I. Introduction
The importance of the interactions between land-use and transport is clearly demonstrated in the way in which our cities have evolved. Each technological innovation in transport has encouraged both people and industry to change their location to take advantage of the improved mobility; similarly each change in land development (e.g., houses, factories, offices or shops) has influenced the demand for travel and ultimately the provision of new transport infrastructure. These interactions have been a driving force in the development of cities and are continuing to affect transport and urban change (Webster and Dasgupta, 1991).

When evaluating transport or land-use policies it is important to take these interactions into account because the repercussions of policies take place over many years and their long term impacts are likely to be very different from the short term responses. The various impacts of policies occur over vastly different time scales and are frequently masked by changes unconnected with the policy, making it difficult to isolate cause and effect. Because of the complexity of these interactions the only practical way to evaluate policy impacts is to develop a consistent quantitative framework based on a thorough understanding of the mechanisms at work.

A variety of mathematical models are already available to the policy maker. These models have been designed to provide different capabilities and vary in the way they represent the process of change. The “standard” four stage model remains the most widely used in urban transport planning. The recurrent assumption within these traditional transport models has been that land use forecasts can be made independently of transport, and that transport forecasts can then be made on the assumption of fixed land use. While many of the relevant processes remain imperfectly understood there can be no doubt about the necessity to incorporate the two-way interactions between land use and transport for any long term prediction of urban travel demand and for a proper evaluation of policies.

A number of interactive land-use/transport models have been developed over the last twenty years and these have been applied to cities in various parts of the world. Such models have fallen out of use due to the perceived difficulties of implementing them and, perhaps, also due to the claims for their capabilities. However, it is now being recognised that there is a need for an understanding of the long-term effects of investment in transport infrastructure and that these models offer one way of developing such an understanding.

Several approaches to land-use/transport modelling have been proposed in literature (Simmonds 2000). As it will be seen, one of the last proposed approaches applies behavioural discrete choice modelling to activity and residential location decisions, obtaining a theoretical consistency among land-use and transportation models.

The objective of this paper is both on the methodological issues and practical implications of the behavioural approach. Two residential and activity location choice models consistent with Random Utility Theory are presented. The models outlined, developed and calibrated for the city of Naples (Italy) and the city of Rome (Italy), are specified and the calibration results are discussed.

In order to validate the approach followed a comparative analysis based on empirical criteria, i-student statistic and model elasticity is finally presented.
parameters calibrated and on the elasticity values, has been carried out. In order to provide the context, section 2 reviews the integrated land-use/transport modelling frameworks found in the literature. In sections 3 and 4, respectively the residential location models and the activity location models for the two study areas considered are presented. In section 5 the comparison criteria are identified and the results obtained are discussed. Finally, in section 6 conclusions and further research issues are outlined.

2. Integrated Land-Use/Transport Model: Possible Approaches
Land-use/transportation interaction models draw from several modelling traditions. This is natural, since the field encompasses so much of human activities in general. The range of models to be considered can be classified in many different ways: theoretical basis, modelling method, dynamics, aggregate/disaggregate, and so on. The first layer of the three (see Fig. 1) separates out a group of models whose purpose is to optimise urban systems rather than to predict their behaviour. These models are intended as tools which can find a design that optimises a particular function, and are therefore quite distinct from the majority of models which respond to a design input by the user.

![Figure 1: Integrated land-use/transport model](image)

These optimising models may be informative for research and (very) long-term planning, but in general they are difficult to link to the practical planning problems of individual cities. Note also that increasing computing power and better algorithms are making it possible under some circumstances to use predictive models in an optimising way, to find the best package of policies within a range that has been defined as possible or realistic (Simmonds, 2000).

The second layer of the three distinctions between dynamic and static models. Dynamic models run for a series of time periods, with transport changes taking one or more periods to have an impact upon land use. Static models represent a single point in time, with the more limited objective of adding a land use dimension to more standard horizon year transport models. Much of the early work in land-use modeling consisted of static models which attempted to predict the location of certain variables taking other simultaneous variables as given (see, in particular, Lowry, 1964) and the whole range of Lowry-inspired models. Static models are powerful tools to cases where a dynamic land-use/transport model is unaffordable.

Among the dynamic models three further groups can be distinguished:

1. models based originally upon analogies with statistical mechanisms (entropy) pioneered by Alan Wilson in the 1970's;
2. models based primarily upon the integration into a spatial (multizonal) form of separately developed (and often non-spatial) economic models; and
3. models based primarily upon representation of the different processes affecting the different types of activities considered.

Static models are still used for two reasons:

- as a means of adding a land-use impact dimension to existing transport models, without embarking on the extra work needed to create a dynamic model; and or/
- because the static model represents an equilibrium state which is of interest itself.

The category of static models represents can be divided into:

- models which estimate the pattern of land-use given one set of transport inputs; and
- models which estimate changes in land-use given two sets of transport inputs.

