presented in section 3. Section 4 shows the empirical results of the calculation of GTCs for the Spanish road freight transportation industry since 1980. Here we present the Konüs price and quantity indices and discuss the sources of GTC decline. Using Moran's indicator and Anselin's local indicator, in section 5 we explore the existence of significant geographical clusters where the variations in GTCs and their economic and infrastructure components exhibit significant 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 of 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 road freight transportation.[1] Here we expand their notation so as to introduce the index number methodology, and denote 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}. The arc speed, s_{a}^{t}, can be determined from these last two (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 ultimately summarized by its associated distance and time variables: d_{a}^{t} and t_{a}^{t}.

The economic distance unit costs (prices) in time t, denoted by e_{k}^{t}, *i.e.*, Euro per kilometre, 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 by multiplying the fuel price (Euro per litre) 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: $accom\&allow^{t}$; (iv) tire costs: $tire^{t}$, and,

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[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 for all the optimal values solving the minimum cost routes, is consistently used throughout the text for reasons that will become apparent below.

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

(v) vehicle maintenance and repair costs: *rep&mant*[t]. Taking into account these operating costs, the total distance cost is:

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

Likewise, the economic unit costs (prices) associated to time denoted by e_l^t –e.g., Euro per hour– include the following $l = 1,\ldots,6$ variables: (i) labour cost associated with gross salaries: lab_i^t, including social security payments; (ii) financial costs associated to amortization: $amort^t$; and (iii) vehicle financing: 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 overheads (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 economic time costs in period t, and the existing road infrastructure in t, the overall cost associated to travelling the whole length of an itinerary is: [4]

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

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: $\mathbf{I}_{ij}^t$:

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[4] Time could be allocated for "loading and unloading" the truck, which can generally be considered as the time associated to the ancillary logistics for a given transportation service: t_{log}^t. This would be a comprehensive variable that would capture the improvements occurring in schedule optimization techniques regarding truck 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 the extent to which the time associated to these transportation logistics has decreased over the years in the Spanish case, we omit loading and unloading times from the analysis.

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

$$= \sum_{a \in I_{ij}^t} \left(\sum_k e_k^t \right) d_a^{t,t*} + \left(\sum_l e_l^t \right) \left(\sum_{a \in \mathbf{I}_{ij}^t} t_a^{t,t*} \right) = \left(\sum_l e_l^t \right) \left(\sum_{a \in I_{ij}^t} \frac{d_a^{t,t*}}{s_a^t} \right), \tag{3}$$

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 should point out that from the economic theory approach to index numbers, these optimal accessibility values depend on 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 consider economic costs (*e.g.,* as in portable GPS devices).

2.2. Generalized transport cost variation and its decomposition

Since $GTC_{ij}^{t,t}$ is the outcome of an optimizing behaviour by firms which minimizes 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 in $GTC_{ij}^{t,t}$ between a base period *t* = 0 and the current period *t* = 1. This approach assumes that given the unit prices relating to distance and time incurred by the transportation firm in period *t*, the choice of the optimal itinerary based on 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 in $GTC_{ij}^{t,t}$ between two consecutive periods is defined through the following value aggregate index that compares the costs of the transportation service in both periods: [5]

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

As this index incorporates information relating to the change in both cost (economic) and physical (infrastructure) aspects, the problem is how to decompose it in a sensitive manner so as to identify the contribution that each one of these elements makes to the variation in GTC. This will result in a *price index* which comprises 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 the optimal

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[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.

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 rise to these variations we use the Konüs (1924) true cost of producing index, which at our current setting allows the comparison between the minimum cost of linking 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:

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

where the denominator corresponds to (3), but the numerator represents a hypothetical generalized transport cost: $GTC_{ij}^{1,0}$, involving the calculation of the cost 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.*,

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

$$TimeC_{ij}^{1,0} = \left(\sum_k e_k^1 \right) \left(\sum_{a \in \mathbf{I}_{ij}^0} t_a^0 \right) = \left(\sum_k e_k^1 \right) \left(\sum_{a \in I_{ij}^0} \frac{d_a^0}{s_{a(r)}^0} \right) =$$

$$= \left(lab_i^1 + amort^1 + fin^1 + ins^1 + tax_i^1 + ind_i^1 \right) \left(\sum_{a \in I_{ij}^0} \frac{d_a^0}{s_{a(r)}^0} \right). \tag{7}$$

Therefore,

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

$$= \sum_{a \in I_{ij}^0} \left(\sum_k e_k^1 \right) d_a^{1,0^*} + \left(\sum_l e_l^1 \right) \left(\sum_{a \in \mathbf{I}_{ij}^0} t_a^{1,0^*} \right) = \left(\sum_l e_l^1 \right) \left(\sum_{a \in I_{ij}^t} \frac{d_a^{1,0^*}}{s_a^0} \right). \tag{8}$$

If $EC_{ij}^0 < 1$, there is a deflationary process. Conversely, $EC_{ij}^0 > 1$ indicates an increase in economic costs, whereas $EC_{ij}^0 = 1$ 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 for the firm, which may opt for an alternative route, *e.g.*, if the price of toll highways in the current period decreases 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 vary 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) corresponds precisely to the familiar Laspeyres (1871) formulation that uses the base period quantities as a 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 means of the product rule. Denoting this infrastructure change index by IC_{ij}^1, 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:

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

The IC_{ij}^1 index reflects the change in the aggregate quantity variables using the current period unit prices as a 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 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. Conversely, $IC_{ij}^1 > 1$ would indicate an increase in transport costs, caused by deterioration in the infrastructures (as would be expected in countries where the condition of the infrastructures declines due to lack of maintenance). Finally, a value of $IC_{ij}^1 = 1$ would be obtained when changes in the infrastructure network do not produce 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* which considers the reference network infrastructure to be the one existing in the current period $t = 1$.

In this 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 as (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 $\Delta GTC_{ij}^{0,1} = GTC_{ij}^{1,1} / GTC_{ij}^{0,0} = EC_{ij}^1 \cdot IC_{ij}^0 = \left(GTC_{ij}^{1,1} / GTC_{ij}^{0,1}\right) \cdot IC_{ij}^0$, allowing us to recover its counterpart *Laspeyres-Konüs implicit quantity index*, which uses the base period prices as a 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 note 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 calculating their implicit quantity indices IC_{ij}^1 and IC_{ij}^0, it also possible to start out by defining these quantity indices and, from there on, to recover their associated price indices by means 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 as those already introduced, but represents an alternative way to obtain the economic and infrastructure components into which generalized transport cost variations can be decomposed.

2.2.2 The Fisher version of GTC variation and the transitivity property

These results show that there are two alternative ways of decomposing the variation in 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 $\Delta GTC_{ij}^{0,1}$, which does not settle for one particular period, but takes them both into account in a symmetrical way:

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

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

(11)

We 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 such as 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. These might include, for example, time periods where there have been major investment efforts resulting in improvements in the transportation network, which should translate into larger GTC reductions, or price inflationary periods that would have the opposite effect due to 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 see that, given a sequence of T periods, $t = 0, \dots T$, it is possible to decompose the variation in GTC between the first and last periods into any subperiod using any of the available alternatives:

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

(12)

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

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

(13)

That is, we can recover the chain component $\Delta CGT_{ij}^{t,T}$ of the variation in GTC by 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 ($n = 1$ would give the year by 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, and constitutes a substantial advance with respect to other studies on the sources of transport cost variations which do not use the index number theory and its potential when decomposing them, in order to consistently identify their 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 aforementioned studies; and, particularly those by 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, makes it possible to establish a reference framework to analyze the change in any GTC pertaining to any transportation industry.

