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ASSESSING THE LINK BETWEEN URBAN FORM AND URBAN MOBILITY: EVIDENCE FROM SEVEN ITALIAN METROPOLITAN AREAS

Roberto CAMAGNI[1], Chiara M. TRAVISI[1,2]

1. Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Italy
2. Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Italy, and Fondazione Eni Enrico Mattei (FEEM), Milan, Italy

ABSTRACT

Sound empirical and quantitative analysis on the relationship between different patterns of urban expansion and environmental or social costs of mobility are still very rare in Europe and the few studies available provide only a qualitative discussion on this (Breheny et al., 1993). Recently, Camagni et al. (2002) have performed an empirical analysis on the metropolitan area of Milan, aimed at establishing whether different patterns of urban expansion generate different level of land consumption and heterogeneous impacts of urban mobility. Results confirm the expectation that higher environmental impact of mobility is associated with more extensive and sprawling urban development, more recent urbanisation processes and residential specialisation. Such results have been confirmed by two subsequent studies on the metropolitan areas of Brescia (Camagni et al. 2002) and Bologna (Musolino and Guerzoni, 2003). The present paper enlarges further the empirical analysis to other seven Italian metropolitan areas (namely, Bari, Florence, Naples, Padua, Perugia, Potenza and Turin) to corroborate previous results obtained in the context of the metropolitan area of Milan, Brescia and Bologna for 1991. The novelty of the present paper is threefold. Firstly, we are interested in exploring the changes occurred to the intensity of the mobility impact across a ten year period, from 1981 to 1991, corresponding to the Italian economic boom years. Secondly, using an econometric analysis in cross-section, we consider several metropolitan areas at once, being therefore able to explore whether there are significant differences in the way the model explains variations in the mobility impact across various Italian metropolitan areas. Finally, we propose a conceptual interpretation of the causal chain in the explanation of the mobility impact intensity and we test it using Causal Path Analysis.

1. INTRODUCTION

Urban mobility is considered one of the main factors of social and environmental pressure in metropolitan areas –both at local and regional scale- leading to high private and public costs (WHO, 2002; Marletto, 2002; Lattarulo, 2003; TCRP, 1998). Nevertheless, efforts toward the introduction of corrective actions are often subordinated to other economic objectives, as well as the impact of urban mobility is often not explicitly (or not properly) tackled within decision making on urban planning (Camagni et al, 1998; Camagni et al, 2001; Fouchier, 2000).

Whether there is a relationship between different patterns of urban expansion and environmental or social costs of mobility is, therefore, a question that has increasing policy relevance and -thought with one decade of delay compared to the US context- it is now becoming an important issue in urban research also in Europe. In this respect, the commitment of European governments on urban planning is explicitly directed toward sustainability, and relies on the widely shared conviction that extensive development of urban fringe is not consistent with the sustainability principle, as it generates high cost of infrastructure and energy, reduces efficiency of transport networks, increases segregation and land use specialisation, while contributes to environmental degradation (for a discussion see Camagni and Gibelli, 1997; Camagni et al., 2002).

Despite the debate on urban development and its consequences on environmental and social issues has started to be tackled in the European spatial policy, sound empirical and quantitative analysis are still very rare and the few studies available provide only a qualitative discussion on this (Breheny et al., 1993). It is indeed not straightforward to measure such externalities and, even more, to describe quantitatively the link between the way in which an urban settlement develops and its consequences in terms of the collective costs of urban mobility, especially due to the difficulties of finding sound and reliable performance indicators.

Besides, the few empirical studies available relate mostly to North America and, therefore, results refer to rather different suburbanisation patterns and to a completely different institutional/administrative context. Yet, results show a significant correlation between different forms of urban development and collective costs (Real Estate Research Corporation, 1974; Altshuler, 1977; Windsor, 1979; Frank, 1989; Burchell et al., 1992; TCRP, 1998). In the European context, instead, even thought the phenomenon of sprawl is more and more evident, there has so far been little research on its collective costs. A qualitative comparative analysis of pros and cons of different urban growth patterns by Breheny et al. (1993) presents suggestions and recommendations for urban planning actions aimed at various administrative levels but lacks relevant results on the preferable urban growth mode.

More recently, Camagni et al. (2002) have performed an empirical analysis on the metropolitan area of Milan, aimed at establishing whether different patterns of urban expansion generate different level of land consumption and heterogeneous impacts of urban mobility. In particular, the study provides first insights on whether there is any significant correlation between variables describing the form of urban expansion and the impact of urban mobility, as an indicator of pressure on the quality of day-life in metropolitan areas and on urban environment, with the aim of providing a basis for orienting future planning policies. A mobility impact based on commuting data referring to 1991 is used to capture the level of environmental impact of mobility on commune level, estimated on the basis of trip time and modal choice. Intensity of mobility impact is then explained by few variables controlling for geographical, socio-economic, morphology and transport efficiency factors. Results confirm the expectation that higher environmental impact of mobility is associated with more extensive and sprawling urban development, more recent urbanisation processes and residential specialisation. Such results have been confirmed by two subsequent studies on the metropolitan areas of Brescia (Camagni et al. 2002) and Bologna (Musolino and Guerzoni, 2003), both referring to the year 1991.

The present paper enlarges further the empirical analysis of the previous studies by Camagni et al. (2002a, 2002b) and Musolino and Guerzoni (2003) to other seven Italian metropolitan areas (namely, Bari, Florence, Naples, Padua, Perugia, Potenza and Turin) to corroborate previous results obtained in the context of the metropolitan area of Milan, Brescia and Bologna for 1991.

The novelty of the present paper is threefold. Firstly, we are interested in exploring the changes occurred to the intensity of the mobility impact across a ten year period, from 1981 to 1991, corresponding to the Italian economic boom years. Secondly, using an econometric analysis in cross-section, we consider several metropolitan areas at once, being therefore able to explore whether there are significant differences in the way the model explains variations in the mobility impact across various Italian metropolitan areas. In other words, the paper tries, on one hand, to find empirical evidence of the increasing collective impact of urban mobility –envisaged by several commentators but not measured so far- and, on the other hand, to figure out whether factors expected to influence the intensity of mobility impact do vary as the metropolitan area of concern varies or, instead, if results are confirmed for all the Italian urban settlements under analysis. Finally, we propose a conceptual interpretation of the causal chain in the explanation of the mobility impact intensity and we test it using Causal Path Analysis.

The reminding of the paper is organized as follows. In Section 2 we present the conceptual underpinnings of the development of the mobility impact model and describe our hypotheses as to the reasons for heterogeneities in mobility intensity. In Section 3 we present results of the dynamic analysis of the intensity of the mobility impact across 1981-1991; while Section 4 discusses the main findings of our empirical analysis using data in cross-section. In Section 5 a conceptual interpretation of the causal chain in explaining the impact

of mobility is proposed and empirically tested. Finally, Section 4 provides conclusions and recommendations for future research.

