World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

Measuring the long-distance accessibility of Italian cities

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Abstract

Long-distance accessibility is a crucial element for economic development and for territorial cohesion. However, an accurate and realistic measure of accessibility must consider not only the distance or travel time of a single mode, but also the fare levels, the frequency and the interchanges of all modes available.
The paper aims at answering at the question whether and where there is a problem of accessibility to Italian regions, thanks to a comprehensive measure of accessibility of the entire Italian territory. The measure used in the paper is potential accessibility, with exponential decay impedance function. Differently from similar studies, we go more in detail in the definition of impedance parameters, thanks to the availability of a transport model, including the entire Italian long distance supply (roads, coaches, long distance rail services, air services, ferries). The opportunities at destination are proxied by population, private and public sector employees.
The main paper outputs are detailed maps of accessibility, much more realistic than using simple infrastructure indicators. Modal maps clarify also the different roles of the modes in the different areas of the country.
Finally we draw some policy conclusions, in terms of past and future investment policies. In particular, we show that the geography of inaccessibility is more complex than the expected one, based on the rough North/South opposition.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: potential accessibility; rail; air; coach; remote regions; transport model

1 Introduction

1.1. How much do we know the Italian the transport system?

The geography of Italian transport is barely known in detail. Studies on the entire country including long distance transport, such as in the UK (Eddington, 2006), simply do not exist. Official documents and statistics are always very aggregate (CNIT, 2013; ISTAT, 2013), seldom accompanied even by charts. At best, modal studies have been produced, such as the recent Airport Plan (Ministero delle Infrastrutture, 2014), but the focus firmly remains on the infrastructure side, almost ignoring the demand and even the services. The last national planning exercise, by the way, dates back to 2001 (Ministero dei Trasporti, 2001) and it was never implemented in practice. It included a very aggregated description of the network extensions and of the demand, not clearly supported by models or surveys.
Nonetheless, the Italian ministry of transport takes decisions and invests relevant amounts of money (nearly 10 b€ in 2011; Beria and Ponti, 2012), usually basing on single-scheme studies (Beria et al., 2012), produced *ad hoc* by the proponents and scarcely coordinated with other concurrent and competing projects. This limits of this approach are evident, and may result in biased decisions, overinvestment, underinvestment or simply in inappropriate infrastructure design.
We can find more deep, and sometimes also more detailed, studies published by other subjects, unlinked with the Transport Ministry (MCC, 2003; Banca d'Italia, 2011; Uniontraporti, 2011), but the focus (infrastructure) and the data used (aggregated) are always the same.
Only locally (regions, cities) one can find comprehensive and up to date planning documents, not limited to the infrastructure side and often based on transport models for the estimation of future scenarios.

1.2. Paper aim

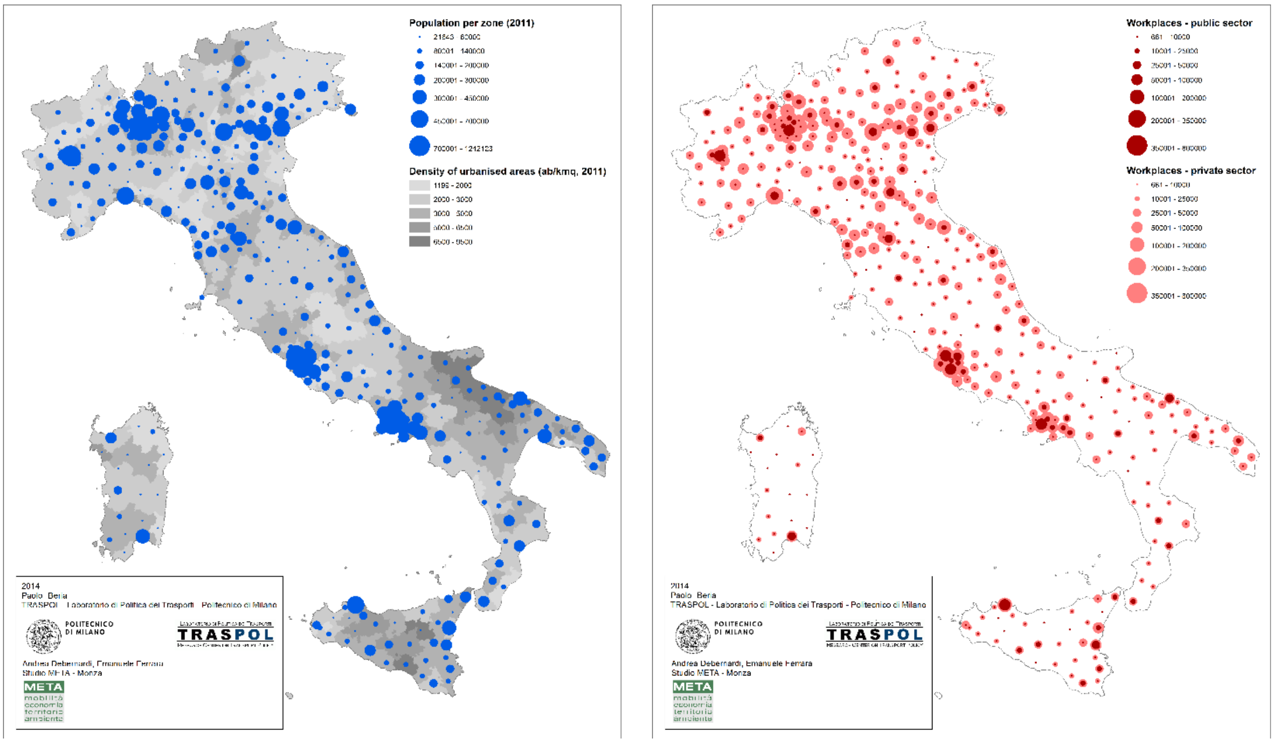
In this unsatisfying context, the paper aims at answering at the question of whether and where there is a problem of long distance accessibility to Italian regions, measured in a consistent way, also overcoming a debate based on the sole networks extension. Population in Italy is far from homogeneously distributed. Similarly, the networks connect the main cities, but their performance is influenced by design and orography. While regional or local accessibility for Italy are sometimes studied (Lattarulo, 2009; De Montis, 2011; Cascetta et al., 2013) because more data is available at that scale and more interest is shown by the local authorities, the national dimension is barely known, with the relevant exception of Alampi and Messina (2011).
By means of a transport model, including the entire Italian long distance supply (roads, coaches, long distance rail services, air services, ferries), we build a consistent measure of accessibility of the entire Italian territory. The measure does not consider only the infrastructure or the frequency of public transport services, but is based on a comprehensive estimation of the generalised cost to reach all destinations in Italy according to their relative attraction power. As most of the previous researches focus on single modes, the calculation of accessibility using multimodal measures is a challenging exercise (van Wee, 2016).
The paper is structured as follows. The next section will briefly introduce the geography of Italian transport. Section 3 revises the main accessibility indicators and comments their meaning in terms of representativeness and consistency. Section 4 introduces the methodology and the data used. Section 5 computes the accessibility for Italy according to the chosen definition. Thanks to these results, partially counterintuitive because revealing the complexity of the geography of a transport system of such a scale, the last section will provide some policy indications, especially in terms of actual needs of new infrastructure in the country.

2 The geography of Italian transport system

2.1. Population and cities

Italian population is almost totally urbanised. Urban areas however, present very different characteristics and densities. The following Figure 1 represents the distribution of population (left) and of workplaces (right), together with the density of urbanised areas.

Figure 1. Demographics of Italy. Left: population per zone and population density based on urbanised areas. Right: workplaces per zone, private and public sector. Source: our elaborations on 2011 census data.