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

3.1 The economic (unit-price) cost database

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

Figure 1: Economic costs of road freight transportation
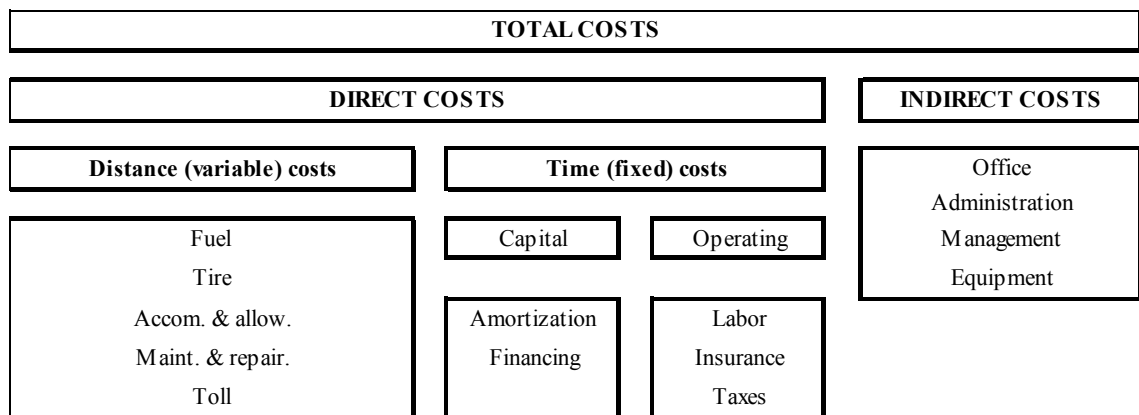
Source: Observatory of Road Freight Transportation, MF (2010).

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[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 determining the fares for road freight transportation.

Compiling the economic database is an intricate task due to its complexity, the variety of potential alternatives and the lack of data for 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 shown in annex 1.2). All the formulae (annex 1.1) and technical assumptions (annex 1.3) apply to all regions and provinces in Spain, but their specific values may differ for numerous reasons (*e.g.*, in Spain collective bargaining takes place at the provincial level, which results in wage differentials at 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 should point out that these reference costs are influenced by institutional, regulatory and legal issues (taxes on fuel, driving and resting times, minimum wages...). The industrial structure (relationship between efficiency and competition, firm size...) also plays an important role in their behaviour over time.[8] Therefore, the different components which make up 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 below.

Considering the above 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 cost variations between 1980 and 2007 for the above categories (column 5). The data reveal 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– underwent an accumulated growth of 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 –specifically, new engines consuming as much as a 25.5% less, see annex 1.3. Secondly, labour costs –accounting for 13% of the total costs– have increased by a contained 13.9% during these years. This is a result of strong liberalization and deregulation processes, as well as the competitive pressures that have characterized the Spanish road freight transport industry during recent years, which has kept salary increases moderate.[9] Finally, taxes have also suffered an upward trend, although their weight with regard to total costs is negligible, and they therefore have a limited impact on the overall cost. Despite the increase in these three economic costs, the downward behaviour of the rest of the categories has resulted in a −16.1% reduction in total unit costs at constant prices from 1980 to 2007. For example, Spain's entry into the European Monetary Union resulted in a sharp downturn in 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 decreased significantly over these years are the accommodation and allowance costs –representing about 10% of total costs–, insurance, tires and tolls. Factors such as the modernization and consolidation of insurance markets, technological advances in retreading and

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[8] For example, the road freight transportation sector is atomized in Spain, where 87% of the firms are small (with fewer than five vehicles). This gives rise to high competitive pressures and greater cost efficiency.

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

tire manufacturing, and negotiations between toll highway operators and government agents have played a role in this cost reduction.

Table 1: Levels and variations in 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)	Δ 07/80 (5)	Δ 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
Labour	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), one-time costs (per hour) are converted to distance costs by dividing by the average speed: Economic costs / km = Distance costs / km + Time costs / hr. ÷ speed (km/hr.).
[c] Shift-share variation. Unit cost variation weighted by their 1980 cost share in total economic costs.
[d] The toll cost is an average cost for the reference vehicle assuming that 10% of the annual distance corresponds to this category. However, GTC calculations consider actual tolls of the arcs really used.
Note: Annual distance driven of the representative 40t. articulated truck increased from 90,000 km in 1980 to 120,000 km in 2007, while the number of total annual hours driven remained stable at 1,906 over the whole period.
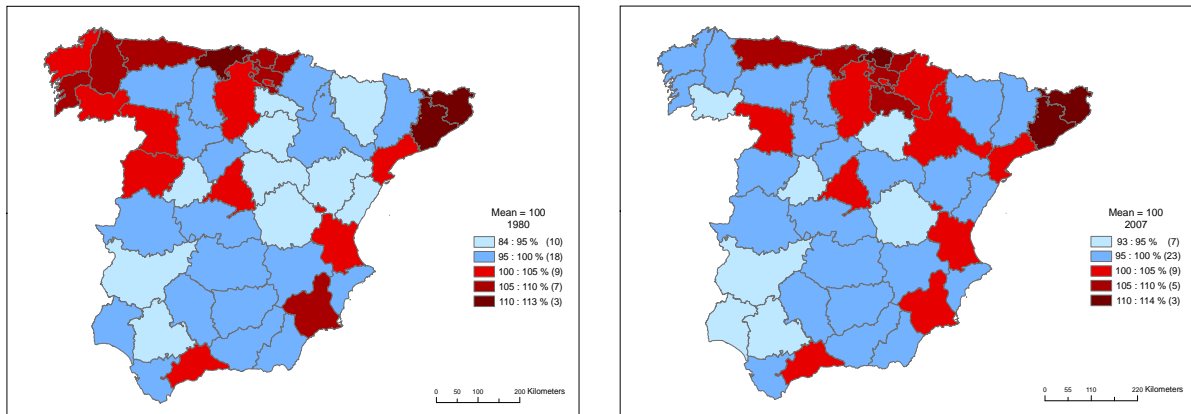*Source:* Authors' compilation