2. EXPLAINING THE DEMAND FOR MOBILITY AND ITS SOCIAL COSTS

2.1 Creating a mobility impact index

Studies on urban sustainability show that the demand for mobility is an important component of the environmental impact of urban growth but, so far, empirical evidences of this phenomenon are still lacking in the European context and still partial at the Italian level. In consideration of this, the first research question addressed in this paper is whether is possible, by enlarging our analysis to other 7 Italian metropolitan areas, to corroborate previous results by Camagni et al. (2002a, 2002b), which show, for the Italian context, the expected “high pressure” character of sprawling development patterns in terms of the environmental impacts generated by the demand of urban mobility. Besides, an additional question relates the dynamic of the collective costs of urban mobility in the Italian context. In particular, as we move from 1981 to 1991 commuting data, we expect to find a positive trend in the intensity of the mobility impact.

The hypothesis underpinning this paper is that within a relatively homogeneous area (in terms of income level and main socio-economic conditions), such as each of the seven Italian metropolitan areas of concern here, the local differences in the mobility patterns can be explained, at least to a certain extent, by the typology of urban development occurred in such areas. In particular, we expect that four types of variables might influence the intensity of mobility impact at a local level: geographical, socio-economic, morphology variables, and variables measuring the accessibility and efficiency of private versus public transport.

How to capture urban mobility? For Italy, the lack of reliable mobility data entails a methodological and operational problem. As far as mobility is concerned, we use the only reliable data available at the local (commune) level, i.e., the journey-to-work data recordered in the 1981 and 1991 Census for each active resident. These are disaggregated by mode into 6 categories[1] and, within each mode, by the time taken: up to 30, 31-60, over 60 minutes.

As trip length is not recorded in the Census, a drawback of this approach is that it is not possible to link trip duration and length, thus distinguishing between the effect of distance and the effect of vehicle speed and traffic conditions. Other limitations concern the nature of available data, which account only for one segment of urban mobility (commuting), disregarding all the non-systematic aspects of mobility. Being aware of the existing data limits, we employ – as in Camagni et al. (2002b)- journey-to-work data to develop a so called *mobility impact index*.

[1] The categories considered are: walking or other soft means; car driver; motorcycle; car passenger; train, tram or metro.

From the data on travel modes and the time length of commuter trips (direction outside or within each municipality), an indicator of the environmental cost of mobility is created. As the environmental pressure of mobility is strictly related to mode and time length, a weighted index of pressure was therefore defined for 18 different combinations of mode and time, according to the structure of available data.

The matrix of weights for time and mode, applied to each commuting trip to capture its level of environmental pressure is described in Table 1, and it is based on two main assumptions:

(A) For any given mode, the impact of a trip per unit of time decreases with the trip length, according to a number of simple, but not trivial, evidences: gas emissions and pollution generated by vehicles are higher at the beginning of the trip; traffic fluidity increases outside urban areas; trains stops decrease on longer journeys, etc.

(B) Set conventionally at 1.00 per passenger per minute the weight of the trip by car, then, the weight of the various modes for a given duration is, respectively: 1/3 for motorcycle and bus; 1/5 for rail trips and transported passengers; zero for pedestrians or bicycle trips and passengers (this is justified by considering that the possible lengthening of a journey due to the presence the passenger is already absorbed by the length of the journey travelled by the driver).

Using the values in Table 1, the commuters recorded in the Census are transformed into 'Equivalent Impact Commuters' (EIC). Given the municipality *k*th, the intensity of the mobility impact, I_k, can be estimated as the ratio between the EIC and the actual commuters (at commune level) as follows:

$$I_k = \frac{\sum_{ij} m_{ij} w_{ij}}{\sum_{ij} m_{ij}} \qquad \text{Eq- 1}$$

where: m_{ij} is the number of commuters moving within the *k*th municipality plus the number of commuters going outside the *k*th municipality for the *i*th travel mode and the *j*th trip time class; and w_{ij} is the weight assigned to the *i*th travel mode and the *j*th trip time class (see Table 1).

A drawback of this approach relates to the definition of the weight matrix that, as it is now, it is not linked to any physical impact dimension, and therefore provides a relative rather than absolute measurement of the urban mobility impact. On the other hand, a big advantage of this methodology compared to other, more direct indicators of environmental impacts, is that it refers directly to the demand of urban mobility generated in each municipality as a consequence of its settlement pattern, rather than referring to some mobility effects, often originated from other municipalities[2].

[2] To improve the methodology, we are now trying to re-define the weight matrix on the basis of gas emission factors related to travel mean and trip time.

Table 1: Weights by travel time and travel mode.

	Classes of travel modes (*i*th)	Weights for modes	Time		
Classes of trip time(*j*th)			***0-30 min***	***31-60 min***	***>60 min***
Average trip time			15 min	45 min	75 min
Weight per time unit			1.20	1.00	0.80
Equivalent trip time			18 min	45 min	60 min
	Walking or other soft means	0.00	0.00	0.00	0.00
	Bus	0.33	0.13	0.33	0.44
Travel mode	***Private car (driver)***	1.00	0.40	1.00	1.33
	Motorcycle	0.33	0.13	0.33	0.44
	Private car (passenger)	0.00	0.00	0.00	0.00
	Train, tram, underground	0.20	0.20	0.20	0.27

2.2 Factors determining the intensity of the mobility pressure

The form in which urban growth has occurred and, as well, its dynamic is expected to influence the intensity of the mobility impact at a local level. In particular, the economic literature on this issue suggests that a number of factors might have a role in explaining why urban mobility changes in intensity across various countries and urban areas.

In our model the mobility impact is used as the dependent variable, and variables relating to theoretically expected differences or factors relating to the study setting are used as explanatory variables. The relationship is established using least squares estimators.

Among the others, four types of variables are included in the econometric analysis: geographical, socio-economic, and variables measuring the efficiency of private versus public transport and the form of urban aggregation. A detailed description of explanatory variables is provided in Table 2, while Figure 1 provides descriptive statistics.

In particular, the model includes the distance of the municipality from the chief town of the related province (metropolitan area), and a variable estimating its rural ratio. Among the possible socio-economic variables, we consider: the dynamic of urban growth, and the residential *versus* productive attitude of the municipality. As a proxy of sprawling behaviour, we use the density of the urban development; while, accessibility and efficiency of public transport is captured by, respectively, the share of public over private transport and the ratio between the average trips time with private and public modes of transport, respectively. Our main expectations are summarised briefly as follows.

In light of what expressed by international literature, population density is expected to have mainly an indirect negative effect on the mobility impact, through its influence on the average trip time of public transport and, hence, on the modal spilt of commuter trips in favour of public transport.

Demographic growth rate is expected to show a positive relationship with the intensity of mobility impact. The impact index is expected to increase with the urban dynamisms of the commune of concern: in fact, a high population growth rate is generally also associated with the existence of areas of recent expansion.

The literature also gives considerable importance to the residential *versus* productive attitude of a municipality, in connection with mobility demand. This relationship can be conveniently interpreted as an indicator of the level of functional diversification-integration-segregation, i.e. sort of a ‘functional mix’ of each commune. In particular, we expect to find a negative relationship with the mobility impact indicating that urban mobility becomes more intense as the proportion of employment decreases whereas the residential specialised nature goes up.

