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Transport costs: measures, determinants, and regional policy implications for France*

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Abstract

We develop a methodology to accurately compute transport costs. Based on the real transport network, our measure encompasses the characteristics of infrastructure, vehicle and energy used, as well as labor, insurance, tax and general charges borne by transport carriers. Computed for the 341 French employment areas, road transport shipments and the period 1978–1998, this new measure is compared to alternative ones such as great circle distance, real distance, or real time. We conclude that these proxies do a very good job in capturing transport costs in cross-section analysis. However, important discrepancies limit the possibility of using them in time series analysis. Moreover, our measure allows us to identify the policies that most impact transport costs. We show that transport technology and market structure are responsible for most of the transport cost decrease. Infrastructure improvements only condition the spatial distribution of the gains. Finally, some implications for researchers and regional policy makers are derived.

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1. Introduction

As argued by Obsfeldt and Rogoff (2000), 'By explicitly introducing costs of international trade (narrowly, transport costs but more broadly, tariffs, non tariff barriers and other

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trade costs), one can go far toward explaining a great number of the main empirical puzzles that international macroeconomists have struggled with over twenty-five years'. This statement could be easily extended to regional and urban economics. However, researchers who want to confront recent theoretical advances in these fields to data, need first to accurately evaluate trade and commuting costs arising both between and within countries, regions, or even smaller geographical units, such as cities. This paper puts into perspective various strategies that can be chosen for such a purpose.

Measuring transport costs has benefited from a long tradition in geography and urban planning to which we refer and compare our contribution. The issue is more recent in international trade and economic geography. It imposes itself as crucial now, due to the move of these fields towards empirical validation. Furthermore, given that theoretical predictions of spatial patterns depend on the level and variation of trade costs (as the bell-shaped pattern of inequality induced by economic integration for instance), accurately measuring them is crucial. Obviously, trade and commuting costs do not restrict to transport costs on which we focus here. Nevertheless, and contrary to some authors' claims (Glaeser and Kohlhase, 2003, for instance), the transport share of trade costs is still far from zero. For instance, Anderson and van Wincoop (2004) estimate that they put a 21% markup over production costs, on average in industrialized countries. Transport costs should be even larger in developing countries. Thus, despite the development of infrastructure networks, transport cost barriers remain large, which justifies to put efforts in correctly evaluating them.

Due to the lack of data, researchers use two main families of variables to approximate transport costs: *Ad valorem* shares of trade values and distances. One might wonder whether resources should be devoted to improve these crude measures of transport costs. Researchers could exploit, as we do here, years of work by geographers or transport planners who have already developed more accurate measures such as real freight costs, or distances and travel times matrices derived from Geographic Information Systems (GIS). However, adapting their methodologies is costly and difficulties arise from systematizing (across different transport modes, commodities or periods) their use. Therefore, those remain mainly devoted to specific transport planning purposes. We study here whether it is worth encouraging the profession to combine real freight costs and GIS analysis to obtain transport costs.

The methodology we develop is based on the real transport network and encompasses other distance or time features related to traffic conditions, transport technology, and the market structure of the transport industry. We apply this methodology to France and road transport by truck, the most common mode for commodities in this country. The new measure is compared to alternative ones (great circle distance, real distance, and real time). Less information demanding, these various proxies are usually preferred in empirical work. However, assessing to which extent the simplifying assumptions they are based on might hide important questions is rarely presented. We therefore first compare the performance of our measure to such alternatives at given points in time (1978 and 1998). We conclude that simple proxies do a very good job in capturing transport costs in such a cross-section point of view, spatial correlations being as high as 0.99 on levels. Conclusions are reversed on 1978–1998 variations, however. Transport costs variations are only imperfectly captured by real travel time variations, with a correlation at 0.78, and even more badly by real distance ones, with a correlation at 0.42 (not even to mention great circle distance that does not vary at all). Our third set of results regards the determinants of transport cost variations. Actually, contrary to other existing measures, ours allows one to determine the respective magnitude of transport costs determinants, such as energy savings, infrastructure and technology improvements, and the market structure of the transport industry. This leads to the conclusion that infrastructure is responsible for a minor part of the 1978–1998 transport cost decline: it contributes at −3.2% points to a total variation of transport costs at −38.3%. Changes in the market structure (−21.8% points) and in technology (−10.9% points) are the real engines of the decrease of transport costs, while the impact of the decrease of fuel prices (−2.8% points) is also minor on the period studied. The regions where the decline is the largest are those where the infrastructure impact is also the strongest, however. Thus, in France, between 1978 and 1998, transport determinants would appear to act as complements: Market structure and technology determine the magnitude of the transport cost decline, while infrastructure improvements drive the spatial distribution of the gains. Finally, we detail how such contributions can be of interest for economists who want to predict and quantify frictions arising from trading goods, as well as for geographers, transport scientists, and regional policy makers focusing for instance on the accessibility impacts and rates of return of infrastructure investments.

The rest of the paper proceeds as follows. Section 2 reviews the criteria an accurate measure of transport costs should fulfill. In Section 3, we present a methodology incorporating most of these criteria within a single measure of transport costs, and we illustrate its computation at the geographical scale of the 341 French employment areas, for the road transport mode and the period 1978–1998. Section 4 provides descriptive statistics on the level, evolution and determinants of this measure, and compares it to alternative ones. Finally, Section 5 gives some insights on the gains that researchers could find in replicating the methodology at larger scales and for other countries, while Section 6 concludes.

2. Criteria that an accurate transport cost measure should meet

This section discusses the criteria that a measure of transport costs should encompass to accurately capture the characteristics of the infrastructure network, of the vehicle and energy used, as well as labor, insurance, tax and general charges borne by transport carriers.

The first criterion to consider is that transport costs can vary considerably according to the itinerary chosen for the trip.

Criterion C1–itinerary

Transport cost measures should depend on the itinerary chosen between the origin and the destination of the trip.

Criterion C1 encompasses three underlying effects:

Effect C1a–distance

Transport cost measures should depend on the real distance incurred between origin and destination.

Effect C1b–time

Transport cost measures should depend on the real time elapsed between origin and destination.

Effect C1c–direction

Transport cost measures should depend on the direction of the trip.

It is a standard feature that transport costs increase with the distance between origins and destinations, since it is more costly, due to energy consumption among others, to travel or to deliver goods faraway than close by.

More recently, increasing concerns about fast deliveries led to refer to time as a major component of transport costs (See for instance Hummels, 2001a, or Deardorff, 2001). Indeed, modern industries bear time-delivery constraints due to increasing flexibility, inventory costs or 'just-in-time' practices. The truism 'time is money' encompasses the feature that an increasing proportion of trade nowadays includes high-valuable or perishable goods that need secure and fast delivering associated with large freight and insurance costs. Individuals may also be ready to pay a large premium to save time, for business trips purposes as well as for not waiting too long for delivery. Micro-foundations for this demand for timeliness can be found in the models of Evans and Harrigan (2003) or Harrigan and Venables (2004), where products depreciate because of both the real time elapsed to ship them and the subjective corresponding change in the consumers' valuation of their utility.

Finally, transport costs are not necessary symmetric for a given pair of origin and destination. For instance, congestion might entail delays on one way of the trip only. Moreover, other discrepancies might arise from origin and destination differences in the costs of boarding and containerization or from an asymmetric configuration of the network.

The transport mode used is another major factor determining transport costs. This leads to our second statement.

Criterion C2–transport mode

Transport cost measures should depend on the transport mode used, which is the combination of a transport infrastructure and of a transport vehicle.

Transport costs depend both on the infrastructure (road, rail, airports, or ports) and on the vehicle used (truck versus car, for road transport for instance).

Energy represents the first source of costs leading to variations across transport modes. Other operating costs, as those related to the wages of vehicle operators/crew or to the vehicle maintenance, share the same feature. Recent concerns about sustainable development also lead public authorities to implement policies designed to correct environmental, insecurity, noise or congestion externalities. This translates into new norms or regulations, which affect the energy and operating costs, but also implies direct fees or taxes on top of those possibly related to the infrastructure construction and maintenance. Last, the market structure of the transport industry has also an impact on transport costs that differs across modes. For instance, the monopoly situation of air carriers on some destinations may give them incentives to price discriminate across locations or customers. The bargaining power of truck drivers or plane pilots may also contribute to the existence of large transport costs, as do some informal barriers to entry erected by public authorities, such as the 'grand-fathering' way of allocating slots to air carriers. Thus, the impact of mode on transport costs drives through different channels, which we group in four broad categories:

Effect C2a–energy

Transport cost measures should depend on the cost of the energy used.

Effect C2b–other operating costs

Transport cost measures should depend on the other operating costs, wages for instance.

Effect C2c–taxation

Transport cost measures should depend on taxes and fees related to the development and use of the infrastructure.

Effect C2d–market structure

Transport cost measures should depend on the transport industry market structure.

Obviously, the list is not exhaustive. We could also mention that the mode chosen affects as well the comfort and the security of transport users, as the welfare of non users who are likely to be involved, because of pollution, noise or other negative externalities arising from traffic growth. Note that, even though finding a monetary equivalent of such nuisances remains a rather difficult task, they are included in our list as long as they translate into additional taxes supported by users.

Next, transport costs may obviously depend on the commodity shipped, which leads to criterion C3.

Criterion C3–commodity

Transport cost measures should depend on the commodity shipped.

Indeed, the nature of the commodity makes it more or less expensive to transport. This may be due to the size of batches, to specific freight and insurance charges related to the quality or price of the good, but also to its perishable nature, the extent to which it has been processed, its solidity, liquidity or dangerousness.

Notice that criteria C1 to C3 are not necessarily independent. For instance, the speed of shipments is influenced by infrastructure policies, which links criteria C1 and C2. Transport for some commodities may be more expensive (C3), because they need a specific transport mode (C2) or fast delivery (C1). Transport costs between two regions may be larger (C1), because one single transport mode enables to connect them (C3). However, one would find examples such that criterion C3 remains necessary because criteria C1 and C2 are not sufficient to encompass all the costs related to a particular commodity.