This −16.1% overall reduction in total unit costs per kilometre is due not only to the relative reduction in the majority of the categories mentioned above, but also to the technological improvements incorporated into the vehicles which have allowed the annual distance driven to increase by one third, from 90,000 km to 120,000 km. In contrast, total unit costs per hour, which have remained constant at 1,906 hours/year, have increased due to the upward pressure of fuel and labour costs. The last two columns in Table 1 (weighted variation) show a shift-share analysis of unit economic costs referred to the distance covered by the reference vehicle in kilometres –column 5–, and the weight of each particular cost category in the overall −16.1% reduction –column 7. For this purpose, time costs per hour have been converted into km, taking into 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 unit costs expressed in km have declined. This explains why in the last two columns, showing respectively the shift-share analysis of the economic cost variation and the percentage contribution of each cost to the −16.1% overall change, the costs of labour 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 with a larger value). In the last column, a positive value shows that the particular cost has declined over the years, thereby contributing to the overall reduction in the associated percentage. In contrast, the

only exception is fuel costs, whose negative value shows an increase in their contribution, thereby counterbalancing the overall reduction. From the perspective of the index number methodology, we note 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 its corresponding share in the total economic costs, but does not take into account the network infrastructure. Even if this decomposition is useful for examining 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 reveal a great heterogeneity and show that higher levels of cost are observed in regions located in northern and eastern Spain. In particular, regions located in the Bay of Biscay area, the Ebro valley, Valencia and Catalonia, together with Madrid, have higher transport costs. The opposite can be seen in the western and southern Spanish provinces where costs are about 10% lower. The individual costs behind these differentials are mainly labour, 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).
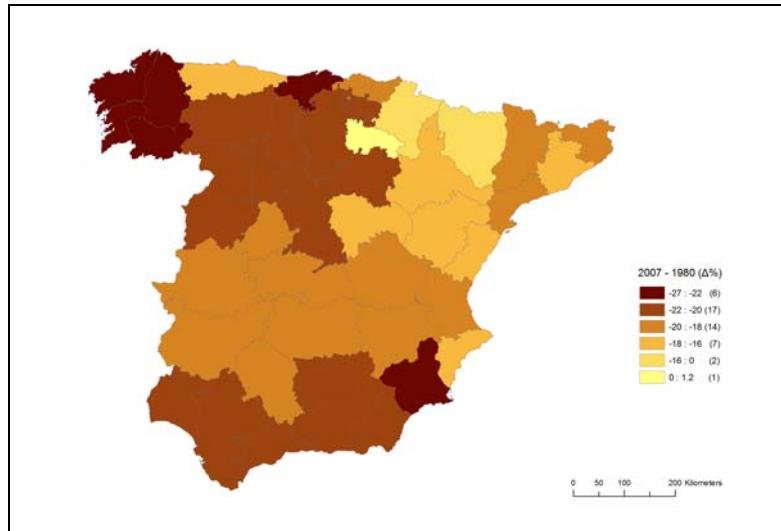(Euros per total annual distance driven by the reference vehicle: 120,000 kms.)

Source: Authors' compilation

If the regional heterogeneity and distribution of economic transport costs in 2007 is noteworthy –a result normally overlooked in aggregate national studies–, it would appear to be even more important to analyze their dynamics from the base year of 1980. Generally speaking, the relative positions do not alter drastically throughout the time span considered. A downward trend in the reference economic costs occurred in most regions, with the exception of La Rioja (a result that contributes to making this the only province where GTCs increase). Regions which presented higher costs at the beginning of the 80s, although experiencing deeper decreasing trends during the following three decades, continued to lead the ranking of economic costs, and were also the most expensive 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, provinces whose reference economic costs were close to the Spanish average in 1980 reduced their costs below that average by the end of the period analyzed, thereby improving their relative position in the

ranking (Navarre, Madrid, Aragon, Castile-León and Valencia). Figure 3 shows the percentage variation of annual transport costs during 1980–2007.

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

2007 - 1980 (Δ%)

- -27 : -22 (6)
- -22 : -20 (17)
- -20 : -18 (14)
- -18 : -16 (7)
- -16 : 0   (2)
- 0 : 1.2   (1)

0   50   100   200 Kilometers

Source: Authors' compilation

3.2. The GIS database of the infrastructure network

Geographic Information System (GIS) techniques have been used to compute minimum cost routes using Dijkstra's shortest path algorithm (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 roads belonging to regional governments (2x1 lanes) and local municipalities (secondary and urban). In general, the length of national 2x1 roads has decreased in favour of high-capacity 2x2/3 highways (Table 2). Highways accounted for 335 km in 1980 and 9,557 km in 2007, representing a notable 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 existing 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 both the physical characteristic already discussed in the empirical section: distance, d_a^t (meters); road type, r =1,…6; gradient (degrees); and speed, $s_{a(r,t)}^t$, from which the associated travel time t_a^t is obtained; and 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 the aforementioned provincial differences. 678 transport zones were considered for the resolution of the origins and destinations of the minimal economic cost routes –including

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

internal travel costs. [11] In this stage of the GIS implementation, other ancillary costs were added in the calculation of the routes. [12]

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

	Toll highways			Free highways			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			Secondary roads			Local roads			All roads		
	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: Authors' compilation

Figure 4: Spanish road network, 1980 *v.* 2007
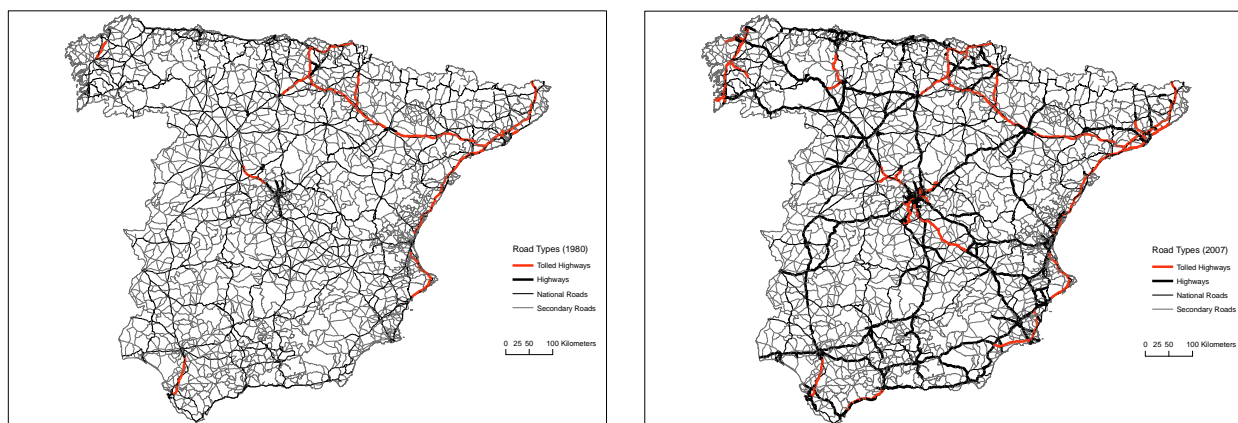
Source: Authors' compilation

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

4.1. Averaging GTCs using trade data

In this section we present the calculations of GTCs and their variations between 1980 and 2007, as well as their decomposition into the infrastructure and economic components as

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[11] Internal travel cost depends on the size of the 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 zone with the lowest population density. Then, internal km and travel times were converted to economic values given the corresponding 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 15 March, 2006 ((EC) no. 561/2006). The regulation states that the driver must rest 45 minutes after 4 hours' driving and 11 hours after 9 hours.