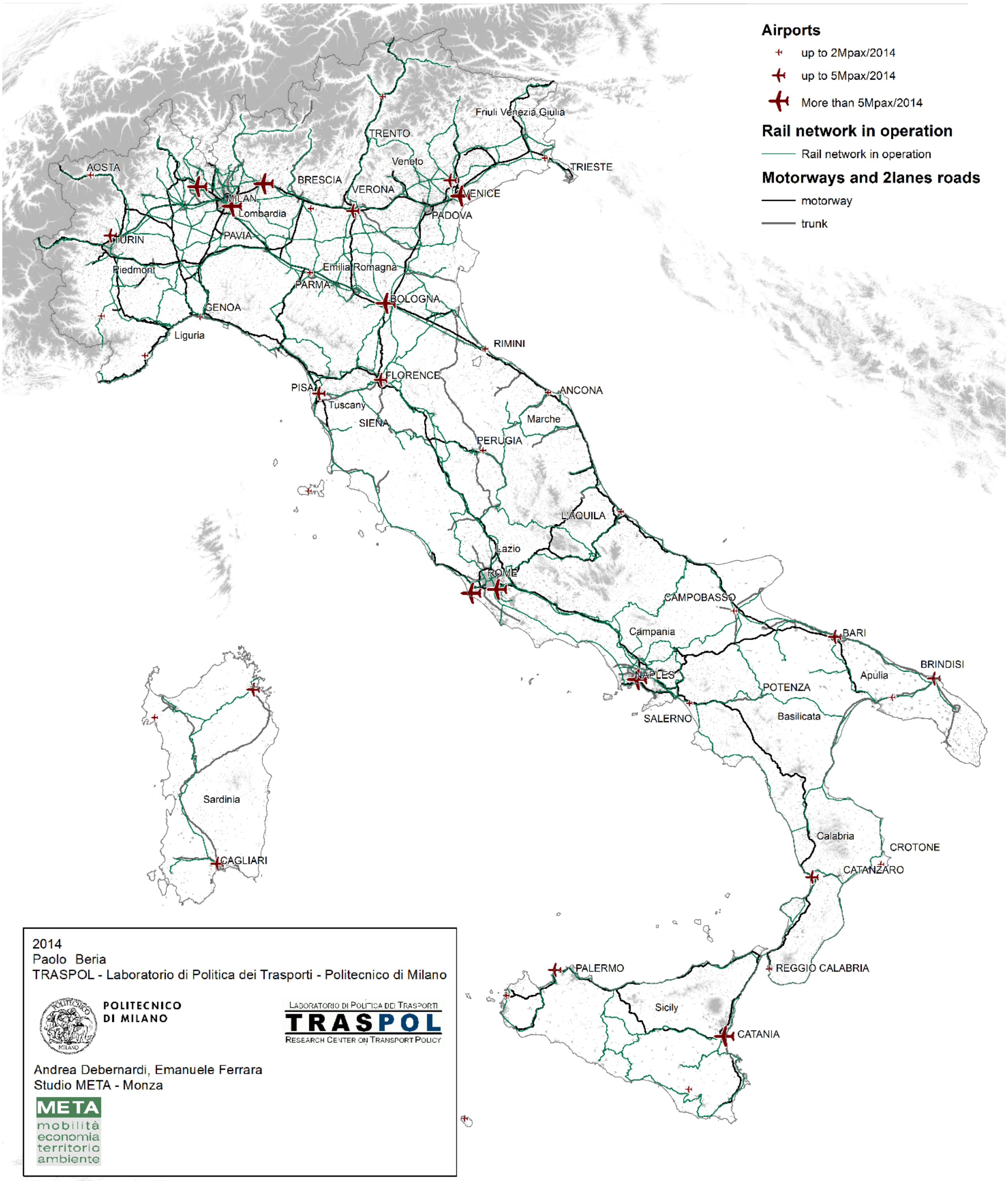
As one can see, the three areas where most of the population is concentrated are the conurbations of Milan, Rome and Naples, also characterised by high densities (Refer to Figure 2 for place names). Secondly, Veneto, Emilia and Northern Tuscany present lower densities, but quite large population. The other main cities (Turin, Palermo, Bari, Catania) are more isolated. The higher densities of settlements excluding urban areas are found in Northern Apulia region, but total population is small and typical of isolated and compact agricultural towns.
The pattern of workplaces is similar, but it is evident both the higher number of workplaces in the North, as well as a lower

incidence of public sector with respect to Centre and South. This entails more concentrated destinations of trips, as public sector employees are almost totally concentrated in provincial and regional capital cities, while manufacturing in the North tends to be spread outside core cities.

2.2. Transport infrastructure in Italy

Italian infrastructure network comprises some 19.000 km of railways, more than 180.000 km of supra-local roads (Uniontrasporti, 2011) and many more local and urban. In addition, a hundred airports exist, of which 37 with commercial traffic, and 16 commercial ports (among more than 200 other ports).
The following chart (Figure 2) represents the main Italian infrastructure networks, namely the active rail lines, the 2-carriages toll and non-toll motorways, the commercial airports.
In the chart it can be seen clearly that the networks are distributed differently. While in the northern plain (the Po Valley) both rail and main roads are reticular, because reticular is the pattern of cities, in the rest of the country (Alps, Centre and South) the corridors match with main valleys and coastlines.
The main rail lines are the Turin – Trieste, the Adriatic coast line (Bologna – Brindisi) and the main North to South line Milan/Venice – Reggio Calabria. Other lines have a local or international importance (Brenner, Milan – Genova, Genova – Rome, Naples – Bari).
Motorways follow, more or less, the same corridors and connect the same cities.
Main airports are well distributed along the country (Milan, Venice, Rome, Naples, Catania, Bari). Secondary airports coverage is sometimes redundant (e.g. the four airports in line between Parma and Rimini) or lacking (Basilicata, Trentino Alto Adige). Rome, Venice and Milan have multiple airport systems.
In conclusion, Italian infrastructure network is mature, with extensive and sometimes redundant infrastructure, locally characterised by saturation phenomena.

Figure 2. Map of Italian rail, roads and airports (Our elaborations on various sources, 2014)



2.3. Transport services

Infrastructure alone is not telling us much about how the Italian transport system "works". Except private transport, in fact, the quantity and characteristics of services determine the level of supply.

A minimum level of rail supply exists in the entire country, except mountain areas. Of course, the capillarity of such system is low and usually only the centres of some dimension are served. Beria et al. (2015) map the overall supply of trains on all Italian rail lines. Rail services and network connectivity is higher in the Po Valley than in the rest of the country. In central and southern Italy, but also along the international corridors across the Alps, supply is almost concentrated on the main lines.

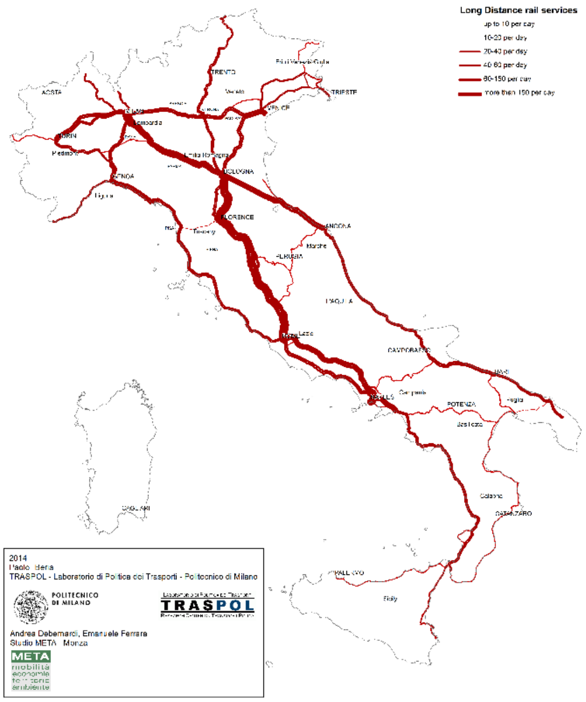
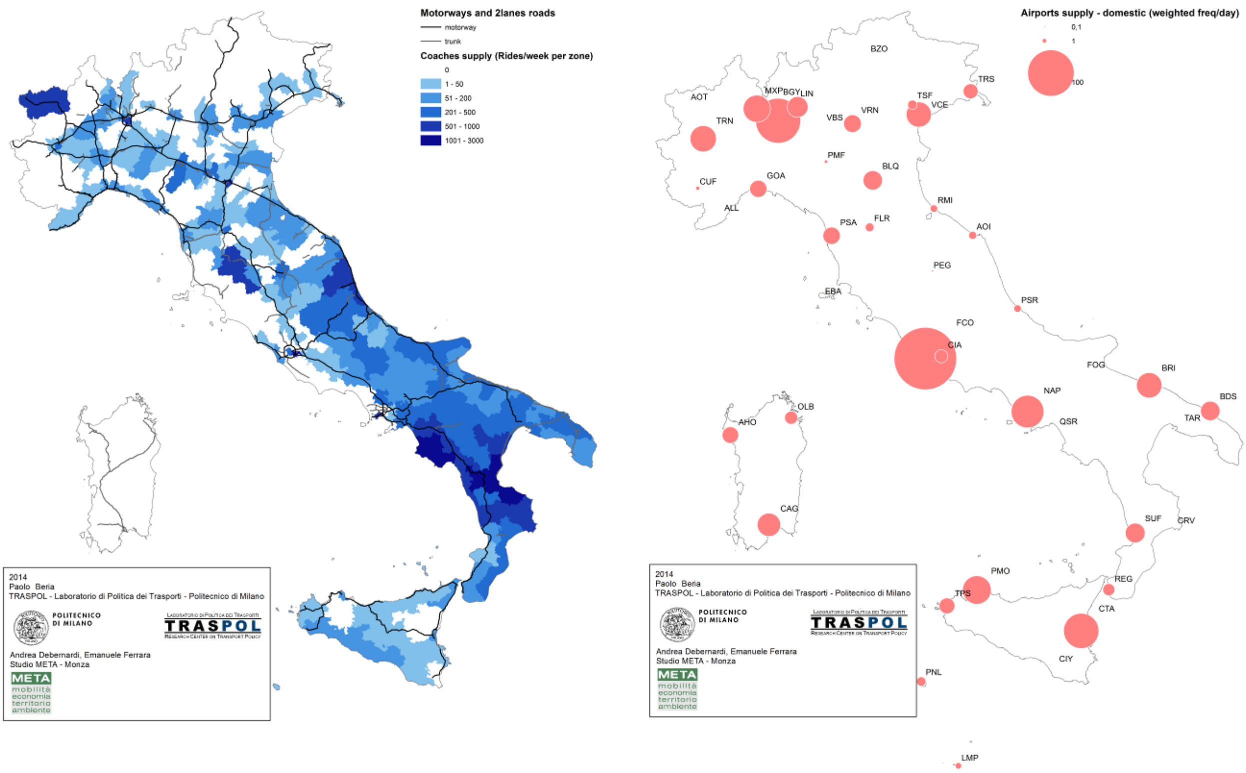