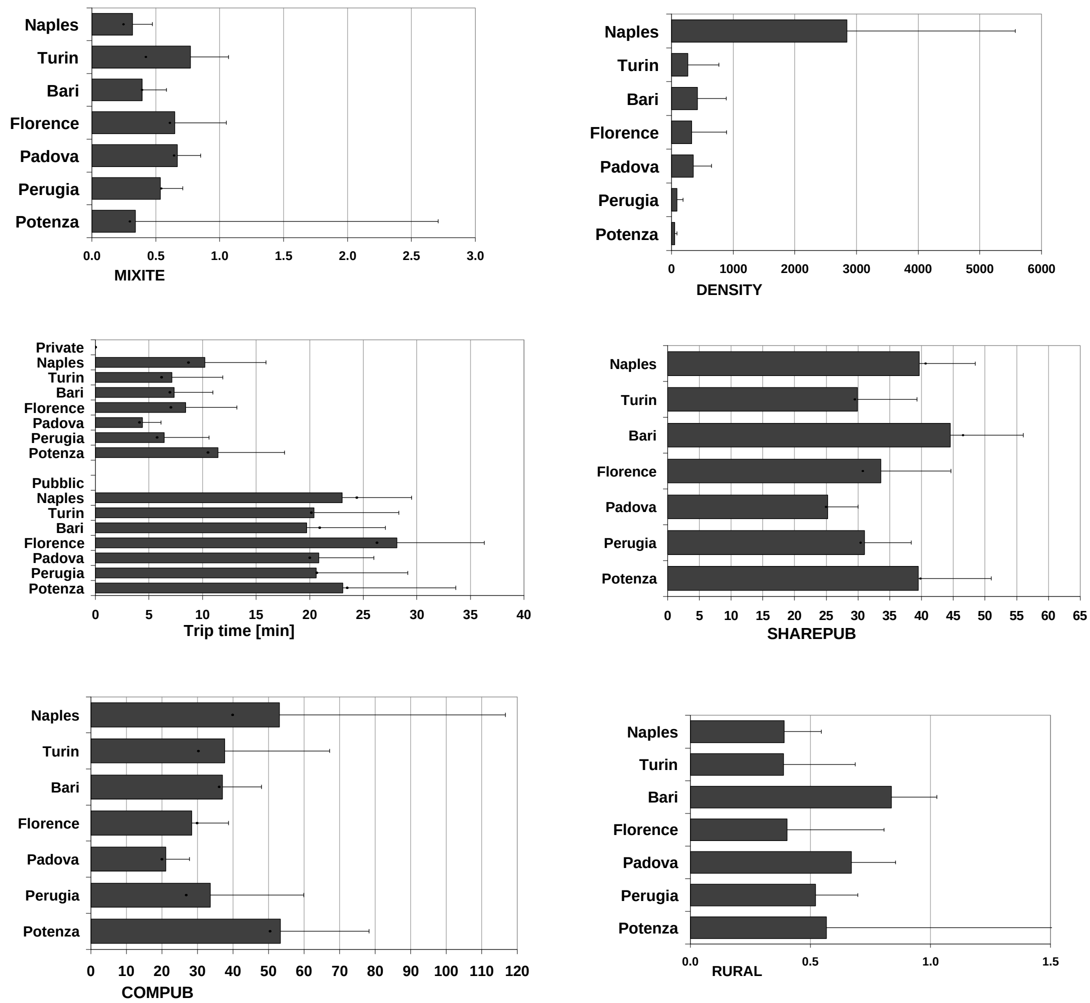
Besides, we are interested in the relationship between the impact of urban mobility and the efficiency and competitiveness of public transport. In respect to this, Camagni et al. (2002) find empirical evidence that, at least for the metropolitan area of Milan, the Mobility Impact Index is inversely correlated to the share and competitiveness of public transport. To explore this, we therefore include in our analysis an explanatory variable for both the efficiency and the share of the public transport at commune level.

Finally, another relevant issue here is related to the effect of the urban dimension on the impact of urban mobility. In particular, we wonder whether the intensity of mobility and traffic is systematically higher in bigger cities or not, due to structural mechanisms.

Table 2: Variables list and description.

Type variable	*Abbreviation*	*Definition*
Dependent variable:	IMPACT	Average intensity of the impact of urban mobility at commune level. The impact of mobility is calculated as the ratio between the EIC and the number of commuters recorded in the Census
Independent variables:	DISTANCE	Distance [Km] between the centroid of a commune and the centroid of the capital of the province
	MIXITE	Ratio between the number of employments and residents of a commune
	GROWTH	Growth rate of the population between 1981 and 1991
	RURAL	Rurality , calculated as the rural area [Km^2] over the total land area [Km^2]
	DENSITY	Gross density of the comune, calculated as the number of residents over the whole land area [Km^2]
	COMPUB	Relative competitiveness of public transport, calculated as the ratio between the average time taken for trips made with private transport and the average time taken for trips made with public vehicles (the ratio is multiplied for 100 for computational reasons).
	SHAREPUB	Market share of public transport calculated as the percentage of all trips made by public transport
	SELFCONT	The degree of containment of urban mobility within a given urban settlement (at commune level), measured as the ratio between the number of commuters moving out of the commune, and the number of commuters moving within and going outside the commune

Figure 1: Descriptive statistics of independent variables, referring to 1991, organised by urban area. The bars represent the mean value, the median is indicated by solid squares, and the error bars represent the



standard deviation of each variable within each urban area.

3. EVIDENCE FROM SEVEN ITALIAN METROPOLITAN AREAS

3.1 Dynamics of mobility impact across Italy during 1981-1991

Before estimating the econometric model, we analyze the distribution of the mobility impact index across the seven city of concern and its variation during a ten years span, from 1981 to 1991. Table 3 provides mean, median, standard deviation, minimum and maximum value of the mobility impact index for urban area and time period, and the percentage increase of the index from 1981 to 1991.

A first look at the results seems to suggest that the dimension of the metropolitan area is not the only determinant of mobility intensity. For instance, Naples and Bari have a relatively low mean mobility impact; while Turin appears to be the metropolitan area producing the highest

average mobility impact (calculated as Mobility Impact Index) both in 1981 and 1991 (see Table 3).

Table 3: Descriptive statistics of the mobility impact index per metropolitan area and time period.