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 which uses the arithmetic mean $\overline{GTC}_{ij}^{t,t} = 1/(N-1)\sum_{j=1}^{N-1} GTC_{ij,z}^{t,t}$ and does not take account of actual trade between zones, in favour of a weighted approach that multiplies the individual i, j transportation cost by zone j's share of zone i's total exports. As a result, our aggregate makes allowances for trade patterns between regions, *i.e.,* the GTC between region i and j is 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 on exported and imported goods between provinces in Spain. The data we use correspond to the volume of exported goods (tons) in 2005 classified at the divisional level (NACE Rev.1.1 classification), which are mainly distributed by road freight transportation. The exports at the 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} the volume reaching zone j, the trade-weighted average of the GTCs corresponds to:

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

4.2. GTC levels and variations

Table 3 presents the arithmetic average and trade-weighted average of GTCs in Spain aggregated at the regional (NUTS 2) level. The first notable feature of our results is that weighting the GTC by trade data leads to a drastic reduction in GTCs, since most of the exports are to nearby locations whose bilateral GTCs are much lower. In 1980 and 2007, trade-weighted GTCs (152.9€ and 128.0€, respectively) represent about 20% of their unweighted GTC counterparts (698.9€ and 559.6€). This is consistent with the reduction in trade as a result of increasing distance reported in Hilberry and Hummels (2008), who used U.S. trade data to determine that the volume (tons) component of the total value shipped from one region to another drops drastically by more than 50% when the shipping distance exceeds 200 miles. Both the mean of unweighted and trade-weighted GTCs decreased during these three decades, when they fell by −19.9 and −16.3%, respectively. This descent was generalized in all Spanish provinces except La Rioja. In 2007, the percentage difference between the lowest value of 74.9€ in Madrid and the highest value of 162.8€ in Asturias was as much as 117.4% (131.9% for the unweighted arithmetic mean). The three costliest regions: Asturias (162.8€), Aragon (157.5€) and Galicia (148.4€) located on the geographical periphery, had GTCs well over the Spanish average of 128.0€. This situation had already been observed in 1980, since these same regions also displayed the highest GTCs. Since the relative drop in GTCs in the regions with the highest GTCs was greater than the national average, it is interesting to ponder 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 greater territorial cohesion is studied in depth in section 5, where we calculate several inequality indicators of individual GTCs and their components.

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

	Arithmetic average: $\overline{GTC}_{ij}^{t,t}$			Trade-weighted average: $\widehat{GTC}_{ij}^{t,t}$		
	Levels (Euros)		Variation	Levels (Euros)		Variation
	1980	2007	Δ 07/80	1980	2007	Δ 07/80
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

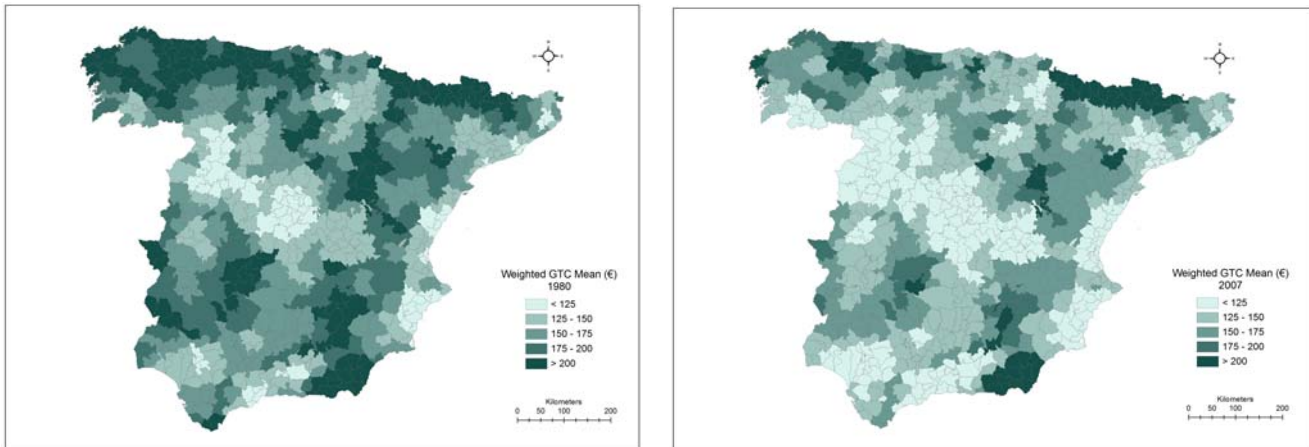*Source*: Authors' compilation

At the highest possible level of territorial disaggregation, Figures 5a and 5b show the GTC results for the 678 transport zones considering the arithmetic and trade-weighted average of GTCs. In the former case a clear centre-periphery pattern can be seen, with the lowest GTCs located in the centre 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 the European level (Spiekermann and Neubauer, 2002). Zones situated in central regions, especially Madrid, have the lowest GTCs due to their location and the network configuration of the Iberian Peninsula. Due to its privileged geographical position in the centre of the country, and its role as the administrative and economic capital, Madrid has benefited from a highly inclusive and dense transport and communications network. For these reasons, a high proportion of the optimal road freight transport itineraries pass through the Madrid region. In contrast, the highest GTCs (darker colours) are located in peripheral regions, especially in Galicia, Asturias and Catalonia. A fuzzier picture can be seen in the two lower maps which show the trade-weighted average of GTCs. In this case, GTCs are strongly influenced by the scope of the commercial flows with peripheral regions which also have low GTCs, due to the short logistical range of their commercial flows. The issue of whether there is systematic geographical clustering in trade-weighted GTCs remains open and, once again, in the next section we test several hypotheses of alternative spatial clustering in GTC variations and their economic and infrastructure components.

Figure 5a. Arithmetic average: $\overline{GTC}_{ij}^{t,t}$, 1980 *versus* 2007 (€).
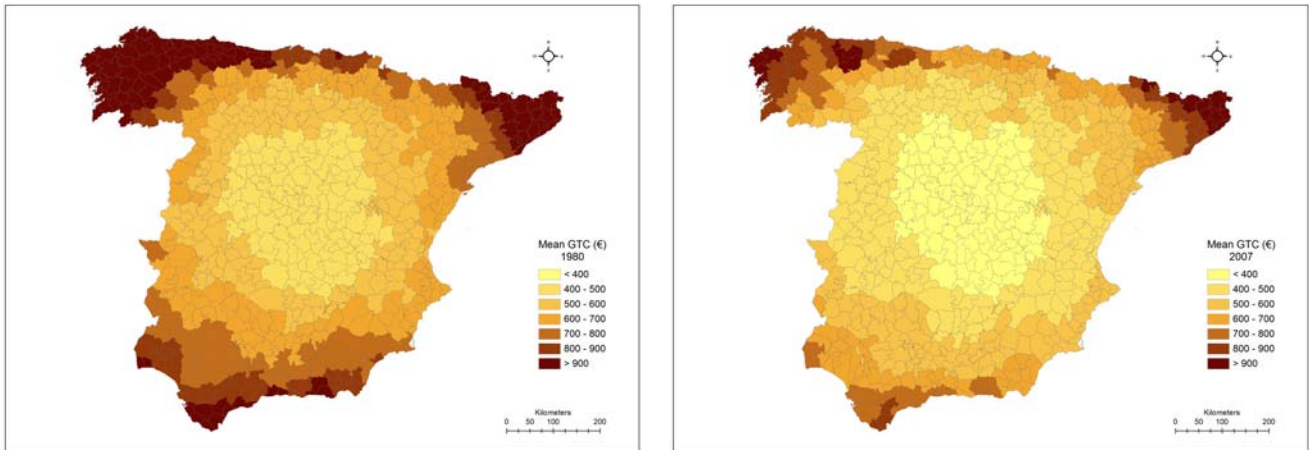
Source: Authors' compilation

Figure 5b.Tradeweighted average: $\widehat{GTC}_{ij}^{t,t}$, 1980 *versus* 2007 (€).