Lastly, in addition to the valuable information embodied within a single and global measure of transport costs, researchers and policy makers might find important to be able to isolate and predict the impact of each component entering the calculation of transport costs. Gallup et al. (1999) underline the importance of such a property: 'How much of [the] differences [in transport costs] are related to policy, market structure, or physical geography? How are transport costs likely to change as a result of new information technologies, improved inter-modal transport, and other trends?'. This leads to our last criterion.

Criterion C4–decomposability

The impact of each component of transport cost measures should be recoverable.

The measure of transport costs we develop in Section 3 is designed to encompass most of these criteria, focusing more particularly on the policy issue of disentangling the sources of transport cost variations. Other criteria could be worth considering, especially when analysing individual mobility or public transports. However, we leave for future research the issue of measuring those social costs that cannot be internalized into private marginal monetary costs, such as comfort, or those arising from traffic growth on transport networks, such as security.

3. Generalized transport costs: methodology and data

Let us turn now to our main methodological concerns. The measure we provide is the cost for a truck to ship a representative batch of goods through the cheapest road route that connects any pair of spatial units. The geographical scale on which we focus here is a sub-regional one. While trade economists have at their disposal a few measures of inter-country transport costs (see Section 5.1 below), the issue of measuring transport costs is even more crucial at the infra-country scale for which no other measures than distance is usually available. Gallup et al. (1999) emphasize that transport cost data ‘within countries, between the hinterland and the urban areas’ are scarce, researchers being left with crude proxies. The methodology we present in this paper is designed, among others, to overcome this issue. It does not rely on trade values but on a GIS enabling one to compute the total inter-regional shipment costs incurred by carriers when using the actual transport network. This measure is a Generalized Transport Cost (GTC) in the sense that it includes both distance- and time-related costs of shipments.

The geographical scale on which we apply our methodology is the ‘Employment Area’ (Zone d’Emploi). This spatial nomenclature, which covers both urban and rural areas, divides the French continental territory into 341 units[1] defined by the French National Institute of Statistics and Economics Studies (INSEE) so as to maximize the correspondence between the people living and working areas. This geographical scale should be therefore more relevant for economic studies than administrative definitions.

As regards the transport mode, we focus on the trucking industry for two main reasons. First, in Europe, around 72% of trade volumes are shipped through the road network (against around 15% for rail, 8% for pipers and 5% for rivers).[2] Second, the road shipments industry is the one whose market structure faced the most drastic liberalization in the 1980s. In France particularly, the government eliminated licence quotas for entering the industry or using vehicles on long routes, and liberalized the pricing of road transport services in 1986.[3] These measures led to a strong deregulation process (the number of carriers almost doubled during the first year of liberalization) that makes the road transport industry evolve nowadays in a very competitive context. These atomicity and low entry costs both reduce potential discrepancies arising from mark-up behaviours and allow one to consider transport costs as non distorted proxies for transport prices. Furthermore, road transport may be a precursor of the changes that could affect other modes. The deregulation of air

1 Non-continental employment areas are excluded because of their insular specificity. The average employment area spreads over 1,570 km^2, which is fairly small and equivalent to splitting the US continental territory in more than 4,700 units.

2 The French Ministry of Transports reports mode shares for most European countries at http://www.transports.equipement.gouv.fr/frontoffice/.

3 The French government had regulated the road market access since 1934 by delivering authorizations to practise to a limited number of firms. Moreover, the price for shipping goods was imposed on these firms since 1961 to protect the French national railroad company from the competition of other carriers.

transport is still too recent to have a precise idea of the long term reduction of transport costs it will lead to. Moreover, this liberalization was less effective on the European continent than in North America, as the number of competitors is still limited by informal barriers, such as the 'grandfathering' way of allocating slots. The rail deregulation of freight transport that a few European countries are currently undergoing, is still too recent to measure its impact on rail fares. Lastly, the multi-modal aspects of traffics would be worth considering, especially from an international perspective, but as we focus in this paper on low geographical scales, we rather leave the issue of mode switching for future research.

Finally, our data relate to 1978 and 1998. Hence we also capture simultaneously the variations due to the oil crisis shocks and those induced by the major developments of the French highway network that occurred during this period.[4]

3.1 Geographic Information System (GIS) analysis

The methodology used to built GTC data sets is the result of our collaboration with the French Ministry of Transports[5] and the MVA Consultancy. GTCs are computed on the basis of an original GIS implemented on the TRIPS transport modelization software. This GIS consists in a digitalized transport network connected to the barycenter of each employment area, called its 'centroid'. This allows us to compute the cheapest itinerary between all these units.

The road transport network we use consists of 4482 and 4801 (for 1978 and 1998, respectively) 'arcs' of six different types ($r = 1, \ldots, 6$): toll and free highways,[6] $2 \times 2/3$-lane national roads, other national roads, secondary roads, and urban roads (in which bridges and tunnels are also included). However, the centroid of an employment area does not necessarily correspond to a junction between two arcs (or 'node'), so that we have to add artificial arcs between centroids and the closest nodes to allow for the network continuity. We label these arcs as urban roads, because of their short length. TRIPS finally extracts the cheapest itinerary from the set of all routes joining each pair of centroids. The inter-area matrix is then assimilated to the inter-centroid one. To derive the cheapest itinerary between two employment areas, one has to define the reference costs according to which TRIPS performs the optimization. Along a particular arc, we define two reference costs, associated with distance and time, respectively. Let d_a denote the distance between the nodes of an arc a and $r(a,t)$ the type of arc a at date t. By reference to the vehicle chosen and to the year studied, t, we first consider the following distance-related reference costs per km:

(i) For each type of arc $r(a,t)$, a fuel cost, $fuel^t_{r(a,t)}$, equal to the product of the fuel price and of the fuel consumption.
(ii) Costs due to tolls that have to be paid on highways under concession, $toll^t_{r(a,t)=1}$.
(iii) Regardless of the arc type, vehicle maintenance operating costs, $main^t$ and tire renewing charges, $tire^t$.

4 Although not presented here, we also implemented our methodology to the geographical scale of the 94 French continental 'départements' and for other years (1993, 1996).

5 Involving the Bureau of Technical Studies on Roads and Highways (SETRA) and the Economic Department of the Bureau of International Affairs (DAEI-SES).

6 In France, part of the highway network is yielded by firms to whom public authorities give the concession of developing and maintaining the infrastructure.

The total distance cost incurred when connecting the centroids of areas i and j at date t using an itinerary I_{ij}^t is given by

$$DistC_{ij}^t = \sum_{a \in I_{ij}^t} \left(fuel_{r(a,t)}^t + toll_{r(a,t)=1}^t + main^t + tire^t \right) . d_a \tag{1}$$

Similarly, we define time-related reference costs per hour. They correspond to the amount saved when an itinerary one hour shorter than another is used, resulting in increased work time and business output for the carrier.[7] They do not depend on the arc type and include:

(i) Labor costs, equal to the sum of the driver's raw wage and premium, $wage^t$, and his/her accommodation costs, $accom^t$.
(ii) Insurance charges, $insure^t$, including premiums and own insurance charges that are not covered by contractual arrangement with insurance companies.
(iii) Depreciation costs, $deprec^t$, including charges spent for renewing the vehicle.
(iv) General charges, $taxes^t$, including taxes and other carriers charges.

Given the speed on the road type $r(a,t)$, $s_{r(a,t)}$, the time for joining the arc nodes is $t_a^t = \frac{d_a}{s_{r(a,t)}}$. The total time cost incurred when connecting the centroids of areas i and j at date t using an itinerary I_{ij}^t is given by

$$TimeC_{ij}^t = (wage^t + accom^t + insure^t + deprec^t + taxes^t) \left(\sum_{a \in I_{ij}^t} t_a^t + t_l \right) \tag{2}$$

$$= (wage^t + accom^t + insure^t + deprec^t + taxes^t) \left(\sum_{a \in I_{ij}^t} \frac{d_a}{s_{r(a,t)}} + t_l \right), \tag{3}$$

where t_l is the time devoted to load and unload the truck. This last term is equal to twice thirty minutes in our implementation on France.

Lastly, if Θ_{ij}^t denotes the set of itineraries that join areas i and j at date t, the GTC corresponding to the cheapest itinerary is

$$GTC_{ij}^t = \min_{I_{ij}^t \in \Theta_{ij}^t} \left(DistC_{ij}^t + TimeC_{ij}^t \right). \tag{4}$$

Note that, in order to stress the importance to consider all these elements within a single measure of transport costs, we compare GTC first with great circle distance, which is the shortest distance between two centroids assuming they would be on a sphere without any physical or network constraint between them. This is also referred to in the literature as the 'geodesic' or 'as the crow flies' distance. Next, GTC is also compared with minimal real distance, and minimal real time. Respectively, these last two measures, the calculation of which also requires a GIS analysis but no reference costs, are given by

$$Dist_{ij}^t = \min_{I_{ij}^t \in \Theta_{ij}^t} \left(\sum_{a \in I_{ij}^t} d_a \right) \quad \text{and} \quad Time_{ij}^t = \min_{I_{ij}^t \in \Theta_{ij}^t} \left(\sum_{a \in I_{ij}^t} t_a^t + t_l \right). \tag{5}$$

7 Timeliness is therefore captured here through opportunity costs and is not directly interpretable as the time spoilage or depreciation affecting the commodities shipped, as in Deardorff (2001) for instance.