Figure 3. Long distance rail services supply (rides/day). Source: our elaborations on 2014 timetable

Limitedly to long distance trains, the regional differences decrease and services are limited to main lines. With the exception of the Turin – Naples, Bologna - Ancona and Turin – Venice, by far the most important lines, the rest of network has quite comparable services. Of course, many secondary lines and stations do not have any long distance service, reducing the penetration of rail in medium and low-density territories.

Figure 4. Left: coach services supply (rides/week per zone). Right: domestic flight frequencies from Italia airports (frequencies/day). Source: our elaborations on 2014 timetables (coach) and 2013 (air).



Coach services network is totally different. Coaches are concentrated in the South and in a handful of single cities in the Centre-North (Beria et al., 2014), as in Figure 4 left. The most served area is the North of Calabria and the South of Campania, where frequent coaches to Naples, Rome and to the North are much more used than trains. This network comes from the past, when coaches were considered as complementary service where the rail was absent or ineffective, but this is rapidly changing with the ongoing liberalisation process.
Finally, Figure 4, right, depicts the supply of domestic flights only in terms of daily frequencies (Mon-Fri average). Rome Fiumicino is the main Italian airport but this dominance makes the rest of Central Italy empty of other airports. The main Southern cities have comparable supply (Catania is the largest), complemented by few secondary airports. The situation in the North is more complex, due to high fragmentation. Milan is the main example, with three airports of comparable dimension competing each other. This increases surely the air accessibility of the served territories, but reduces the frequencies of supply and sometimes also the sustainability of routes (Beria et al., 2011).

3 Accessibility measures

3.1 Classifying accessibility measures

Accessibility is an intuitive concept, related with the easiness, or not, to reach a destination or access to a service (van Wee, 2016). However, to formalise this concept different definitions exist and the indicators used are apparently similar, but not fully comparable. Moreover, some of the most complex accessibility indicators lack of physical meaning, and thus accessibility should always be intended as a relative measure and not as a characteristic of a place.
In addition, the measure of a change in accessibility cannot be used to decide for an investment in substitution of tools such as cost-benefit analysis. This for two orders of motivations: 1) accessibility depends on the definition used and extremely different results can be obtained; 2) accessibility does not tell us anything about the efficiency of an action (i.e. how resources are used), but only about effectiveness (how accessibility is changed).
Notwithstanding these conceptual pitfalls, a properly designed accessibility measure can effectively help in showing the state-of-the-art of the transport opportunities of an area and also to represent the effect of an investment or of a policy change and ultimately to help decision makers and planners in understanding the actual effect of their actions.
Numerous previous works revise and classify the accessibility measures. Handy and Niemeier (1997), Geurs and van Wee (2004), Martìn and Reggiani (2007), Vandenbulcke et al. (2009) and Paez et al. (2012) are among the most known reviews on the topic. Adopting the convincing classification of Geurs and van Wee (2004), accessibility indicators belong to four groups, the simplest being focused on the physical performance of the transport system (*infrastructure-based measures*, such as network extensions or level of services). More complex indicators consider also the characteristic of the location or the opportunities at destination (*location-based measures*), or the characteristics of the individuals (*person-based measures*), or the economic benefit associated to the access for the individuals (*utility-based measures*). The first group's limit is that it focus on the transport side of the problem only, ignoring the purpose of the travel. For example, living along an uncongested freeway in the middle of nowhere might be good from the pure transport point of view, but you keep being in the middle of nowhere. The other measures are instead theoretically coherent and consider also, respectively, land use, individual characteristics and utility of the trip. However, they suffer from being not directly intuitive. For this reason, they are usually presented in normalised or relative forms (e.g. ordered or scaled from the highest to the lowest in a given area).

3.2 Location-based measures: potential accessibility

In this paper, we will use one formulation belonging to the group of *location-based measures*, i.e. the well-known *potential accessibility*:

$$A_i = \sum_{j=1}^{n} M_j \, f(\beta, x_{ij}) \qquad \text{Equation 1}$$

Where A_i is the measure of accessibility from the origin i, M_j is the "mass" of opportunities at destination j, β is the sensitivity parameter to x_{ij}, which is the impedance variable of the trip from i to j. This formulation is general and both M and x can be declined differently. Typical variables used to proxy the attractiveness M of the destination are: population, jobs, GDP. Typical impedance variables are travel time, door to door time, distance, generalised cost. The result A_i is usually normalised for readability, for example around the average.
Also the function f, called *distance decay function*, can take different formulations. Table 1 and Table 2 review the functions used in some of national-scale accessibility studies.

Table 1. National-scale accessibility studies, not using exponential decay functions.

	Geography	Detail	Modes	Accessibility definition	Opportunities indicator M
Condeço-Melhorado et al (2011)	Spain	NUTS4	Ro	□(Mj / C□ij)	GDP, POP, JOBS
Duran-Fernandez & Santos (2014)	Mexico	NUTS3		□(Mj / T□ij)	POP, JOBS (various), income (various)
Geurs & van Eck (2003)	The Netherlands	M	Ro, PT	Log-logistic(Tij)	JOBS
Gutiérrez & Urbano (1996)	EU	98 cities	Ro	□(Tij * Mj) / □Mj	GDP
Holl (2007)	Spain	M	Ro	□(Mj / D□ij)	POP
Jiao et al. (2014)	China	Prefecture (~330 zones)	Ra	□(Mj / T□ij)	√POP*GDP
Karampela et al. (2014)	Greece	Islands	A, F	Access time from Athens including frequency	n.a.
Keeble et al. (1982)	EU	NUTS2	n.a.	□ (Mj / Dij)	GDP
Martin & Reggiani (2007)	EU	88 cities	Ra	□(Tij * Mj) / □Mj □(Mj / D□ij) □(Mj * f(Tij))	GDP, POP
Ortega et al. (2011)	Spain	M	Ro, Ra	Average effective speed	POP
Ortega et al. (2012)	Spain	M	Ra	□(Mj / T□ij), □=1	POP
Östh et al. (2015)	Sweden	M	n.a.	□(Mj / D□ij)	JOBS
Vandenbulcke et al. (2009)	Belgium	M	Ro, Ra	Access time to towns and train stations	n.a.
Vickerman et al. (1999)	EU	70000 cells	Ra	□(Mj / T□ij)	POP

Detail: the level of geographical disaggregation. M: municipality; NUTS4: cluster of municipalities.
Accessibility definition: the formulation of accessibility used. α: friction parameter

Potential accessibility measures, like any other synthetic measure, have a number of limits that must be kept in mind and whose main consequence is that applications are hardly comparable:

- Depend on the study area (Ortega et al., 2012);
- Depend on the level of disaggregation (Handy and Niemeier, 1997; Vandenbulcke et al. 2009);
- Lack of physical meaning and consequently quite "black-box", i.e. not easily interpretable by a third-party reader (Geurs and van Wee, 2004; Vandenbulcke et al., 2009);
- Are not comprehensive, i.e. consider one aspect only (e.g. rail accessibility to jobs);[1]
- Ignore the intra-zonal accessibility (Geertman and Ritsema van Eck, 1995; Vandenbulcke et al., 2009);[2]
- Lack of economical meaning (trade-offs are ignored).