Source: Authors' compilation

As previously mentioned, trade-weighted mean GTC has undergone a significant decrease in recent years to the aggregate tune of −16.3%. However, as in the case of reference economic costs, the fall in GTCs has not been equal across regions and provinces. Cantabria (−25.2%), Galicia (−22.1%) and Murcia (−20.3%) have undergone an even greater reduction. At the other extreme, La Rioja is the only region experiencing an increase in its GTC. Other regions such as Aragon (−10.7%), Catalonia (−12.0%) and Navarre (−13.3%) have also experienced lower reductions in their GTCs. At a provincial level, the reduction in GTCs also shows major differences, even among GTCs belonging to the same region (particularly when a region includes provinces that are far removed from each other and separated by geographical barriers). Provinces located in the northeast zone, and most of the Andalusian provinces, experienced a smaller decrease. Conversely, provinces located in the north-northwest (Cantabria, Galicia and Castile-Leon), and the centre (Madrid and provinces in Castile-La Mancha) showed the highest GTC decrease.

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

We perform a shift-share analysis of GTC variations that allows us to determine the joint contribution made by all the economic and infrastructure factors to the −16.3% reduction in 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 its individual shift (column 3) by its base 1980 share (column 4), which can be expressed as a percentage of the overall change (last two columns 6 and 7). The reasons underlying these figures closely follow the patterns and explanations behind each individual trend in the reference unit economic costs already discussed in section 3.1, Table 1. It can be seen that the fall in GTCs is driven by time costs, with a 75.3% contribution to the overall reduction (−12.2% out of −16.3%). Both capital and operating costs contribute to a similar degree (−5.1% and −7.2%, respectively); while insurance costs, followed by financing costs are the components showing the greatest reductions. Distance costs contribute merely 17.5% to the overall reduction (−2.8% out of −16.3%) with fuel costs counterbalancing the decline in GTCs by 20.0% (3.3% increase versus the −16.3% reduction in GTC). These are sensitive results since the improvement in the road networks results mainly in greater time savings rather than distance savings, and it is therefore the costs associated to the former that drives reductions in GTC. This is confirmed by the reductions observed in the optimal distances and times associated to the minimum cost itineraries: $\Delta d_{ij}^{t;t*}$ and $\Delta t_{ij}^{t;t*}$. From 1985 to 2005 optimal time was reduced by −14.9%, while optimal distance was reduced by −0.3%.

Table 4: $\Delta\widehat{GTC}_{ij}^{t,t}$: Shift-share analysis, 1980-2007

	Levels (Euros)			Share in total costs (%)		$\Delta\widehat{GTC}_{ij}^{80,07}$	
	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
Labour	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: Authors' compilation

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

We now decompose the variations in the trade-weighted average of generalized transport costs $\Delta\widehat{GTC}_{ij}^{0,t}$ to identify the individual sources behind their reduction in terms of transport economic costs and 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 made by the change in economic costs $\widehat{EC}_{ij}^{0,t}$ and the infrastructure accessibility variables $\widehat{IC}_{ij}^{0,t}$ to the reduction in GTCs.

For the overall period between 1980 and 2007, about two thirds of the reduction in GTCs is the result of improvements in the network infrastructure, as described in section 3.2 (with an accumulated 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 and discussed in section 3.1. Thus, the role of infrastructure in GTC reduction is much greater than the role played by the reduction of economic costs. This result is hardly surprising in the Spanish case, since it was in this period that the central and regional governments, making use of major European development programs such as the structural and cohesion funds (*e.g.,* ERDF), invested most heavily in the expansion and improvement of the high-capacity road network. [13] We can also consistently study the accumulated change in GTCs and their economic and infrastructure components in periods of five years. Table 5 shows that the decrease in GTCs driven by infrastructure reductions is

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[13] The approach followed by Combes and Lafourcade (2005) to identify the sources of GTC reduction calculates the Laspeyres (producer) price index for transport costs EC_{ij}^{L}, which assumes that the optimal itineraries do not change over the whole period (*i.e.,* average optimal distance and time remain constant). Expressing as a 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 caused by this simplification on the economic index and, by extension, on the associated infrastructure index. Particularly, we calculate the standard Laspeyres price index $\widehat{EC}_{ij}^{L}$ and compare it to the true Laspeyres-Konüs price index $\widehat{EC}_{ij}^{0}$—eq. (5). For the whole period the bias in economic costs is $\widehat{BE}_{ij} = \widehat{EC}_{ij}^{0} - \widehat{EC}_{ij}^{L} = 0.9299 - 0.9336 = -0.0037$ or −0.37 percentage points. As a result the contribution of economic costs to GTC decline using the Laspeyres formulation is lower than the true contribution by an amount that can be related to the true index: $\widehat{BE}_{ij}(\%)/\widehat{EC}_{ij}^{0}(\%) = -0.37/-7.01 = 5.3\%$. 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 $\widehat{BI}_{ij} = \widehat{IC}_{ij}^{1} - \widehat{IC}_{ij} = 0.9901 - 0.8966 = 0.0036 = 0.36$ percentage points, or 3.5% of the true $\widehat{IC}_{ij}^{1}(\%)$. At a NUTS 3 provincial level, the maximum observed economic bias corresponds to Castellón (Comunidad Valenciana) with −1.53 percentage points, resulting in an overestimation of the true contribution of infrastructure to GTC decline by 1.42 percentage points.

monotonic, as it is constantly reduced in a cumulative way. However, the inflationary trends affecting fuel and labour costs as a result of the oil crisis and the indexation of salaries to the consumer price index (increasing on average about 10% a year in the 1980s)[14], explain why the increase in the price index offsets the reduction in the infrastructure quantity index, resulting in a 3.0% increase in GTCs between 1980 and 1985. Although 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%) offsets this increment, thereby resulting in a −2.7% reduction in GTCs. 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 accumulated economic index falls by a greater percentage than the infrastructure index (−6.4% v. −5.0%).

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

	Fixed based indices			Percentage variation (%)		
	$\Delta\widehat{GTC}_{ij}^{80,t}$	$\widehat{EC}_{ij}^{80,t}$	$\widehat{IC}_{ij}^{80,t}$	$\Delta\widehat{GTC}_{ij}^{80,t}$	$\widehat{EC}_{ij}^{80,t}$	$\widehat{IC}_{ij}^{80,t}$
85/80	1.0296	1.0387	0.9912	2.96	3.87	−0.88
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
	$\Delta\widehat{GTC}_{ij}^{80,07}$	$\widehat{EC}_{ij}^{80,07}$	$\widehat{IC}_{ij}^{80,07}$	$\Delta\widehat{GTC}_{ij}^{80,07}$	$\widehat{EC}_{ij}^{80,07}$	$\widehat{IC}_{ij}^{80,07}$
07/80	**0.8370**	**0.9304**	**0.8996**	**−16.30**	**−6.96**	**−10.04**

Source: Authors' compilation

Finally, using 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. Although the first row coincides with the first row 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 greatest (−7.15%). In this period the price of fuel underwent mild increases and inflation levels dropped sharply, thereby containing salaries. Additionally the reduction in interest rates resulted in lower increases in capital costs, while the rest of the categories followed a similar pattern. Nonetheless, in the subsequent five-year period the situation reversed and economic costs increased by 2.5%. As expected, this uneven evolution of the economic index cannot be perceived in the periodical infrastructure index, which shows a steady decline over the years. As a result we can conclude that successive investments in high-capacity roads have contributed steadily to the reduction in GTCs in all periods except the first five years when the modernization of Spanish roads was taking off.