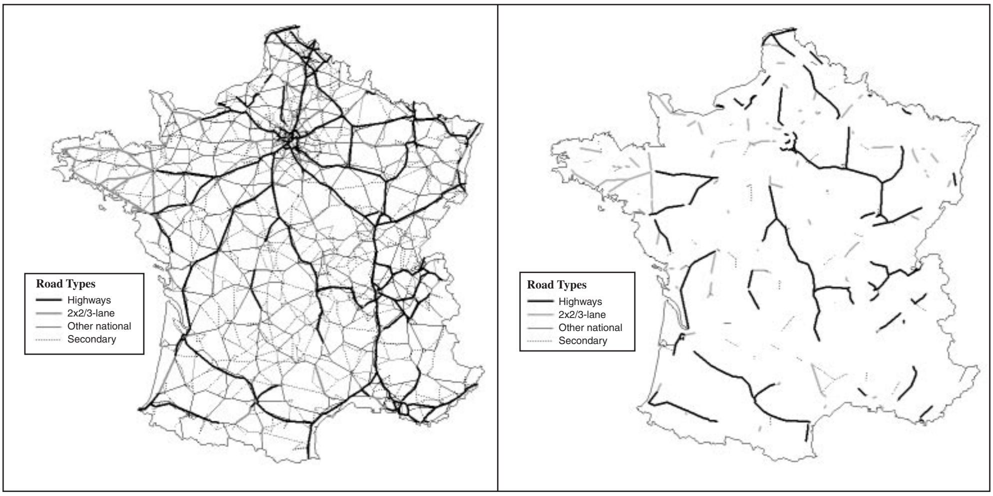

Figure 1. French road network in 1998 (left) and arcs improved between 1978 and 1998 (right).

3.2 Road transport networks

The digitalized road transport network for the year 1998 was provided by the MVA Consultancy, on behalf of the French Ministry of Transports. The 1978 digitalized network has been retropolated by comparison with the paper road maps of the French National Geographic Institute (IGN) at the same date. Arcs that did not exist in 1978 were deleted and the type of many other arcs whose capacity had been upgraded since, was actualized. Figure 1 (left) gives an insight of the network used in 1998. As an example of the infrastructure development during the period, Figure 1 (right) draws the arcs that have been created or improved between 1978 and 1998.

Two main features emerge from Figure 1. First, the road coverage of the French territory is very good, any region benefiting from a dense transport network. Besides, the network structure is conditioned by the French physical geography: For instance, the 'Star' structure of the highway network, which is centered around the largest city, Paris, and the lower number of highways in the Massif Central (Middle-South) and in the Alpes (South-East), due to the presence of mountains. Second, drastic infrastructure improvements occurred during the period of study.

To confirm these visual findings, Table 1 exhibits for each type of road, the variation of the number and length of arcs. The total number of arcs and the distance covered have slightly increased between 1978 and 1998. By contrast, the distance covered by $2 \times 2/3$-lane roads has doubled during the period, mainly at the expense of other national roads, whose number of arcs and total distance were reduced by around 8%. Distances on secondary roads remained stable and urban roads were slightly extended. Hence, the transport infrastructure improvement was mainly geared towards an important increase in the road quality,[8] and therefore, in the average speed on the whole network.

8 This also improves security, which is not taken into account in the GTC, however.

Table 1. 1978–1998 Variations of the number and length of arcs

	2 × 2/3-lane roads								
	Toll Highways			Free Highways			National		
	1978	1998	Δ%	1978	1998	Δ%	1978	1998	Δ%
Number	174	331	90.2	192	294	53.1	253	357	41.1
Dist. (km)	2970	6104	105.5	1128	2163	91.8	1948	3509	80.1

	Other roads											
	National			Secondary			Urban			All roads		
	1978	1998	Δ%	1978	1998	Δ%	1978	1998	Δ%	1978	1998	Δ%
Number	1355	1255	−7.4	827	828	0.1	1681	1736	3.3	4482	4801	7.1
Dist. (km)	21,587	19,897	−7.8	16,111	16,082	−0.2	13,384	14,299	6.8	57,128	62,053	8.6

Δ%: 1978–1998 variation in %.

3.3 Reference transport costs

GTCs depend on both distance- and time-related reference costs ($main^t$, $tire^t$, $fuel^t_{r(a,t)=1,\ldots,6}$, $toll^t_{r(a,t)=1}$, $wage^t$, $accom^t$, $insure^t$, $deprec^t$, and $taxes^t$). Tables 2 and 3 report the values and variations of these components. Notice first that these numbers represent the annual averages of the statistics reported monthly by the French National Road Comity (CNR). The reference vehicle chosen by the CNR to perform long term statistics on the operating costs of carriers in road transport is a 40-ton container articulated truck that is considered as representative for industrial goods shipped by road: This vehicle represents more than 57% of the road transport float in France indeed. Recently, the CNR also applied this vehicle reference to other European countries. Averages are computed on the basis of the French 200 hours/month maximum authorized length of work.

As regards distance-related reference costs, truck manufacturers reacted to the two oil shocks by developing new engines and eliminating obsolete vehicles. Moreover, public authorities put incentives on road carriers so that they implement new strategies such as training drivers to save energy. Both led to a sharp decrease in fuel consumption in France.[9] Besides, fuel prices significantly decreased, including both brent price fluctuations[10] and new fuel tax regulations.[11] The net outcome of both consumption and price effects is a large fall in fuel costs during the period, by around 37% on average.

9 Fuel consumption depends on the road type on which the truck is driven. Simulations performed by the French National Research Institute on Transports and Security (INRETS, 1980) have shown that fuel consumption is lower on highways, despite higher speeds. We keep the INRETS distribution across arc types around the average road fuel consumption (44.8 l/100 km in 1978, and 35.7 l/100 km in 1998) for each year of study.

10 The oil price sharply climbed before the 1980s and fell after 1984.

11 As the variations of the Interior Tax on Petroleum Products (TIPP).

Table 2. Distance reference costs

	2 × 2/3-lane roads								
	Toll Highways			Free Highways			National		
	1978	1998	Δ%	1978	1998	Δ%	1978	1998	Δ%
Fuel consumption (*l*/*100 km*) (a)	37.0	28.9	−21.9	37.0	28.9	−21.9	41.0	32.0	−21.9
*Fuel price** (/*l*) (b)	0.62	0.50	−19.0	0.62	0.50	−19.0	0.62	0.50	−19.0
Fuel (1) = (a) × (b)	23.0	14.6	−36.8	23.0	14.6	−36.8	25.5	16.1	−36.8
Tire (2)	7.21	3.66	−49.2	7.21	3.66	−49.2	7.21	3.66	−49.2
Maintenance (3)	28.4	10.4	−63.4	28.4	10.4	−63.4	28.4	10.4	−63.4
Tolls (4)	11.7	12.9	10.7	0	0	0	0	0	0
Total = (1 + 2 + 3 + 4)	**70.3**	**41.5**	**−41.0**	**58.6**	**28.6**	**−51.2**	**61.1**	**30.2**	**−50.6**
	Other roads								
	National			Secondary			Urban		
	1978	1998	Δ%	1978	1998	Δ%	1978	1998	Δ%
Fuel consumption (*l*/*100 km*) (a)	49.0	38.3	−21.9	49.0	38.3	−21.9	50.0	39.1	−21.9
Fuel price (/*l*) (b)	0.62	0.50	−19.0	0.62	0.50	−19.0	0.62	0.50	−19.0
Fuel (1)=(a) × (b)	30.5	19.3	−36.8	30.5	19.3	−36.8	31.1	19.7	−36.8
Tire (2)	7.21	3.66	−49.2	7.21	3.66	−49.2	7.21	3.66	−49.2
Maintenance (3)	28.4	10.4	−63.4	28.4	10.4	−63.4	28.4	10.4	−63.4
Tolls (4)	0	0	0	0	0	0	0	0	0
Total = (1 + 2 + 3 + 4)	**66.1**	**33.3**	**−49.6**	**66.1**	**33.3**	**−49.6**	**66.7**	**33.7**	**−49.5**

Levels in 1998 euros/100 km. Δ%: 1978–1998 variation in %. *Exclusive of VAT, which is paid back to road carriers.
Note: National and secondary roads share the same distance reference costs but do differ in average speeds.
Sources: DAEI-SES, CNR, INRETS, and authors' own computations.

Table 3. Time reference costs

	1978	1998	Δ%
Driver's wage (1)	16.6	12.4	– 25.3
Driver's accommodation costs (2)	3.3	3.2	– 1.3
Insurance (3)	2.4	1.7	– 30.1
General charges, Taxes (4)	9.6	6.9	– 28.8
Truck renewal cost (5)	11.4	7.3	– 36.3
Total time opportunity cost = (1 + 2 + 3 + 4 + 5)	**43.4**	**31.5**	**– 27.4**

Levels in 1998 euros/hour. Δ%: 1978–1998 variation in %.
Sources: DAEI-SES, CNR, INRETS, and authors' own computations.

Moreover, the development of maintenance contracts by vehicle makers and technological innovations in the transport equipment industry led to a decrease of carriers' tire and maintenance charges. French highway tolls slightly increased during the period in order to compensate for the increase of the regional development

Table 4. Total reference costs

	1978	1998	Δ%
Toll highways	128.2	83.5	−34.9
Free highways	116.5	70.6	−39.4
2 × 2/3-lane national roads	119.0	72.2	−39.3
Other national roads	145.0	90.6	−37.5
Secondary roads	152.9	96.3	−37.0
Urban roads (without Île-de-France)	211.4	138.7	−37.0
Urban roads (Île-de-France)	273.4	240.4	−12.1

Levels in 1998 euros/100 km. Δ%: 1978–1998 variation in %.
Total reference cost/100 km = (distance cost/100 km) + (time cost/hour÷speed) × 100.

tax[12] and to better charge heavy-goods vehicles their real contributions to the operating costs of concessionaires.

All things considered, variations affecting these components led to a reduction of the distance-related reference costs ranging between 41% and 51%, depending on the road class.