The works reviewed give a glimpse to this heterogeneity.

3.3 National scale applications using an exponential decay function

One of the most common formulations of *distance decay functions* is the *exponential decay* one. The resulting definition of *potential accessibility* is (Geertman & Ritsema van Eck, 1995):

$$A_i = \sum_{j=1}^{n} M_j e^{-\beta x_{ij}} \qquad \text{Equation 2}$$

While most of the studies on accessibility are applied at the local level, some focus on the national scale. Table 2 revises the most recent ones and gives an idea of how different the models used can be, both for the indicator of the opportunities at destination and the impedance variable. Table 3 lists some examples of local scale.

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[1] One could imagine to build comprehensive indicators, for example "summing up" both population, GDP and jobs at destination, or weighting different modes (e.g. in Karampela et al., 2014). But this risks to decrease the readability and comparability of the indicator, making it even more "black-box".
[2] Which also means that introduce a bias depending on the dimension and contents of the zones.

Table 2. Recent studies on accessibility at national or supranational scale, using an exponential decay impedance function $e^{-\beta X_{ij}}$

	Geography	Detail	Modes	Opportunities indicator	Impedance variable X	□ value
Alampi and Messina (2011)	Italy, EU	NUTS3	Ro, Ra, A	Population	Dij, Tij	0.005
Axhausen et al. (2011)	Switzerland	M	Ro, PT	Population	Tij	0.2
Brödner et al. (2014)	EU	NUTS3	Ro, Ra, A	Population	Tij	n.a.
Reggiani et al. (2011)	Germany	M	Ro, Ra	Jobs	Tij	0.008**
Rosik et al. (2015)	Poland	M	Ro	Population	Tij	0.005775 (int), 0.013862 (nat), 0.034657 (reg)
Spiekermann & Schürmann (2007)	EU	NUTS3	Ro, Ra	Population	Tij	0.005
Stępniak & Rosik (2015)*	Poland (Mazovia)	M		Population	Tij	0.023105

Notes. *: the paper looks at Mazovia region accessibility, but uses a national scale model; **: the beta is calibrated using commuting trips only (i.e. without the other purposes, very relevant in the long-distance segment).
Detail: the level of geographical disaggregation. M: municipality; NUTS4: cluster of municipalities.
Modes: the mode considered. Ro: road. Ra: rail. A: air. F: ferry. PT: public transport.
Impedance variable adopted. Cij: generalised cost. Tij: travel time. Dij: distance.

Concerning the opportunities indicator, population of the destination zone is the most used, but entails evident limits. The first of which is that population is not a real proxy of the importance of a destination, moreover if we are talking of long distance trips different from personal purposes. Business trips could be better proxied by GDP or by the number of jobs at destination. Touristic importance depends by the number of beds. Student trips could be better described by the dimension of universities and administrative-purpose trips depend on the administrative importance of the destination. For example, all trips to ministries and embassies are necessarily directed to the capital city, whatever is its dimension (e.g. Rome trips are more than proportional to its dimension).
Similarly, the simplest impedance variable is the distance, but it cannot describe the effect of different infrastructures, like high speed rail lines or motorways with respect to zone similarly distant in space, but unconnected with the main networks. For this reason, most of the studies use travel time as impedance variable. However, also travel time ignores some relevant differences, such as the presence of competition (lowering prices) or of a large low cost airport. For this reason, a more complete variable should be the generalised cost (Koopmans at al., 2013), but it is never used in the consulted literature, most likely due to the complexity of its calculation.

Table 3. Studies on accessibility at local or regional scale, using an exponential decay impedance function $e^{-\beta X_{ij}}$

	Geography	Detail	Modes	Opportunities indicator	Impedance variable X	□ value
Caschili et al. (2015)	Sardinia	M	Ro	Commuter trips	Dij	0.225 – 0.855 (calibrated)
Cheng and Bertolini (2013)	Amsterdam	$500m^2$	Ro	Jobs	Tij	0.15
Wang et al. (2015)*	Madrid	90 zones	all	Jobs	Cij	0.0163 (calibrated)

Note: *: the impedance function used has a second parameter $\alpha e^{-\beta X_{ij}}$, valued α=0.16

The different formulations used make, unfortunately, different studies hardly comparable. Moreover, the *beta* used (calibrated or not) are very different, which means that consider differently accessible places located at the same distance. The implications of *beta* will be discussed in detail in Section 4.3.

4 Methodology

In this work we refer to one of the accessibility measures described above, namely *potential accessibility*, using an *exponential decay function* as in Equation 2.
This measure has some relevant characteristics (Geurs and van We, 2004):

i. Takes into account the combined effect of land use and transport elements, being the first represented by the number of opportunities M_j at destination and the second included in the variable of the decay function.
ii. The exponential decay function effectively represents individual perception of distance, declining more than linearly.[3]
iii. The computation is not excessively complex, at least not implying recursive calculation.

With respect to the previous studies, we use the conventional function, but we go much further in the detail level of the impedance function, which includes also the fares and the interchanges, cover all transport modes and is differentiated in two different travel purposes.

4.1 The accessibility indicator used

Differently from most of long-distance accessibility studies, we are in fact able to consider all components of generalised cost, as suggested by Koopmans et al. (2013). The availability of a transport model, briefly described below, gives us the generalised cost c_{ij} for all transport modes and for two different traveller profiles, considering also the presence of competition and simplified function of real-world fares. This allows us to be much more detailed and show also the effect of different pricing strategies, of frequencies of services, of timetables in intra-modal connectivity.
In addition, we consider three different measures of attractiveness of destinations: population and private and public sector jobs, as provided by official Italian census (2011). The three measures are not alternative, but proxy three different travel purposes, where population may represent personal purpose trips, private sector jobs the business trips and public sector jobs the "administrative" trips, such as the broad range of visits to public offices, tribunals, hospitals and all trips typically attracted by administrative centres at various levels.[4] This degree of detail in describing attraction power of zones, elsewhere seldom considered, is present also in El-Geneidy and Levinson (2011).
The three equations used are:

$$Apop_i = \sum_{j=1}^{n} Population_j \cdot e^{-\beta c_{ij}} \qquad \text{Equation 3}$$

$$Ajob_i = \sum_{j=1}^{n} Private\_sector\_jobs_j \cdot e^{-\beta c_{ij}} \qquad \text{Equation 4}$$

$$Apub_i = \sum_{j=1}^{n} Public\_sector\_jobs_j \cdot e^{-\beta c_{ij}} \qquad \text{Equation 5}$$

In addition, we compute also a more standard accessibility index, based on the simple road distance, more similar to the usual applications found in literature. It will be useful to compare its results, ignoring the shaping-space effect of transport, with the ones taking into account the transport supply characteristics.

$$Adist_i = \sum_{j=1}^{n} Population_j \cdot e^{-\beta d_{ij}} \qquad \text{Equation 6}$$

The combinations of modes and traveller purpose are in Table 4. All combinations are calculated directly with the mentioned equations, except the multimodal one. In this case we preliminarily select, for each single origin-destination pair, the mode with the lowest generalised cost, and the overall accessibility of the *i* zone is calculated aggregating them. So, for example, from a remote region the overall accessibility is due to road accessibility for the nearest destinations and to air accessibility for the farthest.

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[3] However, it would be interesting for future applications the use other functions, even more precise in the extreme ranges of near and far distances. See Martinez and Viegas, 2013 or Halás et al., 2014.
[4] Theoretically, one could imagine to further split travel purposes, for example using university students, beds in hospitals, etc. to quantify the attraction power of zones. However, we believe that this could be too detailed and losing generality and interest for a policy-level work. Different would be if we used accessibility measure to build a distribution model to be calibrated.

Table 4. Combinations of modes and travellers' profiles considered.

	Business travellers	Economy travellers
Road	●	
Rail	●	●
Air	●	●
Coach		●
All modes	●	●

Once calculated, the A_i are normalised dividing the values found by the average value of the series, putting 100 for the zone with an accessibility equal to the Italian average. Consequently, the nearest to 100 are the values found, the more the country is homogeneously accessible. As we will see, quite relevant differences instead exist.

4.2 Transport model and generalised costs calculation

While population and jobs are easily accessible data, generalised costs c_{ij} must be computed using a transport model. The model is a conventional 4-steps model, fed with a large supply database, developed by the authors and described in more detail in Beria et al. (2015).

The adopted zoning splits Italy into 371 zones. Each one identifies a traffic catchment area that generally represents a homogeneous aggregation of Municipalities on the base of their population. This aggregation corresponds with the European statistical level NUTS-4 (European Commission, 2007) which however does not have a direct correspondence with any Italian administrative boundary (intermediate between single municipalities and provinces).