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

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

	Interannual indices			Percentage variation (%)		
	$\Delta\widehat{GTC}_{ij}^{t,t+n}$	$\widehat{EC}_{ij}^{t,t+n}$	$\widehat{IC}_{ij}^{t,t+n}$	$\Delta\widehat{GTC}_{ij}^{t,t+n}$	$\widehat{EC}_{ij}^{t,t+n}$	$\widehat{IC}_{ij}^{t,t+n}$
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: Authors' compilation

## 5. Geographical analyses of GTC variation: spatial association and territorial cohesion

5.1. Geographical clusters of GTC variation: market and network effects

GTCs and their economic and infrastructure indices show 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 greater than that of the economic index. This suggests that the expansion and improvement of the high-capacity road network has played the most important role in the reduction in GTCs over the last three decades in Spain. But, as expected, this effect has not been geographically homogeneous. The contribution of infrastructure was greater within those peripheral regions whose accessibility to the Iberian peninsula was lowest as a result of physical barriers, particularly the provinces situated near the Bay of Biscay (Galicia, Asturias, Cantabria, and the Basque Country), as well as some Andalusian provinces situated in the southeast of the peninsula (Almeria and Granada). In contrast, the provinces located in the centre have profited relatively less from the new infrastructure, and particularly Madrid and the surrounding provinces.

Before we determine whether there are significant clusters in the variations by means of the Moran global and local indicators of spatial association, we analyze particular trends in economic and infrastructure indices following the methodological approach proposed by Camagni and Capellin (1985). The central idea consists of studying the evolution of the variations in GTC 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 are above the national average, lagging provinces where they are below, economy-driven regions where this component is above but the infrastructure component is not, and infrastructure- (accessibility) driven regions where the opposite is observed. All four categories are shown in Figure 6. Provinces in shaded circles lag behind in both the economic and infrastructure indices, or in only one of them, but still present lower GTC reductions than the national average (represented by the 45º bisecting line). Conversely, unshaded circles show leading provinces where both indices are below the average –or at least one of the two– but in this case resulting in greater than average GTC reductions. We find a differential of eight percentage points between the regions with the largest and smallest cumulative infrastructure decrease. The regions benefiting most from the improvements in the

infrastructure network include Cantabria (CAB), where its contribution to the fall in GTCs is a notable −17.5% (7.5 percentage points more than the Spanish average of −10.0%), twice the reduction in its economic index, which is −9.3% (2.3% percentage points below the −7.0% average). On the other hand, the region with the contribution of infrastructure is greatest in relative terms with respect to economic costs is Asturias (AST), where infrastructure is five times higher than economic costs (−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 situated in northwest Spain (PON, ACO, OUR, LUG) leading GTC reductions, while all four north-eastern Catalonian provinces (GIR, BAR, LER, TAR) present the lowest GTC reductions.

Figure 6. Economic $\widehat{EC_{ij}}^{80,07}$ and infrastructure $\widehat{IC_{ij}}^{80,07}$ indices (%)
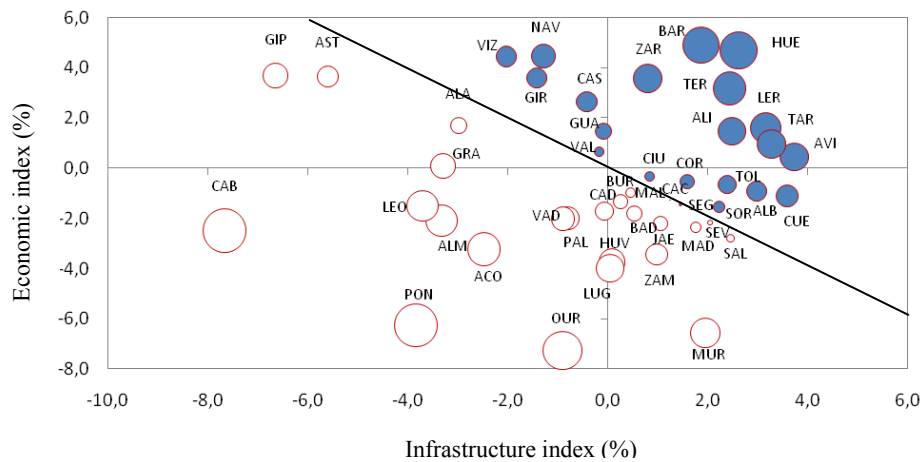
In principle, a certain degree of spatial clustering of the economic and infrastructure indices should be expected as long as neighbouring provinces present similar evolution in their cost structures and infrastructure endowments. For example, regarding the economic costs of transportation services, labour 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 repairs, tires, etc., where the degree of competition will result in similar pricing rules (*e.g.*, mark-ups), as long as there is effective competition between firms within a geographical range. In fact, we have shown that the levels and rates of change of economic costs differ widely across Spanish regions as a result of all these factors, and since the likelihood of similar trends in economic costs depends on the way in which the specific input markets are integrated across neighbouring regions, as well as on the way in which 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 infrastructure endowments, infrastructure investment would make a similar contribution to GTC decline in neighbouring areas provided that an improvement to 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") such as the kind existing in Spain in the 1980s, where the peripheral and central regions

connected by corridors jointly benefited from improvements in the radial arcs. Here we should highlight two points 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 centre, that particular connection is only one of its multiple radial links. This is further reinforced when trade-weighted GTC variations and their components are taken into account, since all exports from an outer node must travel the radial arc, and therefore benefit fully from its improvements, while the percentage of exports from the centre toward that node is only a share of its total exports. This result is evident in the Spanish case, where reductions in GTC driven by infrastructure improvements are greater in peripheral regions than in 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 by clusters of provinces presenting a subnetwork structure (*e.g.*, in the Spanish case, Galicia, the Basque Country and Catalonia are good examples), while the centre corresponds to a single territory (*e.g.*, the Madrid region itself). Given this network topology, improving a single 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 there is spatial autocorrelation at the aggregate level in GTC variation, as well as in its economic and infrastructure components associated to market and network effects, we have calculated Moran'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. Any 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 greater value of infrastructure suggests that the network effect predominates over the market effect when favouring spatial clustering.

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

|	Moran indicator	*p*-value
$\Delta \widehat{GTC}_{ij}^{80,07}$	0,2346	0,0000
$\widehat{EC}_{ij}^{80,07}$	0,2378	0,0000
$\widehat{IC}_{ij}^{80,07}$	0,2740	0,0000

Source: Authors' compilation

This is further corroborated in Figures 7a, 7b and 7c, where the values of the local Moran's indicator (Anselin Local Moran's Indicator) are shown. This indicator allows areas to be identified 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 GTC variation, 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 GTC and its components, since the higher the value of the indices, the lower their reduction from the base year. Conversely, 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; this situation is unlikely 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 benefit from network effects because of geographical barriers.