Let us now review the levels and variations of time-related reference costs, which are given in Table 3.

As regards time-related costs, the drastic decrease of wages, accommodation and other general expenses is due to the productivity gains arising from advances in logistics, from the reorganization of supply chains according to just-in-time practices, and from the road transport deregulation started in 1986. Both the disappearance of licence quotas for entering the French road transport market and the price liberalization of related transport services led to stronger competition and then to a drastic reduction in carriers' costs. Changes in the national insurance system, as for instance the end of taxes related to the premium on both commodities and vehicles, also lowered the corresponding budgets. Everything considered, time costs also experienced a large decrease of 27.4%.

Tables 2 and 3 show that driving through some arcs is more expensive than through others in terms of both distance and time costs, since, even if time-related reference costs do not depend on the arc type, the speed does. However, cheapest road types according to each criterion differ. Table 4 exhibits the total cost per km obtained from adding distance and time reference costs considering the speeds on each arc. Average speeds by road type have been chosen in accordance with the free-flow averages reported by the SETRA: 75 km/h for highways and 2 × 2/3-lane national roads, 55 km/h for other national roads, 50 km/h for secondary roads, and 30 km/h for urban roads, apart from the Île-de-France region, where speeds have been reduced by 30% to compensate for congestion costs in some employment areas where the traffic is huge.

Both distance and time costs taken into account, the cheapest arc types are free highways and 2 × 2/3-lane national roads. Although toll highways are more expensive than other 2 × 2/3-lane roads, tolls do not absorb the whole gain arising from larger speed

12 This specific French tax, devoted to a regional development fund, is paid on each km of the network yielded by firms to whom public authorities gave the concession of developing and maintaining highways.

and lower fuel consumption, making them still less expensive than less than 2×2-lane roads. The largest total reference cost is incurred on urban roads. Road carriers would therefore prefer to use free highways or $2 \times 2/3$-lane national roads, when available, than other roads. They also prefer toll highways than less than 2×2-lane roads, which correspond to a frequent alternative.

3.4 Criteria requirements and GTC properties

We detail in Section 2 the properties that an accurate transport cost measure should meet. It is straightforward to see that the methodology we provide for computing transport costs makes it globally compatible with criteria C1 and C2. GTC combine both a distance- and a time-related cost on each arc of the network and each arc can be defined according to a single or a double direction[13] (criterion C1). Moreover, reference costs depend upon the transport mode and the vehicle characteristics (criterion C2). Criterion C4 is also fulfilled. Knowing the level and variation of reference costs, and the average distance or time incurred on optimal itineraries, a shift-share analysis giving the contribution of each transport cost component can be easily performed, as presented in Section 4.3.

However, it could well be that reference costs, because they are averages, do not fully reflect the true costs of shipping goods for particular routes. Since the GIS we use does not include traffics on the road network, we do not consider the possibility of overcrowding, bottlenecks, safety or ease of driving for instance. The only part of the network on which we partly correct for the congestion bias is the Île-de-France region, for which we assume that speeds are systematically 30% lower than in other areas. We do not introduce delay penalties in other economic centers (in proportion to their population, for instance), because bottlenecks are far less systematic there. Nevertheless, by considering that fuel consumption is larger on national and secondary roads, and even more on urban roads, we implicitly capture the fact that numerous stops systematically occur on these arcs which overcompensates for the consumption decrease due to lower speed. We do not consider either unsystematic nor random overcrowding. This would require data on the truck float and on the ton-km shipped for each arc, which is well beyond available statistics. Finally, as the French legislation regulates heavy-good traffics during evenings, week-ends and holidays, where bottlenecks are more likely to occur because of individual transport, the road capacity is not a real issue in France, at least for inter-city traffics.[14]

Importantly, GTC does not satisfy criterion C3, as it does not depend on the good shipped, since it consists in the costs of driving a representative truck from a centroid to another. However, GTC corresponds to a specific mode and vehicle (road and truck here), and may therefore apply to some commodities only. Furthermore, in this class of commodities, if one knows the number of units that can be loaded into the vehicle, the GTC per unit shipped does depend on the commodity. Finally, if one incurs extra costs due to special packaging for instance, as for fragile goods, those can be directly

13 However, the digitalized network we use does not allow us to fully exploit this property. Each arc is defined according to a double direction but a *single* type, which induces the symmetry of GTCs.

14 Aggregated data might help, however, to evaluate how the issue of road capacity could be problematic. Flows traded within the French borders amounted to 1,782 million-tons (respectively 1,318) in 1998 (respectively 1978). Trade volumes grew therefore by 35.2% during the period, which can be compared to the 105% (respectively 91.8%) increase in the distances shipped by toll (free, respectively) highways.

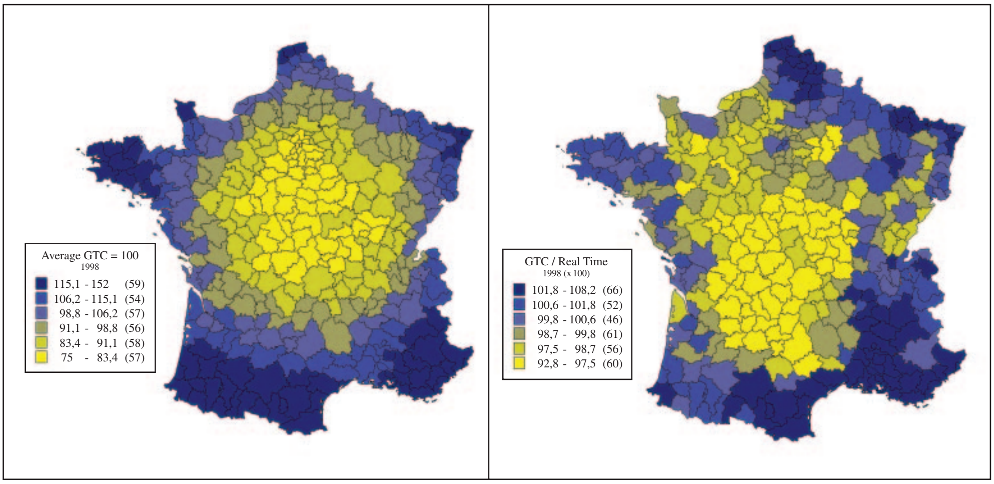

Figure 2. Average GTC (left) and average GTC versus average real time (right), 1998.

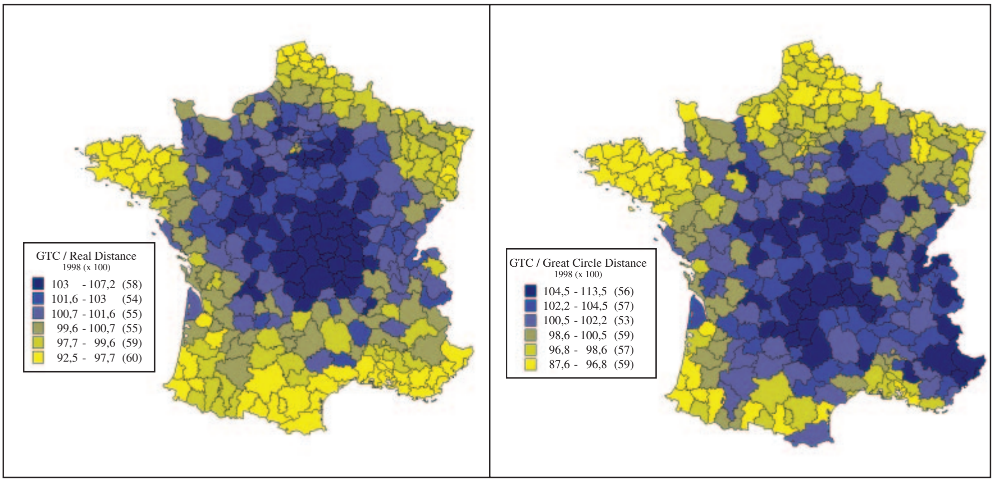

Figure 3. Average GTC versus average real distance (left) and average GTC versus average great circle distance (right), 1998.

added to the GTC per unit shipped, which easily makes it dependent on the good transported.

Finally, GTC also ignores either perishability, security, comfort or environmental social costs related to transport. Although it is far beyond the objective of the paper to deserve attention to each of these issues, our GTC methodology leaves the door open to incorporate such elements. As long as some taxes and fees can make private agents internalize their (excessive) use of transport infrastructure or their contribution to the decrease of social welfare, one could add them to other monetary charges borne for a particular mode, vehicle or energy.

Let us move now to the analysis of the GTC computed for France on the period 1978–1998.

Table 5. Correlations between the levels of transport cost measures in 1978 and 1998

	1978			1998		
	Real time	Real distance	Great circle distance	Real time	Real distance	Great circle distance
GTC	0.993	0.997	0.986	0.993	0.997	0.986
Real time	1	0.983	0.972	1	0.986	0.974
Real distance		1	0.991		1	0.990

Correlations computed over the 58311 non-repeated employment area pairs. All correlations significantly different from 0 at the 1% level.

4. Transport costs in France, 1978–1998

The spatial distribution of GTC in France is described in Section 4.1 while Section 4.2 studies its variations between 1978 and 1998. Both spatial and temporal variability are systematically compared to those of three other standard transport cost measures: Real distance and real time and the simplest measure, great circle distance. Using the decomposability property of GTC, Section 4.3 finally identifies the main sources of its decline over the period 1978–1998.