	Mobility Impact Index										
	Mean		**Median**		**Std. dev**		**Minimum**		**Maximum**		**Increase rate**
	1981	*1991*	*1981*	*1991*	*1981*	*1991*	*1981*	*1991*	*1981*	*1991*	*1981-1991*
Naples	0.151	0.189	0.149	0.189	0.043	0.042	0.039	0.045	0.242	0.312	20.4%
Turin	0.245	0.287	0.235	0.287	0.059	0.049	0.093	0.121	0.526	0.453	14.8%
Bari	0.105	0.159	0.102	0.159	0.021	0.019	0.067	0.119	0.146	0.201	33.9%
Florence	0.195	0.260	0.194	0.260	0.037	0.028	0.085	0.206	0.288	0.326	25.2%
Padua	0.198	0.237	0.178	0.237	0.089	0.028	0.123	0.167	0.572	0.289	16.3%
Perugia	0.189	0.244	0.195	0.244	0.032	0.030	0.091	0.139	0.240	0.323	22.5%
Potenza	0.109	0.174	0.108	0.174	0.032	0.036	0.038	0.019	0.202	0.246	37.3%

The calculation of the mobility impact index for the seven urban areas across 1981 and 1991 shows an overall increase of the intensity of urban mobility that ranges from a minimum fluctuation of +14.8% for Turin, to an increase of the 37.3% for Potenza (see Figure 2 and Table 3). A first result is, therefore, that during this ten year span the impact of urban mobility has increased noticeably across the whole Italian peninsula, for reasons that are beyond the increase of the Italian population, which on average has not exceeded the 5.3 percent points. Clearly, to provide an explanation for such an increase of urban traffic congestion, we need to take into consideration several other factors, e.g., the socio-economic features of the urban settlement and its development process during this time lag. Without entering into the detail of this discussion, which lies outside the scientific aim of this paper, it suffices to say that among the main drivers of such tendency the literature points at the overall increase in the number of vehicles per capita, related to both the individual behavioural choices of Italians (more and more used to private means of transport) and, to some extent, to the decrease in competitiveness of public compared to private mobility (Giordano et al., 2001; Lattarulo, 2003).

Interestingly, Table 4 shows that overall in Italy, in the decade 1981-1991, the distribution of commuters by travel modes has changed in favour of private travel means, with a relevant increase of the incidence of the most polluting private travel mode, i.e., car. The increase in the use of private car (driver) ranges from a minimum of 9 percent for Naples, to a maximum of 14 percent for Turin and Padua. At the same time, other private soft mean has been abandoned and the incidence of the use of public transport has also decreased, especially for buses. Train, tram and underground have not seen a relevant fluctuation instead. We also notice a slight increase in the number of commuters travelling as passengers of private cars, a result that might suggest an increase in car sharing and car pooling, though collective travel means are not yet common among Italians. In Figure 3 we provide a graphical representation of the same results that can help the reader in their interpretation. A simple regression model (presented in Table 5) shows that the percent variation in the use of private car (driver) is positively correlated to the percent

variation of the mobility impact index during the decade 1981-1991, and have a strong statistical significance for all the urban settlements considered, with the exception of Perugia. Besides, private car elasticity is higher for those urban areas for which the increase in the mobility impact index was bigger. For instance, we observe the maximum car elasticity for Bari and Potenza (3.55 and 3.67, respectively), which correspond to the urban settlement that have registered the higher increase in the mobility impact from 1981 to 1991 (Table 3). This implies that, al else being the same, increasing car use by 1 percent increases the mobility impact index by 3.5 and 3.6 percent, respectively, for Bari and Potenza. Effects of variation of the distribution of trip duration classes are not included in the model as we have observed a substantial stability of trip lengths frequencies during the decade under analysis.

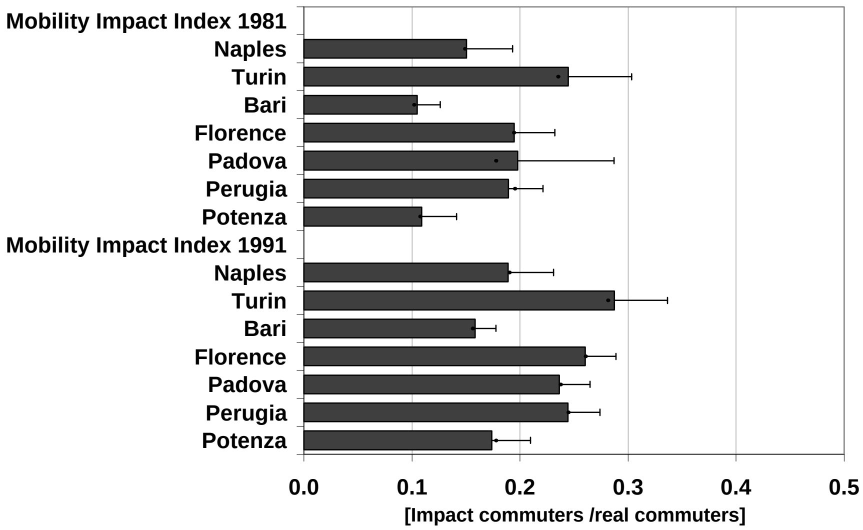


Figure 2: Mobility Impact Index referring to 1981 and 1991, organised by urban area of concern, where the bars represent the average value, the median value is indicated by solid squares, and the error bars represent the standard deviation of the Mobility Index within each urban area.

Table 4: Percent distribution of commuters by travel mean during 1981 and 1991.

		Naples	Turin	Bari	Florence	Padua	Perugia	Potenza
Walking or other soft means	*1981*	44%	29%	56%	30%	37%	28%	58%
	1991	41%	22%	45%	23%	26%	21%	41%
Bus	*1981*	24%	25%	13%	23%	17%	24%	17%
	1991	17%	18%	10%	15%	15%	17%	19%
Private car (driver)	*1981*	15%	28%	17%	27%	25%	32%	16%
	1991	24%	42%	28%	37%	39%	45%	29%
Motorcycle	*1981*	1%	2%	2%	8%	12%	6%	1%
	1991	2%	1%	2%	11%	7%	3%	1%
Private car (passenger)	*1981*	4%	7%	6%	6%	7%	7%	6%
	1991	7%	9%	10%	8%	10%	11%	9%
Train,tram,metro	*1981*	11%	10%	6%	6%	2%	3%	3%
	1991	10%	8%	6%	6%	3%	2%	2%