As regards generalized transport cost variations, $\Delta \widehat{GTC}_{ij}^{80,07}$, there is a cluster of provinces in the northeast –Galicia and León– which exhibit greater reductions (LL) due to both reductions in economic costs $\widehat{EC}_{ij}^{80,07}$, and distance and time infrastructure accessibility variables $\widehat{IC}_{ij}^{80,07}$. Conversely, in the northeast –Catalonia and Aragon– we find a significant cluster of provinces where GTC variation is below the average; this has a HH profile. The source of this latter clustering is the jointly significant increase in economic costs in these neighbouring provinces that prevents a larger decline in generalized transportations costs (Figure 7b). Interestingly, in Catalonia and Aragon there is no HH pattern for infrastructure, a situation which signals that the benefits from greater accessibilities can be found in some of the provinces within these regions, and there is therefore no significant spatial cluster of relatively low decreases (HH) in $\widehat{IC}_{ij}^{80,07}$ 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 generalized, economic and infrastructure transport costs. The case of the provinces in the Basque Country is noteworthy because we identify two opposite clusters according to economic and infrastructure costs. This region conforms an HH cluster in terms of economic costs $\widehat{EC}_{ij}^{80,07}$, which decrease below the Spanish average, while it has benefited from accessibility gains since it also conforms a significant cluster of LL infrastructure costs $\widehat{IC}_{ij}^{80,07}$ as a result of the decrease in distance and time. Consequently, both trends offset each other, and no clustering is observed in terms of the overall aggregate $\Delta \widehat{GTC}_{ij}^{80,07}$. The second case corresponds to the province of Asturias in the northwest, where we identify a significant HL cluster regarding economic costs. This situation emerges because economic costs have decreased to a lesser extent in this region than in the surrounding regions. This disparity is the result of specific market determinants. Comparing the evolution in key economic costs representing the highest shares of 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, located to the east of Asturias, these three costs varied by −10.8, 26.5% and −21.4%; and similarly for the provinces of Cantabria and León located to the west and south, respectively.

Figure 7. Spatial clustering: Anselin Local Moran's indicator: a) $\Delta\widehat{GTC}_{ij}^{80,07}$, b) $\widehat{EC}_{ij}^{80,07}$ and c) $\widehat{IC}_{ij}^{80,07}$
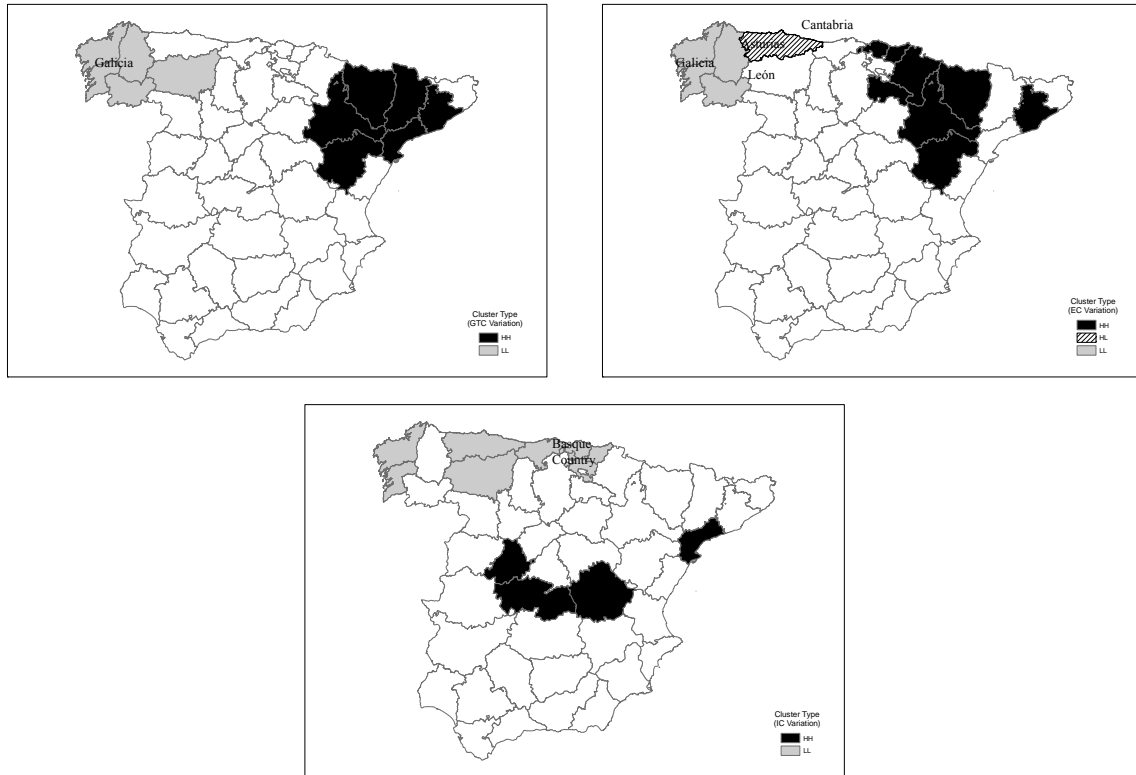
Source: Authors' compilation.

5.2. Effects of GTC variation on territorial cohesion

We conclude our geographical analyses by studying the effects of GTC variations on territorial cohesion using their relative concentration or dispersion around the mean over the different periods. This concept concerns regional convergence or integration, and is becoming an increasingly important issue in European Union countries, particularly since the goal of territorial cohesion was introduced in the EU agenda as an important policy objective (CEC, 2004). The EU defines territorial cohesion as balanced development, with fewer regional disparities, and deems transport policy to be one of the main instruments to improve it, especially insofar as it enhances the accessibility of peripheral regions to central markets. In view of the fact that equal access to markets is one of the main indicators which reflects 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), and particularly the Gini coefficient, the variation coefficient and Theil's index. If the variation in GTCs and their components shows a convergent tendency, then territorial cohesion in terms of accessibility levels has increased.

Table 8 reports these measures of dispersion for the generalized transport cost 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) $\widehat{GTC}_{ij}^{t,t}$, which allows us to determine whether GTCs themselves have converged over the