4.1 GTC versus great circle distance, real distance and time: levels

Distribution patterns of GTC across employment areas are illustrated in Figure 2 (left), which depicts the unweighted average GTC incurred from any employment area to all other ones (including itself) in 1998.[15]

A first striking result is the clear core-periphery spatial pattern of GTC, which monotonically declines towards the French periphery from a center located between the geographic center of France and the transport network center, the Paris area (Île-de-France). The spatial gradient is large: average GTC for the most accessible areas is twice larger than for the most remote ones. Maps of the regional average of the three other transport cost measures, real time, real distance, and great circle distance, present similar core-periphery patterns. However, the real distance gradient is larger than the one of GTC, whereas the real time gradient is lower.[16] Nevertheless, as shown in Table 5, spatial correlations between GTC and alternative measures of transport costs are extremely large, as well in 1978 as in 1998. In cross section analysis, real time, real or great circle distances can therefore be considered as very good proxies for transport costs.

However, if one computes the ratio of the average GTC over one of the three alternative average measures, for each employment area, differences clearly emerge for some areas, as represented on Figures 2 (right) and 3. It is straightforward to see that biases are reversed for center and periphery, and also reversed for distance and time: Real or great circle distances underestimate transport costs borne to reach central areas, when overestimating

15 The average value per region is first normalized by the national average and then plotted with a multiplicative scale of 100, in order to emphasize spatial disparities and to facilitate comparisons between measures.

16 Maps of the regional average of real time, real distance, and great circle distance as well as more detailed results are available in Combes and Lafourcade (2003).

those incurred to connect peripheral ones, and the reverse is observed for real time. Local differences may also be noticed.

Three causes might explain these spatial differences: Average speeds, loading costs, and physical geography.

Firstly, slowing down in urban areas leads to an overconsumption of fuel there, which magnifies the distance component of transport costs with respect to its time-related part. Real time therefore overestimates the transport accessibility of urban areas. This emerges for large urban areas as Lille (in the North) or Marseille (in the South-East). Part of the bias could be corrected by decreasing speeds in the most congested areas. For instance, Figure 2 (right) shows that the bias persists but in lower proportion around Paris, where we applied a 30% reduction on average speeds. As depicted in Figure 3, the accessibility of most central areas is also overestimated by distance proxies: As the time needed to drive on this part of the network may be quite long (national and secondary roads are dominant and $2 \times 2/3$-lane roads rather scarce), both real and great circle distance proxies underestimate the true transport costs incurred to reach them. By, contrast, high speeds on the links connecting peripheral areas to the rest of France (mostly consisting in highways and $2 \times 2/3$-lane roads) make that distances overestimate the real cost incurred to reach the periphery, since tolls paid on toll highways are proportional to distance only.

Secondly, due to the time penalty arising from loading costs, distance measures even more underestimate transport costs in low average GTC areas. Île-de-France, although belonging to central regions, stands as an exception, due to its extreme density of free highways on which the total cost per km is lower than the average.

Finally, real geography leads to an underestimation bias if one uses great circle distance, which ignores the mountains, rivers and other relief constraints. For instance, as regards the employment areas around Nice, which is located in the South-Eastern corner of France, the average GTC is underestimated by great circle distance, but not by real distance. In order to go from Nice to the center of France for instance, due to the presence of mountains, one needs to drive through Avignon indeed, which is located much more West than the great circle line. By contrast, both real and great circle distances lead to comparable results for regions such as Brittany (West) or Pays-Basque (extreme South-West). Despite their remoteness, no geographical barriers prevent from reaching them, making real and great circle distances more substitutes.

Hence, differences between GTC and the three other alternative measures exist. Nevertheless, the large correlations obtained should make them very good substitutes in cross-section studies. Bias on inter-temporal variations are more dramatic, however, as detailed in next section.

4.2 GTC versus great circle distance, real distance and time: variations

All reference costs entering GTC strongly decreased in France over the period 1978–1998: By 27% for the time-related costs, by around 50% for the distance-related costs, and by more than 33% as regards the total cost (per km) (Tables 2, 3 and 4). Thus, even if the road network had not been improved, one could have expected a decrease in GTC. The total decline is of considerable magnitude, equal to -38.3% on average. At the other extreme, and by definition, great circle distance does not vary across time: This measure is therefore useless to capture the transport cost time variations. The real distance varies across time, but only very slightly, by -0.1% on average, between employment areas. This is consistent with the fact that the total number and length of roads only marginally

Table 6. 1978-1998 Variations of transport cost measures (in %)

	Great circle distance	Real distance	Real time	GTC
Varation %	0	– 0.1	– 5.3	– 38.3

Average growth rates computed over the 58311 non-repeated employment area pairs.

Table 7. Correlations between the 1978-1998 variations of transport cost measures

	Real time	Real distance
GTC	0.78	0.42
Real time	1	0.28

Correlations computed over the 58311 non-repeated employment area pairs. All correlations significantly different from 0 at the 1% level.

increase during the period (Table 1). Due to the rise of average speed arising from the road quality improvements underlined in Section 3.2, the average time declines more, by −5.3%. As summarized in Table 6, the average variation of any alternative measure of transport costs is therefore far from the average decrease of GTC and strongly underestimates it.

Another issue is to determine whether such alternative measures correctly predict spatial differences in GTC variations. Still, great circle distance is useless in this respect, since the absence of variation is uniform across space. Table 7 gives the spatial correlation between the variations of GTC, real distance, and real time.

First, correlations between variations are significantly lower than correlations between levels given in Table 5. The correlation between the variations of GTC and real distance, at 0.42, is low compared to the 0.997 correlation obtained on levels. Not only real distance variations strongly underestimate GTC ones on average, but spatial differences are not correctly respected either, as illustrated by the right map of Figure 4. The real time variation is the best proxy for the variation of GTC. The correlation is fairly high, at 0.78, even if it is also lower than the 0.993 correlation obtained on levels. The difference between real time and distance translates into the low correlation between their variations (at 0.28 against 0.986 for levels).

Why do we observe such a discrepancy between correlations in levels and variations? Note first that, broadly speaking, two variables may be highly correlated in levels at two points in time without presenting a strong correlation in their variations. This is the case if variations are independent white noises around the average variation for instance. Thus, the low correlation between the variations of GTC and of real distance is not due to the fact that the former decreases by 38.3% and the latter by 0.1%, but really that the spatial distribution of variations differs. Even if one would uniformly rescale the distance variation by 38%, the same low correlation would be obtained. Mapping the spatial patterns of the variations of GTC and distance, as presented in Figure 4, clearly underlines the relative independence of the spatial distribution of such variations.

As regards GTC, some spatial auto-correlation is observed. For instance, the decrease is large in the western part of France (Brittany and South-West), which opposes to the

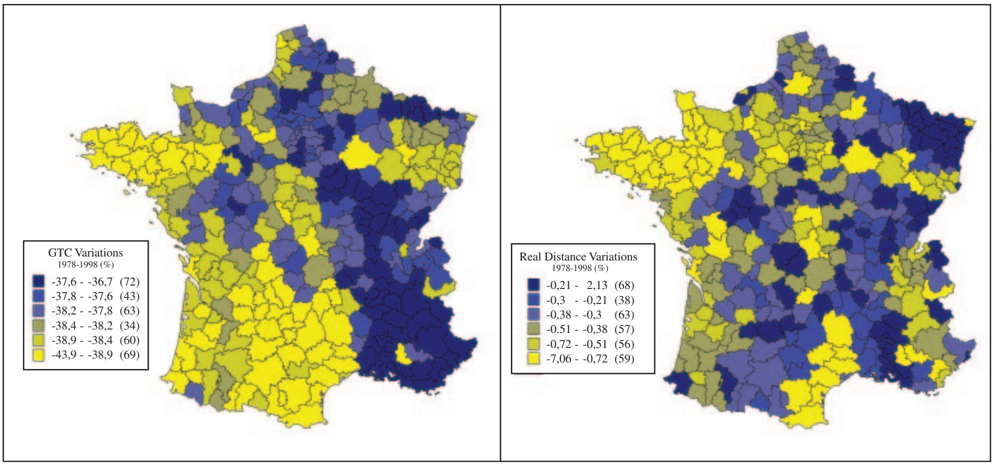

Figure 4. 1978–1998 variations of average GTC (left) and real distance (right).

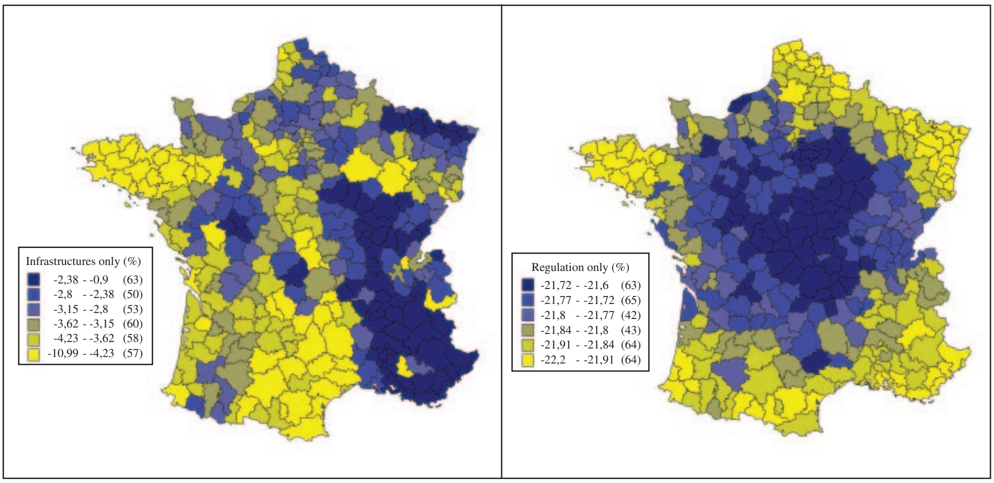

Figure 5. GTC 1978–1998 partial variations, infrastructure (left) and regulation (right).

South-Eastern areas. Employment areas alongside the Paris-Lyon-Marseille highway line, which dates back to 1978, show lower increase in their relative accessibility. No such contrasts appear for distance variations, which are much more patchy and apparently more randomly distributed across employment areas. By contrast, variations in real time[17] much better match those of GTC. Thus, distance improvements are not only marginal but also concern the regions where GTC gains are stronger, on average. The road quality improvements leading to larger time gains are more concentrated on the parts of the network where large GTC gains are achieved.