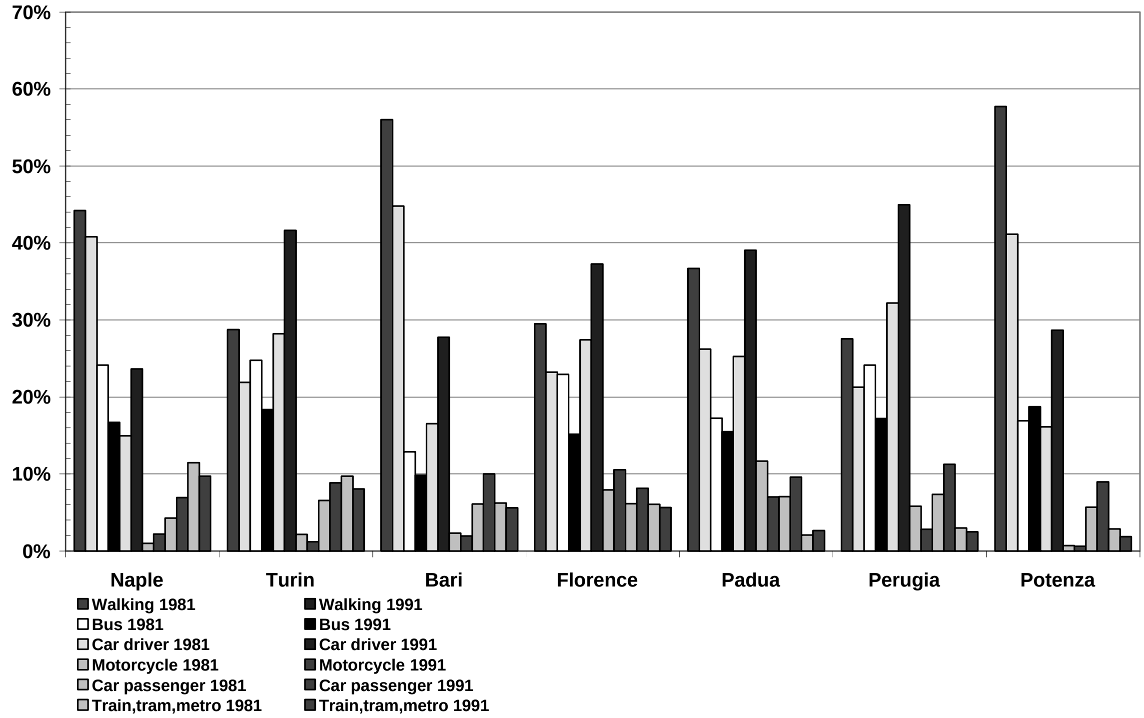


Figure 3: Distribution of commuters by travel mean during 1981 and 1991 for the seven urban areas under analyses.

4. RESULTS OF THE ECONOMETRIC MODEL

4.1 Cross-section analysis

In this paper, we report the results of cross-section regression models estimated from the data of the 1991 Census. As shown in Table 6 we first estimate a basic model (column A) and, subsequently, we progressively enrich the model's specifications (column B, C). The relationship between the intensity of urban mobility and the typology of urban settlement is examined using an econometric analysis to ascertain whether our *a priori* expectations on the factors determining the mobility intensity in Italy can be corroborated by an empirical analysis (see for a discussion Section 2). All the models show a good explanatory power with an R^2 over 0.7.

In the attempt to control for geographical differences, all the models (Table 6) include the distance from the chief town of the related urban area (DISTANCE), and its rural ratio (RURAL). Among the number of socio-economic factors that might have a role in determining the degree of urban mobility we focus on the dynamic of urban growth (GROWTH) and the

residential versus productive vocation (MIXITE) of a given settlement. In addition to this, we use the density of the urban development (DENSITY) as a proxy of sprawling behaviour[3].

As well, an important research issue here is to understand which role accessibility and efficiency of public transport can have in curbing the proliferation of urban traffic and congestion. On this perspective we expect that, as the overall competitiveness of public transport increases, commuters' preferences will move towards public transport means contributing to reduce traffic congestion and the intensity of mobility impact. A part from qualitative argumentations, the results of a regression analysis of the Mobility Impact Index show, indeed, that the increase in the use of private car is one of the main determinants of the sensible increase of the intensity of urban mobility from 1981 to 1991 (see Table 5). To capture these dimensions we estimate the accessibility (market share) and the efficiency of public transport calculated as, respectively, the percentage of all trips made by public vehicles (SHAREPUB), and the ratio between the average trip times taken with private vehicles over the average times taken travelling with public modes (COMPUB).

In column (B), the model also includes a variable that estimates to which degree urban mobility is (at commune level) contained within the city borders or, instead, it spreads towards outside of the city (SELFCONT). We can interpret this as the capacity of a given urban area to contain mobility within its borders, sort of mobility self-containment, which is expected to be positively related to its productive attitude. In fact, to some extent, the higher is the productive attitude of an urban settlement, the higher its capacity to contain commuting within its borders. A regression model of SELFCONT shows that the coefficient of MIXITE is positive and strongly statistically significant for all the cities of concern, with the exception of Potenza and Turin. This suggests that, *ceteris paribus*, residential cities can contribute to generate traffic and congestion more than urban areas with a higher level of 'functional mix'.

Coming back to our main line of reasoning, we expect SELFCONT to be negatively correlated to the level of mobility impact for two reasons: on one side, the average trip times increase whenever moving direction outside the city; second, commuters moving out of their city usually prefer less environmental friendly travel means, especially their own car. We have a confirmation of this in Table 7, which reports the results of a comparison between the mobility impact indexes calculated, on one side, considering both commuters travelling within the town and those going out of it (sort of gross mobility) and, on the other side, indexes calculated considering only the net movements outside of the town. As expected, the intensity of the mobility impact is higher whenever considering the net movements towards outside of the city, up to the 51.3 percent for Potenza. Finally, in column (C) the model includes the variable GROWTH to capture the effect of demographic growth on mobility impact.

[3] We are aware of the limits of such procedure, whereas previous researches have proposed other, more accurate, indicators of urban sprawl (for a discussion see Camagni et al. 2002a). To have a better understanding of the spatial distribution of urban settlement within a given area and about their sprawling attitude, we are at the moment working on the development of graphical indicators of sprawl, based on the methodology proposed by Salvetti (1982).

The main outcomes from these models can be summarised as follows (see Table 6). The MIXITE variable captures the effect of the functional mix of the urban settlement on the intensity of the urban mobility impact. In our three models, coefficients take on negative values for all the areas under analysis and they remain stable. Coefficients are statistically significant for Naples, Padua, Perugia and Potenza.

An inverse relationship is found between the index measuring the mobility impact and the gross population density (DENSITY). Coefficients are small in terms of absolute values, but they are statistically different from zero for Florence, Padua, Turin and Potenza.

Coefficients related to the distance from the chief town (DISTANCE) are all negative and small in terms of absolute values. For the urban areas of Florence, Naples, Padua, Potenza and Turin, coefficients are statistically significant and they remain stables across the three models. The negative relationship between DISTANCE and MOBILITY IMPACT suggests that, going towards the most external part of the province, municipalities become more autonomous and they behave as sort of self-contained 'district' that contribute less to urban traffic.

An inverse relationship also exists with the variable RURAL. Coefficients are statistically significant for Bari, Padua, Perugia, Potenza and Turin, though they are small in absolute values. We can interpret this as an effect of the smaller demand of mobility in areas with higher agricultural land rates.

Interestingly, the effect of SHAREPUB is also negative and highly statistically significant for all the provinces under analysis, with the exception of Perugia and Potenza. As well, coefficients remain stable across the models.

For what deal with the effect of public transport efficiency, we obtain less clear results. Indeed, COMPUB coefficients take on positive -and statistically significant- values for Florence, Padua and Turin; while they are negative –and significant- for Naples and Perugia. Since COMPUB is estimated as the ratio between the average time taken for trips made with private transport and the average time taken for trips made with public vehicles, we would expect to observe a negative relationship with the mobility impact. Nevertheless, we have to notice here that our indicator of competitiveness is biased by the fact that it does not link trip duration with trip length[4].