For the calculation of the generalised cost, we use primarily the supply module, which includes:

- a *multimodal graph*, describing in detail the Italian transport infrastructure (rail network, road network, ports and the main maritime navigation routes, airports and air navigation routes);[5]
- a *timetable database*, including the complete timetables for the year 2013-2014 of air, long distance rail, main ferry service and coaches;[6]
- a *hypergraph of public transport services*, linking together the timetable database and the multimodal graph;

In addition, the model includes functions for the fares, differentiated for the competition level, distance travelled and/or advance of purchase, type of service (e.g. low cost airlines price function differs from traditional airlines; AV rail lines with direct competition are priced less than the rest of Trenitalia network, etc.).

The generalised cost is estimated for two user profiles (*business* and *economy*) having different values of travel time, private car availability (and consequent related marginal costs) and average stay in the place of destination.

The functions of generalised costs vary according to the mode and derive from the usual definitions (Ortúzar and Willumsen, 1990).

Private road transport cost is calculated for each road edge using the following formula:

$$c_{car} = aD + bT + cP \qquad \text{Equation 7}$$

Where D is the distance (km). T is the time required to travel that distance on the base of the average speed (km/h) allowed on that specific arc. P is the toll, where applicable (typically on motorways). a represents vehicle operating costs (€/km) and depends on the type of vehicle and consequently on the different user profiles (business, economy), b is the value of time (€/h) and c is the tariff perception (%).

In the case of collective transport, the generalised cost formula becomes:

$$c_{public\_transport} = bT + cP \qquad \text{Equation 8}$$

Differently from private transport, here T considers also the waiting, access and interchange time and P is the fare for each O/D relation. P is described through two components:

$$P = p_0 + p \cdot d \qquad \text{Equation 9}$$

d is the distance and p is a component proportional to distance, plus a fixed component independent from distance p_0. These

[5] The multimodal graph includes five network classes, including information to describe the performances: national railway network (gauge, tracks, module), national road network (subdivided in highway, provincial road and main connections at the sub-provincial level), maritime and internal navigation network to provide continuity to land transport, air navigation routes (including also landside movement links), zonal and intermodal connectors.

[6] The database includes 12 air companies (6 low cost and 6 full service) operating 1,300 routes, 2 rail companies (Trenitalia and NTV) operating 523 services on an average week day and 80 coach companies operating 391 lines.

parameters are empirically determined case by case.
These definitions are similar to the ones used in usual local scale models, where the peak hour is considered homogeneous and expanded to represent the entire day. However, in our case of long distance trips, the timetable matters. For example, especially for business travellers, the accessibility is different if between two cities if an air route with two flights per day is operated in the morning and in the evening or at, say, 11:00 and at 12:00. Similarly, typical North-South coach rides once per day, departing at night and arriving in the morning. They offer very different accessibility with respect to a train departing every hour, but requiring two interchanges along the route.
For these reasons, the generalised costs used to calculate the long-distance accessibility must be computed for the entire day and not only for a (hardly definable) peak hour. Our assumptions on this are collected in Table 5.

Table 5. Rules for generalised cost calculation during the day, per mode.

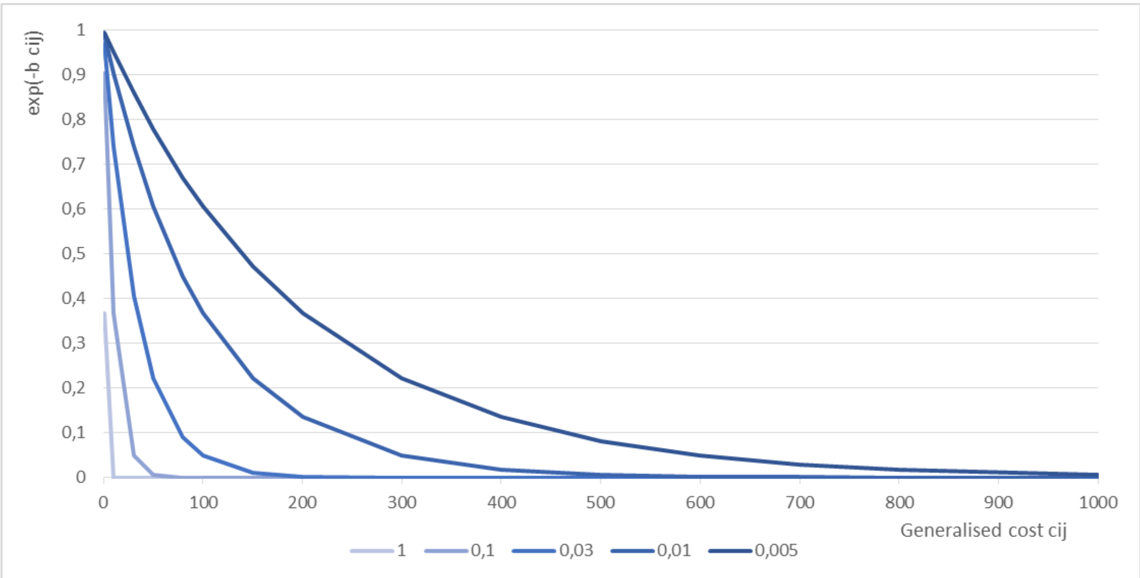
Mode	Rule	Periods
Private, road	Daily average of best path generalised cost	24
Public, coach	Daily average of best path generalised cost, departing at hour	24
Public, air	Daily average of best path generalised cost, departing at hour	24
Public, rail	Best path generalised cost, departing at 7:00	1*

*: Most of rail services are organised with clock-faced timetables, i.e. repeating during the whole day.

4.3 The definition of the beta parameter

Accessibility definitions (Equation 3 to Equation 6) include also the parameter β, describing generalised cost sensitivity of the users. The parameter has a profound influence on the results. Values near to one rapidly reduce the influence of far destinations and are the typical values used for commuters' accessibility. Using smaller values, instead, means that "far" destinations are not irrelevant just because far (for example touristic destinations). Figure 5 depicts the effect of some β in decreasing the weight of far destinations.

Figure 5. Effect of β



Clearly, when studying long distance trips, small β must be preferred. However, using a too large β would simply give a map of the destination weights (for example a map of population), totally ignoring the effect of transport-side in shaping accessibility. Previous studies (in Table 2 and Table 6) use very different values. Moreover, none of the consulted sources applies the same impedance functions as our one, based on generalised cost, and consequently we can hardly transfer their values to our study. Consequently, we refer to β=0.01, which is sufficient to effectively point out the differences among zones. The values is however not calibrated (it would be virtually impossible, as no long distance origin-destination matrix including also non-systematic trips exists for Italy), and thus has only a visualisation purpose.

Table 6. Exponential decay function parameters, from Rosik et al., 2015

Authors	Spatial scale	β parameter	Details
Stępniak and Rosik (2013)	European	0.005775	Cars
Schürmann and Talaat (2000)	European	0.007	Cars
Schürmann et al. (1997)	European	0.010	Cars
Reggiani et al. (2011)	National	0.009	Commuters in Germany
Stępniak and Rosik (2013)	National	0.023105	Population
Stępniak et al. (2013)	National	0.034657	Population
Geurs and Van Eck (2001)	National	0.039	Dutch National Travel Survey
Spiekermann et al. (2014)	National	0.04621	Medical doctors
Skov-Petersen (2001)	National	0.049	Recreational accessibility in Denmark
Martínez and Viegas (2013)	Regional/local	0.068	Lisbon Metropolitan Area
Handy and Niemeier (1997)	Regional/local	0.1813	Convenience shopping travel in the San Francisco Bay Area
Haynes et al. (2003)	Regional	0.289	General medical practise surgeries in East Anglia

5 Results

5.1 Distance based indicators: a measure of remoteness

The accessibility calculated using the road distance as impedance function shows the most extreme differences (see Figure 6, left). The geography of Italy, being long and thin and with the two coasts separated by mountains, together with the distribution of the population concentrated in the northern plain or along the coasts, translates into very inhomogeneous situations. In the North, a large population lives into a round and plain area, from Turin to Venice and Bologna: all of them are relatively near to the others and this gives an accessibility far above the national average. Milan is the main centre of this high-proximity area accounting some 10 million inhabitants.

In the South, only Rome and Naples have the indicator above the average, thanks to their dimension and vicinity. De facto, Italy is not divided in two, but in three: the North, compact and populated, the dipole of Rome and Naples, and the rest of the Centre-South, spread or scarcely populated, at least in relative terms.