17 Not presented here but available in Combes and Lafourcade (2003).

Table 8. Shift-share analysis of the GTC variation

GTC Item	Average			Share in GTC		Contribution to GTC decline	
	1978	1998	Δ%	1978	1998	total (Δ%)	net of infras. (Δ%)
Distance costs							
Fuel	122.7	64.1	−47.8	0.16	0.14	−7.8	−6.0
Tire	35.1	17.8	−49.3	0.05	0.04	−2.3	−2.3
Maintenance	138.4	50.6	−63.4	0.18	0.11	−11.7	−11.6
Tolls	28.5	37.7	32.2	0.04	0.08	1.2	0.4
Time costs							
Wages	164.1	116.4	−29.2	0.22	0.25	−6.4	−5.5
Accommodation	32.4	30.3	−6.5	0.04	0.07	−0.3	−0.1
Insurance	24.0	15.9	−33.8	0.03	0.03	−1.1	−1.0
Gen. charges, taxes	95.0	64.1	−32.5	0.13	0.14	−4.1	−3.6
Truck renewal	112.9	68.2	−39.6	0.15	0.15	−5.9	−5.4
Total = GTC	**753.2**	**464.8**	**−38.3**	**1.00**	**1.00**	**−38.3**	**−35.1**
Infrastructures	—	—	—	—	—	—	−3.2

Levels in 1998 euros/100km (Distance costs), /hour (Time costs). Δ%: 1978–1998 variation in %. Averages computed over the 58311 non-repeated employment area pairs.

The next section is designed to answer two subsequent questions. What are the main determinants of the strong GTC average decline over the period 1978–1998, and thus what are the most efficient tools to improve regional accessibility: infrastructure improvements, fuel price decrease, advances in transport technology, or new regulation devices? Next, which of these determinants shape the spatial pattern of GTC variations and explain the discrepancy between GTC and real time and distance?

4.3 Sources of the GTC decrease

Infrastructure, fuel price, transport technology and the market structure of the transport industry condition both time and distance components of GTC, not in the same way however. For instance, technology and fuel costs mainly drive the distance-related part of GTC, public regulation or fiscal policy affect the time-related part, while infrastructure work on both of them.

A first way to disentangle the contribution of each item of GTC to the total GTC is to perform a shift-share analysis. We consider those items corresponding to all distance- and time-related reference costs entering the GTC definition (equations 1 and 2) and compute how much they contribute to the GTC at each date, and similarly for 1978–1998 variations. The first two columns in Table 8 report the product of the average distance (time, next)[18] by each of the distance-related (time-related, next) reference costs, for the years 1978 and 1998 respectively. The 1978–1998 variations of these averages, as their share in total GTC, are given in columns ‘Averages (Δ%)’ and ‘Share in GTC’, respectively. The last two columns present the contribution of each GTC item to the GTC variation: Column ‘total’ is the product of the item share in GTC in 1978 (fourth column) by its variation (third column). Column ‘net of infras,’ reports the same

18 The average distance and time here correspond to the cheapest route, and not to the average minimum real distance and time used in Sections 4.1 and 4.2, differences being minor however.

contribution net of the infrastructure impact. It is obtained by assuming that the average distance and time did not change between 1998 and 1978, which implies that the variation of any GTC item is equal to the corresponding variation of reference costs. The infrastructure impact, reported in the last line of Table 8, is obtained as the difference between the total GTC variation (−38.3%) and the sum of the contributions net of the infrastructure effects of all GTC items.

Table 8 exhibits striking results as regards the real engines of the decline in GTC. Regional policies often choose to develop transport networks in order to alleviate the costs of trading goods, as emphasized for decades by policy makers. However, it clearly arises from the shift-share analysis that infrastructure investments play a minor role in decreasing transport costs. In France, during the period 1978–1998, improvements in the road transport network translated into a 3.2% decline in transport costs only. By contrast, gains stemming from the externalization of maintenance tasks to the own vehicle distributors led to a large decline of 11.6%. Fuel economies linked to the decrease of both fuel price and consumption also participated to a significant part of the GTC decrease, by up to 6.0%. The third most important source of GTC decline, accounting for 5.5% of the decrease, consists in the cut down in wage bill coming from savings on both the wage per capita and the employment levels. These reductions arise partly from the road transport deregulation context of the 1980s and partly from the labor productivity gains stemming from advances in logistics or just-in-time practices, the latter being probably the dominant engine of decline. The gain due to saving on the costs of renewing trucks is of similar magnitude (5.4%), whereas the contribution of other items is rather similar to the impact of infrastructure. Tolls are the only item that makes the GTC experience a (small) increase.

While the contribution of infrastructure amounts to −3.2%, the net impact of all distance costs sums up to −19.5% and the one of time costs to −15.6%. From an economic policy perspective, it is more interesting, however, to group components by broad categories of determinants, whether these are distance or time costs. Apart from infrastructure, we distinguish now the role of fuel price, of technology (including fuel consumption, tire, and truck renewal costs), of regulation (maintenance, wages, accommodation costs, insurance, general charges and taxes), and of tolls. Note that regulation includes changes in the drivers' wage bill, which are less directly linked to a regulation device than the reforms of the insurance, tax, or maintenance contract systems. However, the decrease of the wage bill is partly due to the strengthening of competition on the road transport market, itself resulting from the removal of barriers to entry. Conversely, changes in fuel taxes could have been also considered as a regulation device. However, they are not distinguishable from other fuel price effects (mark-up strategies of oil companies) in the data, and their nature is really different from structural reforms considered in the regulation group. Last, tolls are considered separately because they result from a complex bargaining between government and highway operators and are the only component that increases GTC over the period 1978–1998.

Knowing that the fuel price decreased by 19.0% and the fuel consumption by 21.9% during the period 1978–1998, one can derive from the shift-share analysis the contribution of each of the fuel cost component to the total variation of GTC. The impact net of infrastructure of the fuel price variation is −2.8% for instance.[19] Therefore, as

19 $2.8 = [19/(19 + 21.9)] \times 6.0$.

Table 9. Contributions to the GTC 1978–1998 variations by group of GTC items (in%)

	Infrastructure	Fuel price	Technology	Regulation	Tolls	**Total**
Contribution	−3.2	−2.8	−10.9	−21.8	0.4	**−38.3**

Average growth rates computed over the 58311 non-repeated employment area pairs.

infrastructure improvements, fuel prices play a minor role in driving GTC variations over this particular period in France. So as tolls, whose contribution to the GTC variation is positive, but small, at 0.4.%.

Summing the impact of all GTC items related to advances in transport technology (including the −3.2% contribution of fuel consumption derived by difference) leads to a total impact of 10.9%. This is more than three times the impact of infrastructures or of fuel price. Half of the variation comes from tire savings due to the quality improvements of both asphalt and production proceeds and from fuel consumption gains, and half from truck renewal savings thanks to the training of drivers and to new truck engines.

Finally, the stronger impact is due to regulation items. They are responsible for a −21.8% decrease, representing almost 2/3 of the total GTC decline. Thus, the important move towards deregulation in the road transport industry characterizing the mid-1980s in France strongly affected the transport cost decline. This includes some pure regulation devices as the abrogation of the road compulsory freight rates and license quotas or the insurance tax reforms on freight transport allowances. Other indirect factors are linked to changes in the road market structure, due to growing competition driven by the entry of new carriers because of organizational changes through new contracts arrangements. The average decline due to each of the five groups of GTC components we consider is reported in Table 9.

Independent of the average impact on the GTC variation of a given group of GTC items, this variation may be more or less evenly distributed across space. In order to address this issue, we move now to the description of the impact of each group of components on changes in the relative accessibility of employment areas. There is a methodological issue here. A shift-share analysis allows one to compute the impact of distance- and time-related GTC items net of infrastructure effects for each pair of employment areas only by assuming that the cheapest route between them is the same in 1998 as in 1978. This crucial assumption, without which the shift-share analysis is not feasible, ignores that, under new values of reference costs, the optimal itinerary might change, independently on infrastructure improvements. In other words, in the shift-share analysis, the gains of choosing a new optimal itinerary enter what we call the infrastructure gain, though one could choose a new route only because changes in reference costs made it cheapest to use.[20]

By contrast, for the spatial analysis we perform now, transport cost gains are computed under the alternative assumption that, when a group of GTC items changes, the optimal itinerary also possibly changes. To evaluate the spatial impact of infrastructure

20 For instance, a decline in time-related costs makes it more efficient to use highways even if no new highways are built.

improvements, we use TRIPS to derive the new cheapest routes obtained through replacing the 1978 network by the 1998 one, while keeping all reference costs at their 1978 values. Conversely, the role of new regulation devices is also obtained *ceteris paribus*, keeping the 1978 road network and the 1978 values for all reference costs that do not enter the regulation group and searching for the new optimal routes under these assumptions. We proceed similarly for the fuel, technology, and tolls items. In practice, this procedure has two implications. Firstly, the average gain for each group of components is necessarily larger than evaluated by the shift-share approach, since it includes the gains linked to the use of better itineraries. Secondly, the sum of all gains might be larger than the total transport cost variation since the optimal itinerary has no reason to be the same for each group of GTC items. However, our results show that both kinds of effects are minor. The average variations obtained are very similar to the shift-share ones (-3.4, -3.5, -11.8, -21.8 and $+0.2$% for respectively infrastructure, fuel price, technology, regulation and tolls). Hence, gains due to the fact that optimal routes differ according to one or the other group of items are of second-order compared to average variations.