years; (ii) eq. (8): $\widehat{GTC}_{ij}^{t,80}$ 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 plays no role in GTC variations; and, finally, (iii) the counterpart to eq. (8): $\widehat{GTC}_{ij}^{80,t}$, measuring whether GTCs have converged due to the equalization of the accessibility variables of distance and time brought about by improvements in the road infrastructure, since the unit economic costs remain 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 in territorial cohesion. The Gini coefficient shows an accumulated reduction in dispersion of −7.1% for $\widehat{GTC}_{ij}^{t,t}$, situated between the reduction corresponding to the variation coefficient and Theil's index. Considering the reductions in disparities regarding the reference unit economic costs $\widehat{GTC}_{ij}^{t,80}$, and the accessibility variables associated to the infrastructure $\widehat{GTC}_{ij}^{80,t}$, the latter shows greater convergence with a reduction in disparities of −4.1% in the Gini coefficient, while the former is reduced by −1.5%. This result is fairly robust, since it holds independently of the dispersion measure 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 governments, particularly in the 1995-2007 period. The fact that the greatest reduction in disparities took place in this period instead of 1980-1995 is because in this earlier period, all major road investment projects were devoted to improving the radial connections between the periphery and the centre of the Peninsula, while in the latter period, investments reinforced the grid nature of the transport network, which benefits peripheral areas more than central areas. Nor is it surprising that economic costs were less relevant when driving transport cost down, since aside from significant technological improvements (in the reference vehicle, logistics, etc.), other political actions determining market conditions such as measures designed to liberalize and deregulate labour and capital markets have not been as successful as their infrastructure counterparts. Thus all the factors previously discussed in section 3.1, showing the evolution of the reference unit economic transport costs and which obey market dynamics which are impervious to manoeuvring by governments, ultimately 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 Spanish provinces, and that this reduction in the distance and time variables has also brought about fewer disparities in GTCs. It is beyond the scope of this paper to study the consequences of this reduction in GTCs in terms of the location of economic activity, but it is a well-known fact that *within* countries themselves, regional disparities throughout this period in per capita GDP have not decreased in Europe, and including Spain, see Duro (2004). Therefore, the generally accepted notion of higher road infrastructure investment bringing greater regional cohesion –as studied for the Italian case by Faini (1983)– would not be supported in the Spanish case, and this in turn corroborates the main proposition emanating from new economic geography models –namely that reducing transport costs may favour core-periphery patterns–, and warns against indiscriminate infrastructure investments that could result in greater disparities (Ottaviano, 2008).

Table 8 – Variation in territorial cohesion: $\widehat{GTC}_{ij}^{t,t}$, $\widehat{GTC}_{ij}^{t,80}$ and $\widehat{GTC}_{ij}^{80,t}$.

		Inequality measures			Variation 1980-2007 (%)		
		GINI coefficient	Variation coefficient (%)	Theil's index	GINI coefficient	Variation coefficient (%)	Theil's index
$\widehat{GTC}_{ij}^{t,t}$	**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
$\widehat{GTC}_{ij}^{t,80}$	**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
$\widehat{GTC}_{ij}^{80,t}$	**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: Authors' compilation

6. Conclusions

In this study we introduce index number methods to improve our understanding of the changes in generalized transport costs and their economic (price) and infrastructure (quantity) determinants. The former is related to the reference unit operating costs, while the latter corresponds to distance and time accessibility determinants. Given its desirable axiomatic and theoretical properties, we decided on a fixed-based version of GTC variations which satisfies 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 GTC variation could benefit from the proposed analytical framework in order to improve their methods and accurately measure and compute the contribution made by these elements to GTC reductions.

From an empirical perspective we illustrate our proposed methodology by calculating the GTCs for road freight transportation in Spain for five-year 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 it into a GIS containing the actual road transport network. For the GIS implementation we also rely on a highly detailed

geographical representation consisting of 678 transport zones. We use the cheapest path-routing algorithms to calculate optimal itineraries associated to minimum GTCs, which are subsequently grouped into the 47 provinces for which individual economic costs are available, and then averaged arithmetically or by way of trade flows so as to take into account the actual trade patterns. Our results show that trade-weighted GTCs declined by 16.3% from 1980 to 2007, and by using a consistent index number decomposition of this value index we learn that the main driver behind this fall is the contribution made by infrastructure improvements in the form of time and distance reductions. In terms of variation rates, the reduction in GTCs associated to infrastructure accounts for about two thirds of the overall GTC decline, −10.0%, with the reduction in economic costs accounting for the rest. From a time perspective, GTC 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 by the fall in the reference economic costs, both sources which contribute to greater GTC reductions.

We find a large geographical heterogeneity in both GTC levels and their variations, particularly for arithmetically averaged GTCs. In this case, the usual centre-periphery pattern favours 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 considering trade-weighted GTCs, since commercial flows are clearly constrained by many factors such as the transport costs themselves, but also by the economic specialization of regions in sectors producing goods with high weight-to-value ratios and which are 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 variation in GTCs and their components exhibit a significant geographical association. Particularly, the values of the local Moran's index not only indicate significant clustering of GTC variations in northeast and northwest Spain –with GTCs falling below and above the national average, respectively– but also considerable market effects where the trends in economic costs correlate in neighbouring regions, as well as significant 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 over 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 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 to an increase in territorial cohesion. In this sense we can differentiate between (i) *economic policy* measures resulting in lower operating costs –*i.e.*, deregulation initiatives bringing more flexible and competitive labour and capital markets (*e.g.*, reforming labour contracts or the adoption of the Euro, respectively)–, and (ii) project-specific investment decisions conforming the *infrastructure policy*, aimed at improving the road network. It could be argued that both types of policies have resulted in a reduction in regional disparities. However, since the evolution of economic costs not only depends on the actions undertaken by the governing administrations but also primarily on global market forces (*e.g.*, fuel costs depending on oil prices) –whereas investment decisions are taken almost exclusively at a political level– we can 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 GTCs can

be associated precisely to the changes in these particular components, have proved successful in driving down the cost of transportation in Spain. 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 for planning and designing similar policies in other developing countries in the same situation.

Appendix 1. Formulae and technical-economic hypotheses for the estimation of reference economic costs.

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:

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

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*:

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

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) *Labour*: Annual labour costs are approximated by the gross annual salary of a heavy vehicle driver, which is fixed in the regional road freight transport collective agreements. This proxy includes seniority, distance, assistance and extraordinary bonuses (Christmas, July and profits). Other expenditure related to Social Security is also included. These expenses account for 37.2% of the reference salary.

B.2) *Insurance*: Annual insurance costs include fully comprehensive insurance on the vehicle, civil liability, insurance against freight losses, driving license withdrawal and other insurance 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 permit…)

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 litres 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 repairs*:

This 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 (*repairs*). Both are calculated per kilometre.

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 were analyzed (from 1 to 5 vehicles, from 6 to 19, and more than 19) and then a weighted average indirect cost was estimated. This included office (real state, supplies, cleaning …), labour (management, administrative, commercial), equipment and facilities, and other financial costs relating to cash flow.

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

Where yearly data on a particular variable is not available, its value was calculated using the available price indices. These indices accurately show the price evolution of each cost category with sufficient accuracy and periodicity. The following points explain the price indices used for each cost category:

A.1) *Amortization*: The label 'motor vehicle and trailer manufacturing' in the Industrial Price Index, as published by the Spanish Statistical Institute, was used to extrapolate the purchase prices for the tractor trucks and trailers.

A.2) *Financing*: Based on interest rates available from the Bank of Spain.

B.1) *Labour*: The overall Consumer Price Index published by the Spanish Statistical Institute, plus a 0.75% differential, was used to extrapolate labour costs.

B.2) *Insurance*: The label 'automobile insurances' in the Consumer Price Index, compiled by the Spanish Statistical Institute, was used to extrapolate insurance costs. Where 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 labour costs.

C.1) *Fuel*: Based on petrol prices available from the Ministry of Economy, Ministry of Industry, Tourism and Commerce, and companies such as CAMPSA and Repsol.

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

C.3) *Tires:* The label 'maintenance and repair services' in the Consumer Price Index published by the Spanish Statistical Institute was used to extrapolate tire, maintenance and repair costs.

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

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

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

Table A.1: Economic and technical hypotheses 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
Labour 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							
Km per year	90,000	94,925	100,119	105,597	111,375	117,470	120,000
Km 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: Authors' compilation.

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