Finally, Model B and C also include a variable controlling for the degree of self-containment of a given municipality and for its population dynamics during the decade 1981-1991. Results show that SELFCONT, whenever significant, has a negative effect on mobility impact. On the other hand, GROWTH, whenever significant, is positively related to mobility impact.

[4] The impossibility of linking trip duration with trip length derives from the Census dataset, which disregards completely this important information.

Table 5: Regression analysis of the variation of the Mobility Impact index from 1981 to 1991.

Dependent variable: Variation of MOBILITY IMPACT (1981-91)	OLS	
Independent variables:	*b*	T-Stat
Constant	-4.250	-1.655
Variation of private car (driver)		
Bari	3.554	6.592***
Florence	2.201	2.870**
Naples	3.157	6.650***
Padua	1.696	4.035***
Perugina	0.526	0.784
Potenza	3.679	13.929***
Turin	2.173	9.858***
Variation of motorcycle		
Bari	1.391	0.322
Florence	- 0.209	- 0.117
Naples	2.924	1.992*
Padua	1.041	0.194
Perugina	- 2.844	- 1.884
Potenza	2.052	0.410
Turin	- 0.255	- 0.443
Variation of bus		
Bari	0.825	0.648
Florence	- 0.526	- 0.039
Naples	1.619	2.904**
Padua	- 0.370	- 0.758
Perugia	- 1.541	- 2.259
Potenza	1.096	3.340***
Turin	1.025	5.483***
Variation of train,tram,metro		
Bari	1.951	0.972
Florence	- 0.929	- 0.441
Naples	0.319	0.335
Padua	4.228	1.554
Perugia	- 1.025	- 0.499
Potenza	2.437	2.615***
Turin	0.585	1.312
Nobs	743	
R^2	0.322	
R^2-adj	0.295	

Note: All variations are measured as percent variation and refer to the decade 1981-1991.
Significance is indicated by ***, ** and * for the 1, 5, and 10 percent level, respectively.

Table 6: Ordinary lest squares regression analysis of the Mobility Impact index 1991.

	Model (A) OLS	Model (B) OLS	Model (C) OLS
Dependent variable: MOBILITY IMPACT 1991			
Independent variables:			
b	0.332 (43.898)***	0.3410 (44.995)***	0.3441 (45.370)***
DISTANCE			
Bari	0.0000 (0.025)	-0.0001 (-0.545)	-0.0002 (-0.587)
Florence	-0.0060 (-1.483)	-0.0072 (-1.621)*	-0.0008 (-1.750)*
Naples	-0.0017 (-3.754)***	-0.0012 (-2.878)**	-0.0012 (-2.927)**
Padua	-0.0011 (-2.946)**	-0.0012 (-3.259)**	-0.0014 (-3.452)**
Perugia	-0.0005 (-1.357)	-0.0005 (-1.348)	-0.0005 (-1.339)
Potenza	-0.0060 (-7.554)***	-0.0062 (-8.218)***	-0.0005 (-5.652)***

	Model (A) OLS	Model (B) OLS	Model (C) OLS
Turin	-0.0061 (-5.257)***	-0.0045 (-3.802)***	-0.0005 (-4.192)***
MIXITE			
Bari	-0.0494 (-1.453)	-0.0459 (-1.406)	-0.0469 (-1.447)
Florence	-0.0131 (-0.739)	-0.0121 (-0.679)	-0.0129 (-0.733)
Naples	-0.0396 (-1.907)	-0.0099 (-0.496)	-0.0106 (-0.535)
Padua	-0.0153 (-1.695)*	-0.0166 (-1.950)*	-0.0155 (-1.826)*
Perugia	-0.0584 (-2.229)**	-0.0643 (-2.453)**	-0.0656 (-2.520)**
Potenza	-0.0311 (-1.528)	-0.0331 (-1.734)*	-0.0478 (-2.465)**
Turin	-0.0005 (-0.650)	-0.0005 (-0.679)	-0.0006 (-0.778)
DENSITY			
Bari	-0.161^{-04} (-1.205)	-0.109^{-04} (-0.787)	-0.860^{-05} (-0.559)
Florence	-0.361^{-04} (-3.353)***	-0.386^{-04} (-3.649)***	-0.370^{-04} (-3.418)***
Naples	-0.228^{-05} (-1.351)	-0.266^{-05} (-1.676)*	-0.282^{-05} (-1.785)*
Padua	-0.403^{-04} (-3.066)**	-0.458^{-04} (-3.619)***	-0.462^{-04} (-3.683)***
Perugia	$-0.1.33^{-04}$ (-0.206)	-0.203^{-04} (-0.321)	-0.219^{-04} (-0.340)
Potenza	-0.221^{-04} (-0.215)	-0.186^{-04} (-0.192)	-0.0002 (-2.019)**
Turin	$-0.1.01^{-04}$ (-2.405)**	-0.199^{-05} (-0.475)	-0.305^{-05} (-0.731)
RURAL			
Bari	-0.0011 (-3.784)***	-0.0009 (-2.660)**	-0.0009 (-2.714)**
Florence	-0.0004 (-1.263)	-0.0004 (-0.997)	-0.0003 (-0.854)
Naples	-0.0002 (-1.150)	-0.0002 (-0.973)	-0.0002 (-1.114)
Padua	-0.0004 (-1.826)*	-0.0006 (-2.395)**	-0.0005 (-2.008)**
Perugia	-0.0005 (-1.599)	-0.0005 (-1.703)*	-0.0005 (-1.749)*
Potenza	-0.0014 (-8.004)***	-0.0014 (-8.318)***	-0.0013 (-7.273)***
Turin	-0.000 (-2.803)**	-0.0002 (-2.986)**	-0.0003 (-3.346)***
COMPUB			
Bari	0.0004 (0.665)	0.0006 (1.044)	0.0007 (1.101)
Florence	0.0015 (2.728)**	0.0016 (2.825)**	0.0015 (2.728)**
Naples	-0.0003 (-5.329)***	-0.0002 (-3.618)***	-0.0002 (-3.679)***
Padua	0.0017 (2.558)**	0.0016 (2.377)**	0.0015 (2.308)**
Perugia	-0.0005 (-2.256)**	-0.0005 (-2.324)**	-0.0005 (-2.375)**
Potenza	-0.0001 (-0.821)	-0.0001 (-0.783)	-0.0001 (-0.774)
Turin	0.0006 (9.219)***	0.0007 (10.469)***	0.0007 (10.456)***
SHAREPUB			
Bari	-0.0015 (-2.450)**	-0.0017 (-2.845)**	-0.0017 (-2.850)**
Florence	-0.0017 (-2.829)**	-0.0017 (-2.720)**	-0.0017 (-2.724)**
Naples	-0.0013 (-3.547)***	-0.0009 (-2.613)**	-0.0009 (-2.679)**
Padua	-0.0020 (-2.241)**	-0.0020 (-2.514)**	-0.0022 (-2.652)**
Perugia	0.0003 (0.540)	-0.387^{-04} (0.055)	-0.624^{-04} (-0.088)
Potenza	-0.0003 (-1.137)	-0.0003 (-0.969)	-0.0001 (-0.495)
Turin	-0.0011 (-5.149)***	-0.0007 (-3.384)***	-0.0007 (-3.340)***
SELFCONT			
Bari		-0.0441 (-1.080)	-0.0560 (-1.080)
Florence		-0.0190 (-0.503)	-0.0280 (-0.728)
Naples		-0.1536 (-6.977)***	-0.1547 (-7.084)***
Padua		0.0210 (0.902)	0.0248 (1.045)
Perugia		0.0246 (0.690)	0.0222 (0.587)
Potenza		-0.0325 (-1.034)	-0.0268 (-0.860)
Turin		-0.1080 (-6.572)***	-0.1062 (-6.498)***
GROWTH			
Bari			0.0002 (0.347)
Florence			0.0005 (0.789)
Naples			0.982^{-04} (0.327)
Padua			-0.0005 (-1.053)
Perugia			0.798^{-04} (0.092)
Potenza			0.0020 (3.546)***
Turin			
N° obs.	736	731	731