Maps of Figure 5 depict the spatial pattern of transport cost variations obtained by assuming that only infrastructure (left) or only regulation (right) items change over the period 1978–1998. As seen in Section 3.2, important efforts have been put into the development of high-speed roads, the length of which has doubled. Although the average effect at -3.4% is quite low, the impact of infrastructure is quite differentiated across space. Larger gains concern some of the least accessible or poorest regions, as remote Southern or Brittany areas, but also some agricultural central areas. The lower impact of infrastructure on South-Eastern areas is clearly explained by the fact that highways there have been built before 1978. Thus, the development of the road network contributed to decrease transport costs in a way targeted to some regions only and not uniformly. Moreover, the distribution of transport cost gains due to infrastructure appears to match the total GTC variations depicted in Figure 4 (left). This evidence is confirmed by the large correlation found between both distributions, which is reported in Table 10. At 0.90, it is the highest of the five groups. Thus, we reach the important conclusion that infrastructure improvements do not reduce drastically GTC, but do determine the spatial shape of its variations.

By contrast, the map depicting the spatial distribution of cost reductions due to regulation [Figure 5 (right)] is really different from map of total GTC decline. It is almost monocentric, gains being uniformly larger for peripheral than for central areas. This means that changes in the road market structure have lessened the core-periphery pattern of GTC. The correlation with the total GTC variations is lower than other ones (tolls excepted), at 0.46, even if it is still significantly positive. Hence, the conclusion goes the other way to what is obtained with the infrastructure impact: changes in regulation devices are responsible for most of the total GTC variation, but do not shape the spatial distribution of GTC gains.

The impact of fuel price decline and technology improvements is in between those of infrastructure and of regulation, both in terms of contribution to the total variation and spatial variations. The regions where their impact is the strongest meet partly the locations where GTC mostly declined.[21] This feature also reflects in the correlations reported in Table 10 that are larger than for regulation. Finally, tolls are the only component that

21 Corresponding maps are available in Combes and Lafourcade (2003).

Table 10. Correlation between total and partial GTC 1978–1998 variations

	Infrastructure	Fuel price	Technology	Regulation	Tolls
Total GTC	0.90	0.63	0.65	0.46	0.32
Infrastructure	1	0.28	0.36	0.14	0.26
Fuel price		1	0.81	0.84	0.14
Technology			1	0.47	0.69
Regulation				1	– 0.23

Correlations computed over the 58311 non-repeated employment area pairs. All correlations significantly different from 0 at the 1% level.

increases GTC. Their average impact is small and variations are quite badly correlated to the GTC ones, probably due to the fact that they play on a small part of the network only (the highways built before 1978).

Lastly, notice that spatial variations in transport cost gains due to changes in fuel price, technology or regulation share the important feature of being smaller than those due to infrastructure improvements. The coefficient of spatial variation[22] is 8, 33, and 45 times higher for infrastructure gains than for the gains due to fuel price, technology and regulation, respectively. This also explains why local differences in total GTC gains are mainly driven by infrastructure improvements, even if the average effect of this factor is low, while larger average variations due to fuel, technology, or regulation much less impact spatial differences in total GTC decline.

The study of the structure and evolution of transport costs therefore yields three original conclusions, when applied to road shipments in France during the period 1978–1998. Firstly, simple proxies such as great circle distance, real distance or real time do a very good job in capturing transport costs in cross-section. Secondly, the adequation is much more imperfect in time series, large discrepancies arising between GTC variations and those of any of the three other alternative measures. Finally, changes in the transport market structure and regulation devices, as gains arising from new transport technologies and practices, control for the magnitude of the transport cost decline, while the infrastructure improvements are confined to drive the spatial distribution of the gains. Actually, such results open new lines of policy advices qualifying the use of road infrastructures as the main policy designed to both increase accessibility and to target inequalities, as detailed in next section.

5. International trade, geography and regional policy insights

This final section is devoted to a discussion of both methodological and policy insights that might be drawn from the detailed study of transport costs we perform. First, we provide a comparative analysis of standard transport costs proxies with respect to GTC, alongside their suitability to meet the criteria presented in Section 2. We want to insist here on the gains that researchers in trade and economic geography could find in extending the

22 Spatial standard-deviation divided by spatial mean.

sample of GTC matrices to countries other than France. Next, we derive some implications, particularly relevant for geographers and regional policy makers, arising from the possibility, with GTC, to disentangle transport costs variations according to different transport policies.

5.1 Lessons for trade and economic geography studies

Clearly, the methodology presented in Section 3 could overcome the lack of reliable data in international trade and economic geography, while enhancing the number of criteria required to bring usual proxies closer to an accurate measure of transport costs. GTC satisfies most of these criteria, even though, as detailed in Section 3.4, it should be extended to become commodity specific and to encompass some extra costs. However, the challenge in measuring trade frictions stemming from transport costs is to get homogenous data sets that are comparable across countries and not unique and specific to one of them. Our methodology appears to be easily replicable to other countries actually, as illustrated by Teixeira (2002) for Portugal (and road transport). This replication needs quite a large amount of information, however. We try here to assess whether such an effort is worthwhile in comparison with less costly existing measures of transport costs researchers are used to work with, which we can group in three families: *ad-valorem* shares of trade values, distance-related proxies and real freight expenditures.

5.1.1 Transport cost approximations based on ad-valorem shares of trade values

Following the widely used iceberg assumption, several empirical studies assume that transport costs amount to a given proportion of the value of trade, namely 10 to 20% (as for instance Smith and Venables, 1988; Haaland and Norman, 1992; Gasiorek et al., 1992; or Gasiorek and Venables, 1997). This measure fulfills none of the criteria we insist on, since the proxy is not even origin and destination dependent (C1), although the potential existence of values differing across industries could make it fulfill criterion C3. Moreover, Hummels and Skiba (2003) point out that if transport costs might be positively related to commodity prices, they are certainly not fully proportional to them, as implied by the iceberg assumption. By contrast, once recovered as commodity specific, GTC could allow one to evaluate real *ad valorem* equivalent transport costs.

An interesting methodology has been developed to overcome the limits of *a priori*-fixed iceberg measures and to disentangle *ad valorem* shares of trade values across destinations, modes and industries. It consists in comparing the value of trade flows inclusive and exclusive of freight and insurance costs. These values are often reported to national customs by both importers and exporters. The fob (free-on-board) value measures the value of an imported item at the point of shipment by the exporter, as it is loaded on to a carrier for transport. The cif (cost-insurance-freight) value is the corresponding imported item value at the point of entry into the importing country. Therefore, it includes the cost of insuring, handling and shipping the item to the importer border, being however still exclusive of custom charges. The cif/fob approach, which has been widely used by international economists,[23] leads to a measure that depends on the itinerary used

23 See for instance Harrigan (1993), Amjadi and Yeats (1995), Amjadi et al. (1996), Amjadi and Winters (1997), Baier and Bergstrand (2001), Radelet and Sachs (1998), Gallup et al. (1999), Limão and Venables (2001), Forslid et al. (2002), and Bernard et al. (2003).

(C1), as GTC does. However, Radelet and Sachs (1998) find that the elasticity of cif/fob costs[24] with respect to distance is fairly low, a 10% increase in sea distance between traders leading to a 1.3% increase of transport costs only. Limão and Venables (2001) add that distance explains only 10% of the cif/fob variability. However, regressing our GTC on real road distance gives an elasticity that is much larger, at 0.8 in 1998, while the R^2 of this regression is 0.95. Thus, the impact of distance on both levels and variations of transport costs could be fairly underestimated by the cif/fob approach, at least at the intra-country level where road transport is still predominant. Anyway, since such data are usually collected by customs, they are rarely available at low geographical scales.

The cif/fob measure can also meet criteria C2 and C3. For instance, Bernard et al. (2003) use data collected by the US Bureau of Census on product-level US imports to compute cif/fob bands for different industries. However, the set of goods and countries covered is still incomplete and does not include Europe for instance. The GTAP global database crudely extrapolates the US cif/fob bands to all trade routes because in Europe, due to the completion of the Single Market, customs do no longer systematically report cif-fob values of trade anymore. Furthermore, Hummels and Lugovskyy (2003) reveal that IMF cif/fob ratios are badly error-ridden in levels, and contain few useful information for time series or cross-commodity variations. Last, the cif/fob measure does not fulfill the decomposability criterion, which limits the study of regional and transport policy implications. As a conclusion, this potentially appealing family of measures presents many drawbacks that seem to be more damageable than the cost of extending GTC to other countries and modes.

5.1.2 Transport cost approximations based on distance

Most proxies used for transport costs are based on distance, a variable that can be obtained at almost zero cost nowadays, which gives it a serious advantage over GTC. From the great circle distance to more sophisticated functional forms including discontinuities due to the crossing of borders or real distance computed thanks to electronic atlas for instance, these measures substitute to *ad valorem* proxies when data are too scarce to make any extrapolation suitable for different sets of countries or regions. These distance proxies more or less meet criterion C1, the discontinuity being interpretable as the time spent at customs for instance. Great circle distance neglects the real geography of spaces, but Section 4 shows that this does not induce large discrepancies, as long as a single point in time is considered. However, such spatial biases could worsen at international scales, crossing oceans for instance possibly inducing larger errors. Moreover, when moving from cross-section to inter-temporal studies, we show that differences between the variations of GTC and those of real distance or time are much larger, while great-circle distance is useless. GTC, by accounting for the real structure of the transport network and its evolution, and for the real underlying freight costs, does a much better job in this perspective.

As *ad valorem* measures, distance proxies do not allow one to decompose the source of transport costs variations, and therefore do not satisfy criterion C4. However, they could be made mode (C2) and commodity specific (C3) by estimation, which might be one of the reasons why researchers spend so few time to measure transport costs more accurately.

24 The 1965–1990 average cif/fob bands used by Radelet and Sachs (1998) are computed from the IMF direction of trade statistics data base, which covers a sample of developed and developing countries.