It is worth also looking at the “far” areas. They are not only in the South (Calabria, Sicily, Sardinia), where geographical farness is evident, but also in the North, especially in the mountains of the Eastern part. This area is clearly marginal in terms of domestic accessibility with respect to the core of Italian population, not much less than the Southern regions. However, the measure is biased by the edge-effect of the country border.[7]

The accessibility weighted with workplaces and public sector workplaces (not represented) instead of population, give slightly different results. In particular when looking at private sector workplaces, the South (including Naples) falls always below the average. This is due to the lower number of workplaces existing in the lower range of distances. To the contrary, the number of public sector employees is more than proportional with population and consequently the accessibility results higher and larger parts of the South are above the average. Considering the number of public sector employees as a proxy of the public functions, it means that the remoteness of the Southern areas from the administrative centres and from public services (hospitals, office, etc.) is less problematic than the one from economic activities.

5.2 Generalised cost based indicators: a measure of real accessibility

Distance alone is not telling us much about the real accessibility, but only on the geographic remoteness of an area from the rest of destinations. Accessibility is more meaningful if the impedance function takes into account also of the travel costs. For example, a far island like Sicily is “less remote” if fast, frequent and cheap air transport services exist.

Using the generalised travel cost as impedance function and considering the best mode to reach the destinations can significantly change the map of accessibility, making it more near to real transport choices. As generalised costs differ between different users, we map both the category previously defined (Section 3) as “Business”, i.e. more time-sensitive and less price-sensitive, and the “Economy”, i.e. with inverted cost perceptions and without the availability of a private car for long distance travels.

Figure 6, centre and left charts, depicts the generalised cost accessibility for both users categories. The “Business” one shows some relevant differences with respect to distance-based accessibility charts. For example, cities such Florence and Rimini are much more accessible than looking at the distance only, thanks to their effective connections. The transport network (rail and motorways), but also the air services, make the Southern areas are slightly less inaccessible than what geography imposes.

The main transport corridors are clearly visible on the map, especially the Milan – Bologna – Florence – Rome – Naples one: the old A1 motorway, the rail line and the new high-speed line, make this corridor definitely more accessible than the average, creating a sort of *continuum*, irrespective of actual distances. The gap of Sicily, Sardinia, Calabria and Puglia decrease with respect to the Northern areas. The inaccessible areas for business segment are now limited to the most insular and peninsular areas (Crotone, Lecce, Apulia and Sicily, Sardinia). In very simplistic terms, Italy of business travellers is divided in two, but the

[7] The accessibility here is only the domestic one. This makes the indicator less representative for the border areas, where important relations exist with the near Austria and Germany. The same is for the West, where relations with Switzerland and France are ignored.

division is not between North and South, but across the Apennine mountains: the North, Tuscany, Rome and Naples above the average, the rest of the country below, even in a centre-north region like the Marche.
When considering the "Economy" travellers, we take into account only the public transport (i.e. no private car is considered) and value the time much less than for business travellers. The picture changes again and tells us of a country much more homogeneous. The areas below the average are similar to the ones for the Business travellers: the Oriental Alps, the Adriatic regions, Sardinia, and the whole South. However, the relative advantage of the North gets lower and the most accessible area is that around Bologna, which is the true centre of Italian rail network.

5.3 Single-mode accessibility

Looking at single-mode accessibility instead of multimodal, can clarify the different role of air, coach and rail in shaping Italian mobility patterns.
Air transport patterns (Figure 7 left and centre) are, not surprisingly, discontinuous. The areas of higher accessibility are around the main airports, and the rest is under-connected. The role of air transport is particularly important for islands. For example, thanks to point-to-point routes of low cost airlines, Sicilian main cities more accessible than many important centres of the North, like Genova. Milan appears less accessible by air from the rest of Italy than many other areas because of higher airport access cost and because of the sharp reduction of Alitalia domestic connectivity after 2008 crisis and after the opening of the high speed rail line. For example, nowadays the flights towards both Rome and Naples are significantly reduced than they used to be. Central Italy is the least accessible area by air. This is due to the relative vicinity to Rome, whose airports centralise nearly all traffic of the area, and to the kind of distance (4-500 km) which separates the area from the Italian main cities, unsuitable for air transport.
Coach transport is a niche mode, mostly used by Economy users in specific areas of the country, usually where no good rail transport exists. In analogy with other countries (Augustin et al., 2014), this is rapidly changing thanks to the liberalisation recently completed and to the new lines opened in competition with rail. The chart in Figure 7, right, show where the core of coach market is[8]: limited in the North, much more developed in the Centre and South, and especially directed to Siena, Rome and Naples (Beria et al., 2014).
Finally, long-distance rail is analysed in the charts of Figure 8. The left one tells us again of a double-faced country. The North and the whole Tirrenic coast up to Salerno are highly accessible (except mountains), also thanks to the recent high speed line connecting Milan and Naples (800 km) in about 4,5 hrs. The rest of South and a long part of Adriatic coast are below the average, due to slower and infrequent services, together with smaller population reached. Central Italy appears less accessible than the national average, despite the proximity to Rome, but this might be explained also by the absence of regional trains in the simulations, together with orographic causes. Again, Business users perceive differently the value of time and this makes the respective maps more sharp. In addition, the main cities are much more accessible than other areas, a consequence of the increasing polarisation of rail traffic on fewer high-frequency intercity connections.

[8] We chose to represent the accessibility to administrative centres because the map presented more clearly the pattern than the ones weighted with population and workplaces.

Figure 6. Population weighted accessibility indicators: left, distance based; centre, business users generalised costs; right, economy users generalised costs. Source: our elaborations

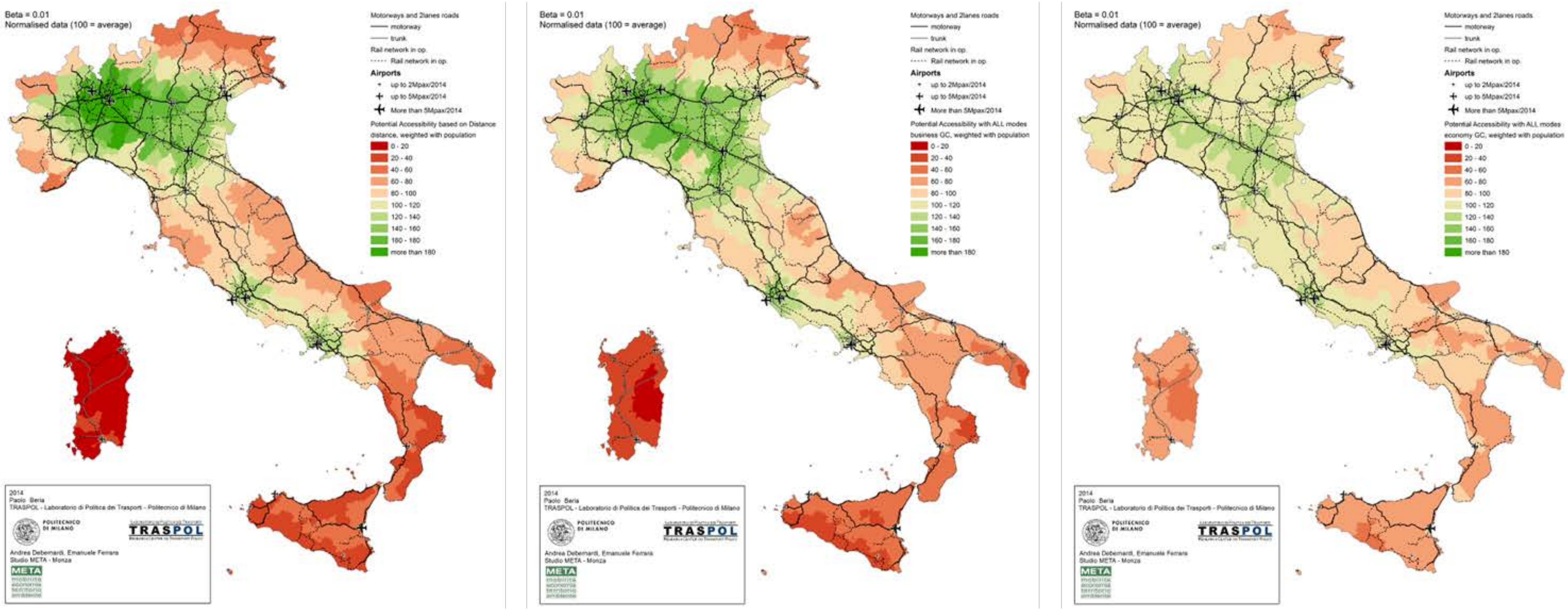


Figure 7. Modal accessibility indicators: left and centre, air accessibility to workplaces for Business and Economy users, respectively; right, accessibility to administrative centres by coach. Source: our elaborations