	Model (A) OLS	Model (B) OLS	Model (C) OLS
R^2	0.706	0.744	0.751
R^2 adj	0.688	0.725	0.729

Notes: T-values are reported in bracket. Significance is indicated by ***, ** and * for the 1, 5, and 10 percent level, respectively.

Table 7: Descriptive statistics of the mobility impact index per metropolitan area.

	Mobility Impact Index										
	Mean		**Median**		**Std. dev**		**Minimum**		**Maximum**		**Increase rate**
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*(a-b)*
Naple	0.189	0.269	0.189	0.270	0.042	0.056	0.045	0.042	0.312	0.400	29.7%
Turin	0.287	0.362	0.287	0.350	0.049	0.064	0.121	0.219	0.453	0.789	20.6%
Bari	0.159	0.296	0.159	0.294	0.019	0.036	0.119	0.245	0.201	0.415	46.5%
Florence	0.260	0.371	0.260	0.354	0.028	0.056	0.206	0.294	0.326	0.556	29.8%
Padua	0.237	0.340	0.237	0.337	0.028	0.032	0.167	0.284	0.289	0.427	30.4%
Perugia	0.244	0.370	0.244	0.361	0.030	0.050	0.139	0.293	0.323	0.544	33.9%
Potenza	0.174	0.357	0.174	0.350	0.036	0.082	0.019	0.048	0.246	0.577	51.3%

Note:
(a) Mobility impact index calculated considering both commuters going outside and moving within a given commune:
(b) Mobility impact index calculated considering only those commuters going outside a given commune.

5. A CONCEPTUAL INTERPRETATION OF MOBILITY IMPACT

5.1 The conceptual model

Moving further from the results presented in the previous paragraph, we try now to enrich our analysis envisaging a conceptual causal chain in the explanation of the mobility impact intensity, in which the mobility impact is the results of the influence of three main territorial dimensions: structural economic and social, as shown in Figure 4. In our model, the causal chain origins from the structural features of the urban settlement that we interpret as drivers of all other elements in the conceptual chain. In particular, we focus on the self-containment capacity of a given city, as a result of urban form and urban functional mix. The structural dimension of our conceptual model, here represented by the self-containment capacity, is therefore supposed to influence the intensity of the mobility impact through the economic and the social dimension. The economic element is represented by the competitiveness of public *vs* private transport (in terms of time efficiency), which is a results of the structural features of the urban settlement (e.g. urban density, functional diversification, etc). The social element is represented by the modal choice of the city inhabitants, depending on the competitiveness of the public *vs* private transport that, on its turn, is related to the urban settlement features.

Stigmatising the previous discussion, we have that settlement of relatively compact structure and good functional mix will be characterised by higher self-containment capacity. This will generate more favourable conditions for public transport competitiveness (in terms of journey-to-

work time) that, on its turn will move people preferences towards public travel means and, consequently, lower impacts of urban mobility.

From this conceptual interpretation we try now to move to the econometric analysis to find some empirical evidence of it. Before presenting our results, however, it is necessary to notice that our causal interpretation of the mobility index derives from *a priori* knowledge on the phenomenon and it can not be derived straight from the statistical estimation process.

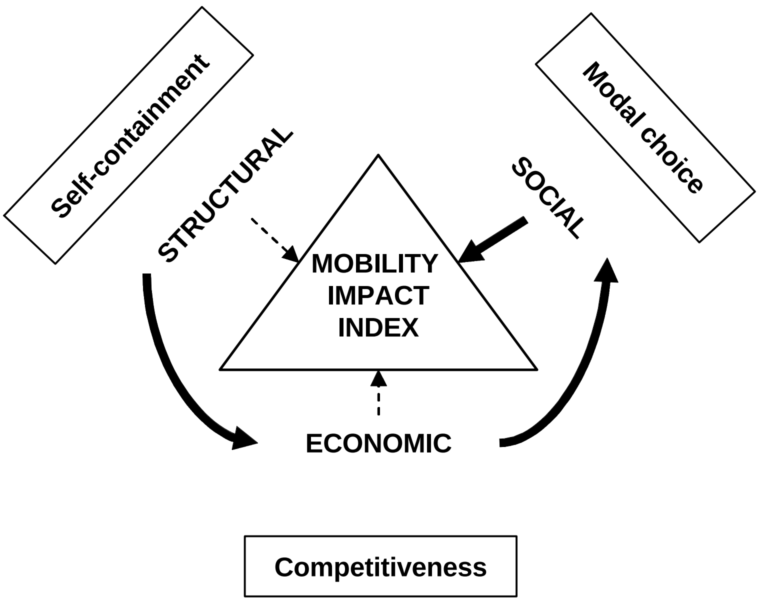


Figure 4: Causal chains in the explanation of mobility impact.

5.2 The Causal Path Analysis

In order to test the hypothesis on the causal chain in the explanation of mobility impact, we employ a methodology based on Causal Path Analysis (CPA) an in-depth description see e.g. Bollen, 1989). This type of analysis formulates the model as a path diagram, in which arrows connecting variables define the structure of the conceptual framework and allow the estimation of reaction parameters, i.e., essentially the regression coefficients. The arrow diagram of Figure 5 contains the structure of the causal path that we want to test, which comes from the conceptual model presented in Figure 5. On the right hand side we have the *endogenous* variable (dependent), i.e. the variable that in the end has to be explained by all other variables in the model. The remaining variable in the scheme are *exogenous* and *intermediate* variables, where the former are independent (in the sense that their variation is taken for granted in the model), while the latter can be influenced by variation in the exogenous variables.

Among various statistical methods, we use the Generalised Least-Square (GLS) method to run the path analysis. GLS allows us to construct a model of linear equations, in which a given variable can behaves both as independent variable (in one equation) and as dependent variable in a subsequent equations. We can therefore estimate regression coefficients in simultaneous regression model. Under the assumption that each variable has been standardised to unit variance and mean zero, the value assumed by individual parameters represents the order of magnitude of each independent variable in explaining the following dependent variable. The statistical significance of each parameter is given by the values of T-students run in parallel to the coefficient estimation analysis.