When trade flows are regressed on distance for instance, if flows are mode and commodity specific, the distance effect (distance at the power estimated if an exponential form is chosen) gives a measure that satisfies criteria C2 and C3 on top of C1. Furthermore, some time might be spent to carefully specify the relation estimated, which should reduce mis-specification biases, as proposed for instance by Redding and Schott (2003), Redding and Venables (2004), Hanson (2005), who use economic geography models under monopolistic competition. One can proceed similarly with GTC however, as Combes and Lafourcade (2001) and Teixeira (2002) implement for an economic geography model under Cournot competition. First, this provides a commodity specific GTC measure, which makes it satisfy criterion C3, and may encompass the fact that all commodities do not use the same mode (C2). Second, Combes and Lafourcade (2001) show that the quality of the fit is not much affected when real distance or time are used instead of GTC in their structural estimations. These are cross-section estimations, however, and results in Section 4.2 warns that the same conclusions might not be reached for time series. Moreover, no such an attempt to compare the performance of the various transport cost proxies has been proposed for other models. Therefore, assessing the magnitude of the biases they induce when their effect is estimated remains to be completed. This would enable one to fully evaluate the gains arising from improving transport cost measures.

5.1.3 Transport cost approximations based on real freight and insurance expenditures

Last, very accurate data on real freight expenditures are sometimes reported for accounts or regulation necessities. For instance, the US Department of Commerce provides detailed freight expenditures supported by ocean, air, and land transport companies for importing to the US about 15,000 goods from anywhere in the world.[25] One of the most advanced steps towards gathering and analyzing such a dispersed information is due to Hummels (1999, 2001a, 2001b), who provides stylized facts on the levels and variations of freight expenditures coming from many data sources. Hummels (1999) underlines that aggregating transport charges across industries underestimate the true magnitude of shipping costs due to composition effects. He also exhibits large variations of transport costs depending on both modes and periods. Hence, criteria C1 to C3, satisfied by such freight expenditure measures, are all proved to be critical devices. However, the collection of such data is still limited to some goods, modes and countries. Our work contributes to extend it to the European continent. The point we want to emphasize here is that systematizing the use of freight costs in association with GIS, as we propose here, both alleviates spatial and temporal bias arising from simple proxies and enables one to predict changes in regional disparities stemming from different policy instruments, an issue to which we turn now.

5.2 Lessons for geographers and regional policy makers

The ability to predict transport cost changes driven by a specific component, such as infrastructure investments, is of crucial interest for regional and public policy. In Europe

25 The World Air Transport Statistics (WATS) also reports world-wide air freight revenues and ton-km performed since 1955. The US Transborder Surface Freight database includes, for overland imports from Canada, the province of origin, the entry port and the shipment mode (rail or truck).

for instance, the gains from alleviating the barriers due to national trade policies would be much lower if the costs of shipping goods were not simultaneously reduced. Improvements of the transport networks themselves are usually claimed as the policy achieving the largest benefits in this respect. The European Regional Development Fund spent for instance around 15 billions euros in developing Trans-European Networks (TENs) during the period 1994–1999, whereas the Cohesion Fund also devoted 8 billions to the least developed European regions. Indeed, transport infrastructures are also often seen as a means to give a locational advantage to some areas, and are therefore privileged to improve the peripheral areas accessibility to large economic centers. However, the rate of return of transport projects is still under debate and so are the claims regarding their spatial redistributive effects, as argued by Vickerman et al. (1999) for instance. This section is dedicated to shed light on new tools that could be used in such an evaluation. Such new devices emanate from the possibility, with GTC, to disentangle the various determinants of transport costs, which is not allowed by any other of the proxies standardly used. GTC would therefore give to geographers, transport planners, and regional policy makers, the possibility to choose the instrument that best targets their objectives.

A long tradition in the transport and geography literature is designed to predict changes in regional accessibility due to the implementation of new transport infrastructure. The accessibility of a region measures the opportunities that households or firms of that region may benefit from in other regions, accounting for the cost incurred to reach them. Most accessibility indicators typically sum over all regions an activity measure (employment or GDP for instance) discounted by an impedance function (the inverse of transport costs, or more crudely distance or time). From this perspective, combining a distance and a time cost within a single impedance function is far from being new. GTCs are indeed often associated to spatial economic characteristics within a GIS to compute accessibility indexes. Botham (1980) for instance uses GTC to estimate the accessibility gains due to the British road investments program on the period 1957–1972. He compares the results obtained when discounting with the real GTC matrices and with the matrix obtained by substituting the original links to all new motorway links. Whereas Botham (1980) uses the shortest routes between origins and destinations, Linneker and Spence (1996) proceed similarly with the quickest routes. Moreover they use, on top of GTC, the real time and distance also obtained to calculate market potential accessibility indexes based on employment data. Gutiérrez and Urbano (1996) extend this analysis to the whole Europe and simulate the changes in accessibility driven by the Trans-European Network (TEN) road plan (at the 2002 horizon).[26]

More generally, thanks to the decomposability property of GTC (criterion C4), a shift-share analysis in the spirit of the one we present in section 4.3 can be performed on any accessibility index based on GTC. This allows one to distinguish in the variation of accessibility not only the impact of GTC relatively to the activity variation, but also the role of each of its component. Applied to France, this would for instance clearly underlines that accessibility gains over 1978–1998 were much more driven by changes in regulation and technology than by new infrastructure. Similarly, maps of the accessibility gains obtained under a given scenario (changes affecting part of the GTC components only, as presented in Section 4.3 or in Botham, 1980) could help to signal those regions

26 The reader will find detailed surveys on this topic in Copus (1999) and Spiekermann and Neubauer (2002).

better targeted by one or the other tool. This would allow researchers to really evaluate the extent to which new infrastructure reach their objective of both improving accessibility *globally*, and for *specific areas*. More generally, it would underline that tools that were not designed in first place as regional devices might have quite a large impact on accessibility. This is the case for deregulation in France over the period 1978–1998, but one could expect that the burden of environmental taxes could make it work the opposite in the future. Conversely, the privileged regional policy tool, infrastructure, would at best impact on the distribution of accessibility gains but not on their magnitude, at least in France and for the period under study. By contrast, apart from a few contributions,[27] most computations of accessibility indexes are based on simple transport cost proxies as distance. While probably giving the correct magnitude of spatial variation in accessibility at given points in time, we show that they cannot provide the correct range for the time variations of such an accessibility and do not allow to decompose these variations. Both points much reduce the implications that can be derived from such analysis. On top of regional policy issues, one also observes a renewed interest in accessibility functions due to their links with economic geography models under monopolistic competition, as first underlined by Hanson (2005). Using the correct impedance function to measure them also appears as crucial in this field.

6. Conclusions

Based on the real transport network, the transport cost measure we develop encompasses the characteristics of the infrastructure, vehicle and energy used, as well as labor, insurance, tax and general charges borne by transport carriers. Comparing this new measure to alternative ones such as great circle distance or real time, we conclude that these proxies do a very good job in capturing transport costs in cross-section analysis. However, important discrepancies limit the possibility of substituting them to our measure in time series analysis. Identifying transport policies that have the strongest impact on carriers transport costs is one of the main contribution of our measure. The mid-1980s deregulation of the road transport industry appears to be the main source of transport cost decline over the period 1978–1998, simultaneously with technological progress. By contrast, deregulation explains a little part of the spatial pattern of the transport cost decline, which is more correlated with infrastructure improvements, while such improvements do not much affect the average transport cost reduction. Thus, there would be a complementarity between these determinants of transport costs. While technology and market structure condition the global magnitude of the transport costs decrease, infrastructure investments target the regions that will benefit from these gains. The spatial impacts of fuel cost and tolls variations, which are low over this period, appear to be minor.

We show finally that these results may have quite strong implications regarding as well trade and economic geography empirical research as regional policy. On this last issue, while the development of new infrastructures is typically meant as the way to further reduce transports costs, our conclusions point that policies non-directly envisioned in

27 On top of the references already quoted in this section, the reader will find in Schürmann and Talaat (2000) a detailed report of European peripherality indexes for both individual mobility and road shipments by lorry.

such a purpose might have stronger effects. The next step would consist in evaluating the cost of these alternative policies, and thus, in comparing the rate of return of both strategies. For instance, deregulation involves no direct costs but some social ones possibly, technology improvement costs are mainly borne by the private sector but could be also partly financed publicly, and so forth. This leaves interesting research directions to deal with.

Besides, it is currently fashioned to claim that time has come for the 'death of distance' (Cairncross, 1997). Glaeser and Kohlhase (2003) announce for instance the disappearance of the costs of moving goods (but not people), arguing that technological change has now eliminated most of the fixed transport charges related to trade activities. However, transport costs remain high in France even following the almost 40% decrease over the last 20 years, and they still vary significantly across space. Furthermore, we also think that transport costs can still experience strong decline even if they have already decreased so much. First, declines in the average consumption of fuel are still undergoing (by 0.5% in 2000 and 1.2% in 2001 for the representative truck).[28] Next, the deregulation process of the transport industry is still very recent for modes other than road. The rail deregulation of freight, a few European countries have just gone through, should strongly increase competition and thus decrease costs. Changes in the European way of allocating air slots to carriers (by introducing for instance an auction procedure) could help to alleviate some informal barriers that still prevent the entry of other competitors. Since we have shown that these factors were major determinants of the transport costs decrease, important decline could be still expected, in our opinion. Last, another source of costs, working in the opposite direction, could also induce important variations. Governments all face important pressure to implement taxes designed to correct for environmental or security drawbacks arising from the traffic growth. Evaluating which of the determinants of transport costs will dominate and what will be the magnitude of future changes thus remain high on the agenda, a debate our methodology could help to tackle properly.

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28 See the statistics provided by the French Ministry of Transports: http://www.equipement.gouv.fr/statistiques/analyses/etudes/transpor/compteT2002/sommaire2002.htm.

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