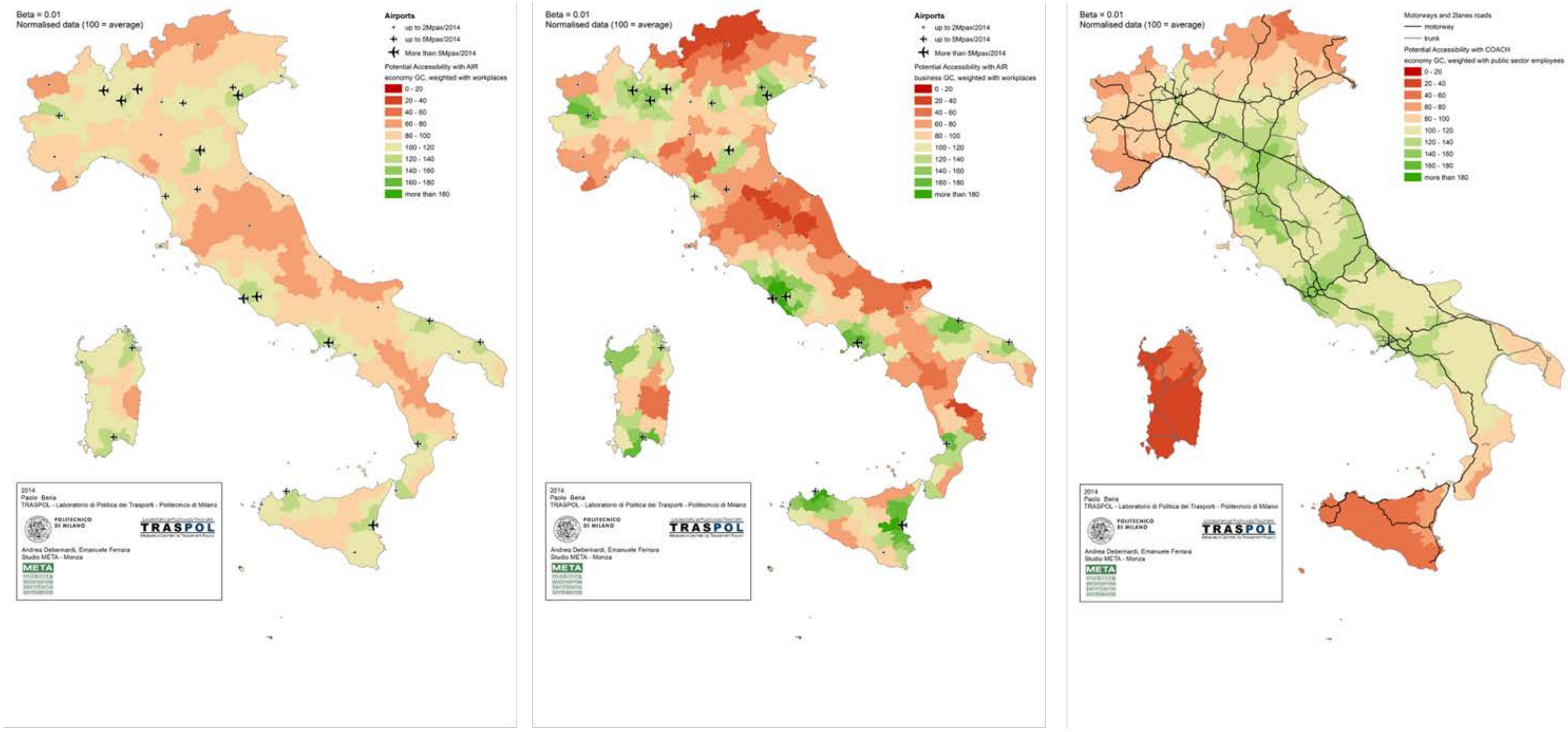
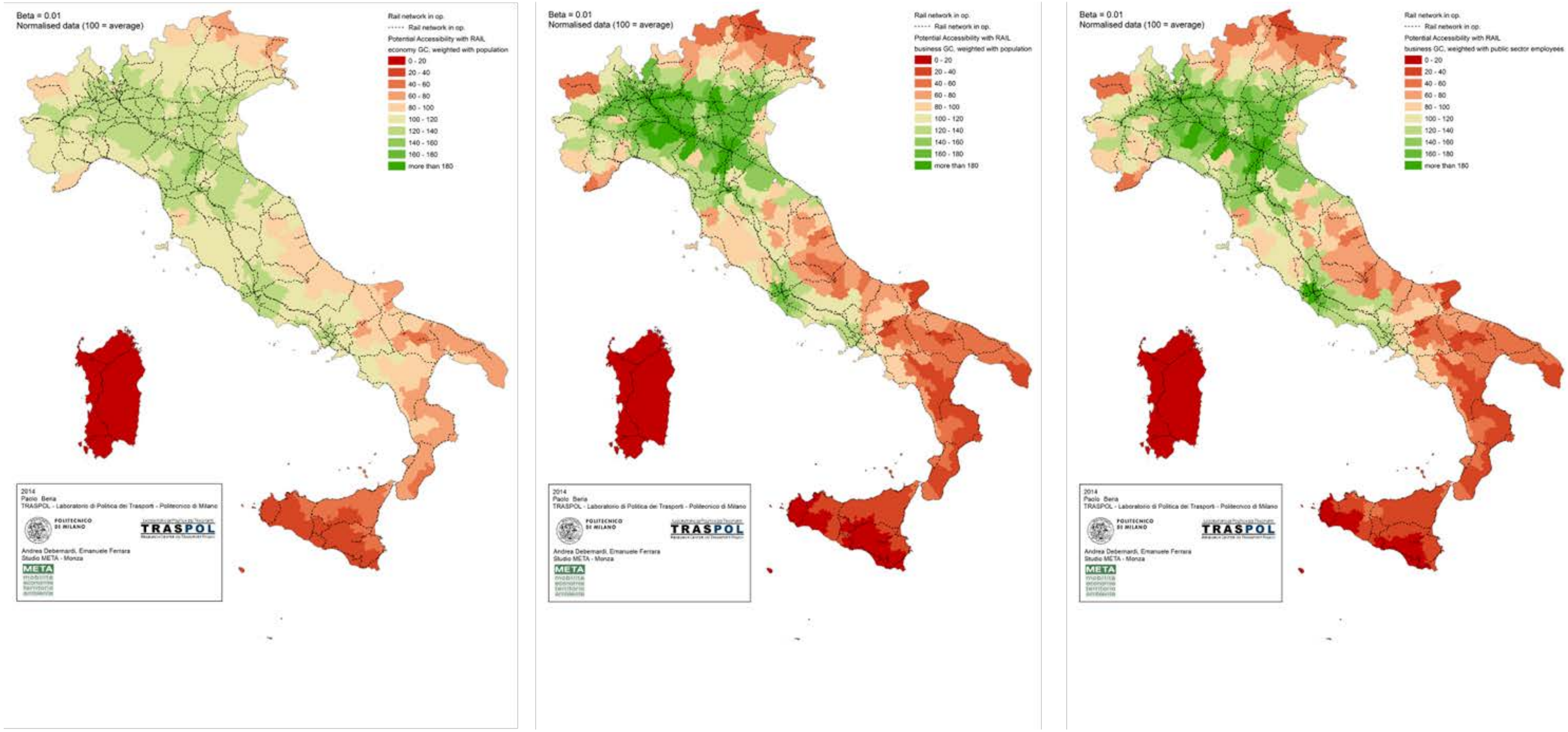


Figure 8. Long distance rail services accessibility indicators: left and centre, Economy and Business users accessibility to population, respectively; right, Business users accessibility to administrative centres. Source: our elaborations



6 Methodological and policy considerations

6.1 Methodological considerations

In this work we applied to a conventional definition of accessibility, as amply described in literature, some methodological innovations, which make the analysis more rich and revealing of real-world conditions.
Firstly, we used a complete impedance function, based on generalised cost estimation including also the fares and the interchange costs, rather than limited to travel time, which is not an acceptable simplification when studying long-distance transport.
Secondly, all calculations are based on a calibrated multimodal transport model, including rail and car transport, but also less studies modes such as coach and air transport. The model includes 371 zones and thus results very detailed, reaching the sub-provincial level. The model is not considering the supply alone, but includes also some elements of the markets. In particular, we used different functions for public transport fares depending on the mode and on the actual level of competition.
Then, to provide a more realistic picture, we differentiated the accessibility measures according to two stylised travel profiles, namely business and economy travellers. The accessibility of a country, in fact, is extremely different for users not owning a car and caring of transport costs, with respect to those which have no limit for costs, but are very time-sensitive and can egress long distance public modes with taxi.