In the framework of our analysis three latent variables are chosen, one for each territorial dimension included in the conceptual model, plus three exogenous variables that capture the structural pattern of any given city. MIXITE, DENSITY and RURAL are chosen as exogenous variables and they describes, respectively, the functional mix and the urban sprawl attitude of a given urban area. SELFCONT is chosen to represent the structural dimension; COMPUBB is the economic element of the model, while SHAREPUB estimates individual preferences for public travel means, i.e. the social element. Impact of urban mobility is estimated by our Mobility Impact Index. The causal direction of the chain is given by arrows in
Figure 6. Results are presented in
Figure 6 with coefficients and T-values in brackets. From this it is easy to see that our conceptual model appears to be confirmed. All parameters are highly statistically significant and have the expected sign. The level of self-containment depends on some structural elements here represented by, in particular, residential density, functional mix and incidence of rural land. In this respect it is interesting to notice that, as the productive vocation of the settlement increases (MIXITE), the level of mobility self-containment increases too. The same goes for urban density and ratio of agricultural land. From the results presented in
Figure 6, we also have a confirmation of the causal link between self-containment and competitiveness of public transport. The SELFCONT coefficient is positive and highly statistically significant, meaning that as self-containment capacity goes up, competitiveness of public transport increases, as expected. Besides, the relationship between modal choice (SHAREPUBB) and competitiveness of public transport (COMPUBB) is also confirmed to be positive and highly statistically significant. As expected, a greater efficiency of public transport contributes to move individual choices towards public travel means and, therefore, to reduces the overall impact of urban mobility. The last link of our chain is indeed negative meaning that, as expected, all else being the same, if individual preferences move towards public travel means, we can expect a reduction of urban mobility impact.

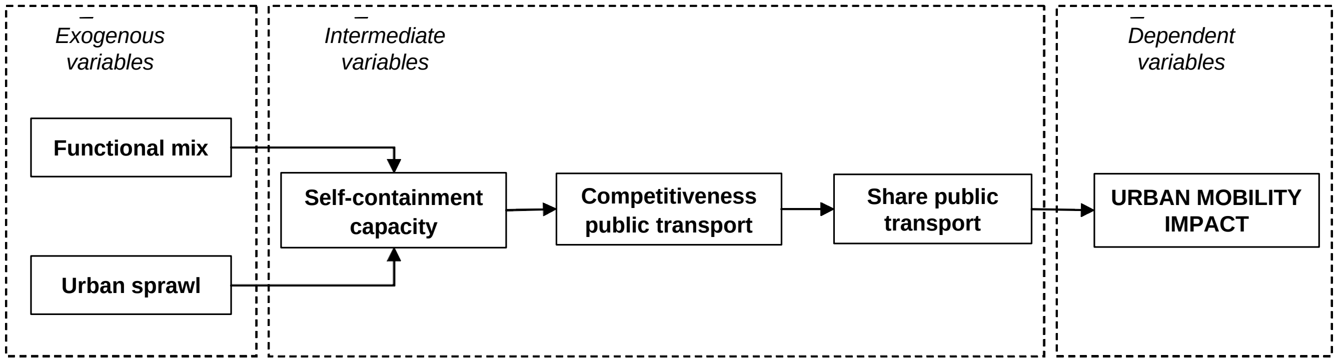


Figure 5: A general model for urban mobility impact estimates.

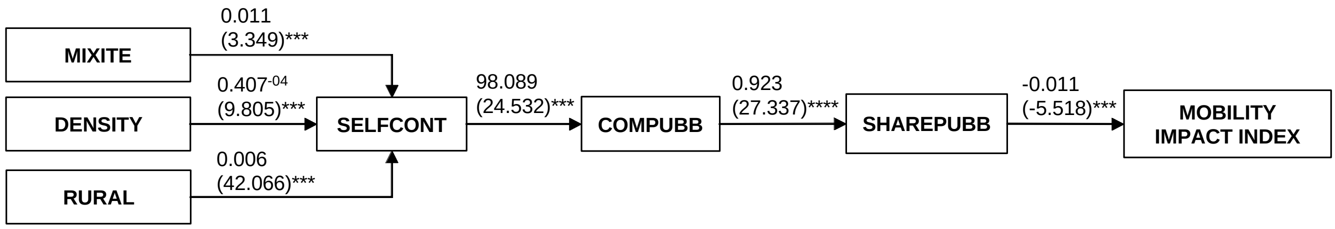


Figure 6: Estimated path analysis model for Italy. T-statistics are provided in brackets. Significance is indicated by ***, ** and * for the 1, 5, and 10 percent level, respectively.

6. CONCLUSIONS

In Europe, the debate on collective costs associated with sprawling urban patterns is recent and it advocates for empirical evidence of their dimensions as, so far, sound empirical and quantitative analysis is still rare. It is indeed a hard task to measure such externalities and, even more, to provide an econometric analysis of the link between the way in which an urban area develops and its effects in terms of collective costs. In this respect, we focus on urban mobility and provide a broad empirical analysis on both the dynamic of urban mobility during the decade 1981-1991 and the factors determining the intensity of mobility pressure in Italy.

We select seven Italian urban areas, located in the north, centre and south of Italy, and use journey-to-work data to compute a mobility impact index at commune level, for the years 1981 and 1991. The mobility index is based on a weight matrix that associates less environmental friendly mobility behaviours with higher impact scores (Camagni et al, 2002b).

A first result is that –as expected- during such decade, the impact of urban mobility has increased noticeably in the whole peninsula, up to the 37.3 percent. A regression model shows that the higher rate of use of private car is one of the main determinants of such an increase.

Subsequently, we describe our hypothesis as to the reasons to explain heterogeneities in intensity of mobility impact and use cross-section regression framework to test them empirically. Models refer to 1991 data and include variables controlling for structural and socio-economic features of the urban settlement, with a special focus on sprawling attitude and competitiveness and efficiency of public versus private transport. Among the structural factors, whenever statistically significant, urban density, functional mix (economic-residential balance) and rural ratio are negatively correlated to the mobility impact index, while demographic growth rate is positively correlated. Higher impacts are associated with diffused, sprawling development, residential specialisation and more recent urbanisation processes.

Finally, we try to enrich our analysis envisaging a conceptual causal chain in the explanation of the mobility impact intensity, which relies on three main components: structural, economic, and social. The three components are represented, respectively, by: self-containment capacity of a given urban area, competitiveness of public *vs* private transport (in terms of time efficiency), modal choice. In our conceptual model, structural factors are drivers of competitiveness of public transport, which, on its turns, influences peoples' preferences on alternative modal travel means. We test such causal relationship using CPA we find substantial confirmation of this, as all coefficients have the expected sign and they are highly statically significant. Results show that the level of self-containment depends on the structural form of urban development, and in particular on its residential density, functional mix and incidence of farmland. Results also show a positive correlation between the self-containment indicator and the public transport competitiveness; and between public transport competitiveness and travel means preferences. Finally, CPA shows a negative and statistically significant correlation between an increase in the use of public transport and intensity of urban mobility.

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