6.2 Accessibility needs and Italian transport policies

Thanks to this articulation, we can more effectively discuss how Italian transport geography works and which are the outcomes of implemented policies, overcoming trivial considerations on network extensions and lines speed.
Transport policies and investments are not the rigid outcome of a totally rational and quantified process of evaluation, moreover when considerations other than the sole transport dimension play a role (Albalate and Bel, 2012; Eliasson et al., 2015). As a consequence, the *geography of accessibility* does not depend only from geography and from demography, but keeps the traces of political choices and of technical limits in the design of the networks.
A key element is how a country wants to be interconnected. We simplify the question by means of two stylised and extreme approaches to long distance accessibility.

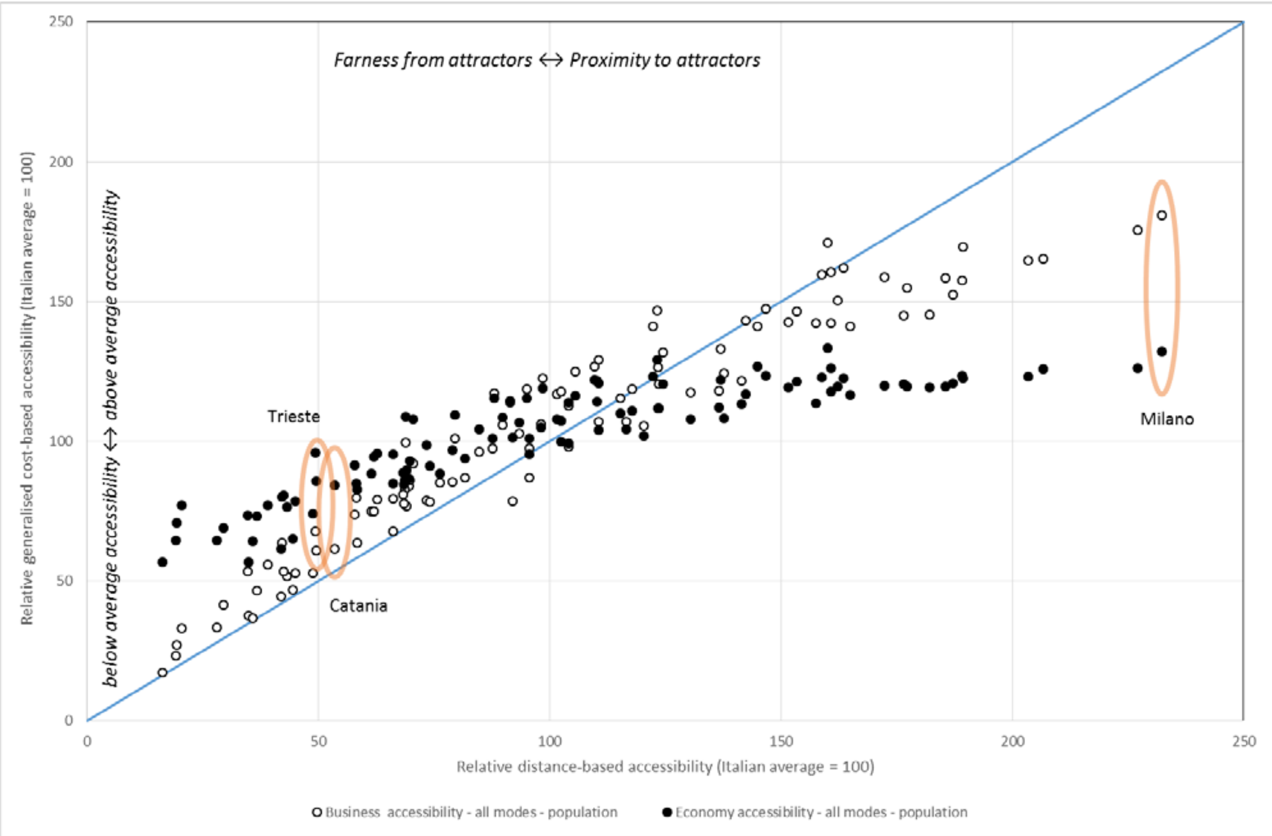
a. On one side, the policies of a country could focus on the connection of the main centres, leaving marginal areas unconnected. This approach looks at efficiency: connecting core areas gives better economic results, for a given amount of resources, because improving the performance of high-density corridors. Conversely, it will sharpen the gap between core-regions and marginal regions.
b. On the other side, a country could decide for a “homogeneous” accessibility. For example, any main city should be connected to the Capital in no more than *x* hours.[***] This approach looks at territorial equity, trying to go beyond the geography by removing the geographical differences. From the economic viewpoint, however, most likely it will give inefficient results, moreover if depopulated areas are also the marginal ones and if the orography does not help.

Of course, real planning choices lay between these two extremes. For each zone we draw on a graph (Figure 9), both distance-based and generalised costs-based accessibility scores, normalised (100 represents the country average).
Points on the diagonal line have the same accessibility than their physical proximity/farness from attractors. Points above the line present a real accessibility higher than the physical distance. For points below, the performance of transport system is worse than what the simple distance would give.
Despite a certain dispersion, the trend of Italian accessibility is rather clear. The transport system tends to reduce the

[***] For example, Spanish high-speed adopted originally this criterion: despite traffic and dimension, any provincial capital must be connected to Madrid in 4 h.

remoteness of geographically remote areas (left side). The centrality of core-areas is less extreme than their pure geographical position. For example, Milan's long-distance accessibility indicator is 132 (economy users, all modes, population weighted), while its accessibility based on the sole distance from attractors is much higher. At the opposite range, cities like Catania (the second Sicilian city) or Trieste (an important centre in the North-East) are similarly far from population cores, but their "gap" is reduced by the transport system.†††

Figure 9. Real accessibility (based on generalised costs) vs. distance-based accessibility for Italian provincial capitals (104 zones out of 371 zones of the model)



However, sharp differences exist between Economy users accessibility and Business users one. For the Economy ones, the distribution shows that the long distance transport system has a visible role in reducing the unavoidable geographical disadvantages of southern and island regions, less populated and far from the core of Italian population. The farthest zones have an indicator firmly below 50 (half of national average) in terms of physical distance, but always above 50 if we consider the generalised cost. This action is not played by the high speed rail only, but especially by air connections and coach system. Despite the undeniable differences among Italian zones and some severe situations of inaccessibility, we can affirm that a national-wide public transport system exists and it has a role in shaping long-distance transport.

To the contrary, the Business distribution is much more adherent to the distance-based one. It means that Business users' choices are too often dependent on car, because the other transport means are not equally effective, except for

††† It is worth mentioning that the slope of the distributions depends on the *beta* used, but the significant aspect is that the distribution is not linear and over a certain accessibility the relative advantage remains quite constant.

the highly accessible zones of the core, like Milan or Rome. In this case, the effectiveness of public transport system for business travels is much less, and is limited to the main city pairs. Consequently, the “distance” of remote areas for business trips remains such, putting a competitive disadvantage on such areas.

6.3 Future policies

The most significant long distance transport investments done in Italy in the last fifty years are the construction of the motorway network, ended in the Seventies and recently restarted after year 2000, and the high-speed rail from Turin to Naples, completed in the main parts before 2009. The high-speed rail has clearly gone in the direction of increasing the differences, reduced in the past by highways and by the overall improvement of all networks. Naturally, high-speed rail tends to concentrate on the main poles and, in fact, the relative accessibility of the touched cities is by far better than any other region in the country. The years 2000 have been characterised in general by a “megaproject” approach, also used rhetorically by decision-makers and quite far from the real mobility needs (Ponti et al., 2007).

Current policies only partially left this “megaproject-based vision”, recognising the need to improve mobility (also public and rail based) in the urban areas and in the secondary corridors, of course leaving a pure-high speed model in favour of fast doublings, revamping of lines, technology, etc. The case of the Adriatic coast rail line is typical. In this context made of many mid-sized cities but lacking of large cities divided by hundreds of km, the restructuring of the existing line reaching typical speeds of 200-220 km/h is much more effective and adherent to the real needs than a bullet-train like the Milan-Rome one.

Southern regions may benefit of a change of vision in this direction. The number of passengers and the distances at play do not require high-speed lines, but fast intercity services especially towards Rome and Naples, as connections with the North are better feasible with air transport. An intermodal vision, better connecting the main airports and the rail network, can also guarantee at the same time both economic feasibility and good accessibility to remote regions.

Acknowledgements

The paper is one of the outcomes of the project “QUAINT”, supported by the Italian Ministry of University and Research (MIUR), within the SIR programme (D.D. n. 197 del 23 gennaio 2014).

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