IMREL (Anderstig and Mattsson, 1991) is representative of the single-input approach, whilst DSCMOD is representative of the two-input approach.

The main example of an entropy-based model was the LILT package (Mackett, 1983), MEPLAN (Echenique et al., 1994) and TRANUS (de la Barra, 1989) are both commercial packages and they are examples of the spatial-economic models.

Activity based models are defined by their focus on the different processes of change which affect activities and the spaces they occupy; they are location-interaction models, typically characterized by more detailed segmentation of activities, and more elaborate treatment of both the decision to move and location choice. In contrast to other models, they do not relocate all activities in a time period, but separate the decision to move (which will affect only a proportion of total activities) and the search for a new location. The best-developed model of this type is IRPUD (Wegener, 1998) a model of Dortmund (Germany) developed for research purposes over a long period. The one UK example is the DELTA package (Simmonds, 2001) which has been applied to Edinburgh and to Greater Manchester, and in an extended regional form to the Trans-Pennine region.

3 Residential location model
The choice of a residential location is actually a cluster of related choices, including the decision to move from an
existing residence, the choice of housing tenure (rent or own), neighbourhood, and housing unit. These choices are implemented through a housing search process. There is a vast literature on residential location and mobility (Pagliara and Simmonds, 2001).

Some characteristics of housing make it a very unusual commodity. The durability of buildings, relatively high costs, and fixed location collectively make housing a highly differentiated product. Each building or parcel of land could be considered quasi-unique, since it differs (slightly) from its neighbours in location. This differentiation of real estate implies varying degrees of substitutability between individual real estate products. Two adjacent houses of the same floorplan in the same subdivision would be considered highly substitutable by most consumers, for example; whereas two houses further apart, or of substantially different floorplan or construction quality would not. The differentiation of real estate products is partly a response to differences between consumer tastes and needs. Households with higher incomes, with children, or with two workers, for example, will demonstrate different consumption preferences for housing and location than will households of differing income and life-cycle characteristics. Market segmentation is related to product differentiation.

Transaction costs, stage of life cycle, and other factors influence mobility. Mobility and location choice have been treated as sequential or nested choices in empirical research (Waddell et al., 2001).

### 3.1 The model for the city of Naples

The models presented in this paper (Cascetta et al., 2000a) follow the random utility approach. In the model for the city of Naples, the study area has been divided in 145 zones, without considering the neighbouring. Different classes of workers have been identified according to income level: a high/medium and a low income groups.

The attributes of the systematic utility are in the following reported:

- \( \ln\text{STOCK} (o) \) is the logarithm of the housing stock in zone \( o \);
- \( \text{PRICE} (o) \) is the price per square meter of the houses in zone \( o \);
- \( A^{\text{user}}(o) \) is the active accessibility to services in zone \( o \) for residents of type \( i \);
- \( Y^{\text{work}}(o,d) \) is the logsum of the mode choice \( m \) between \( o \) and \( d \) for work purpose and type \( i \) of residents;
- \( \text{PREST} (o) \) is a dummy variable, equal to 1 if zone \( o \) is prestigious, 0 otherwise;
- \( \text{CH} (o) \) is the council houses ratio in zone \( o \).

The active accessibility of zone \( o \) is a proxy of the opportunity of reaching the activities located in different zones of the study area for a given purpose (e.g. shopping, workplace, ...) moving from \( o \). For instance, it is possible to calculate the active accessibility of zone \( o \) to the services of the study area, as:

\[
A^{\text{act}}_m(o) = \sum_d E^{\text{act}}(d)^m \cdot \exp(\alpha_i \cdot Y^{\text{service}}(o,d))
\]

where \( E^{\text{act}}(d) \) is the number of people employed in services (e.g. banks, insurance institutes, etc) in zone \( d \); \( Y^{\text{service}}(o,d) \) is the inclusive values of the mode choice for “Other purposes” (i.e. shopping, personal care, etc); \( \alpha_i \) and \( \alpha_2 \) are calibrated parameters.

On the other hand, the passive accessibility is a proxy of the opportunity of an activity located in a given zone \( d \) to be reached from the potential consumers moving from all the various zones of the study area for a given purpose. For instance the passive accessibility of zone \( d \) with respect to households (or equivalently to the whole population of the study area) can be calculated as:

\[
A^{\text{pass}}(d) = \sum_o R(o) \cdot \exp(\gamma_d \cdot Y^{\text{service}}(o,d))
\]

where \( R(o) \) is the number of people leaving (i.e. residents) in zone \( o \); \( \gamma_d \) and \( \gamma_2 \) are calibrated parameters.

The inputs to the calibration of the model include direct observations data gathered through a 1998 mobility survey and population Census data. The utility function parameters, estimated by the Maximum Likelihood method, are reported in table 1.

<table>
<thead>
<tr>
<th>Type</th>
<th>LastOCK</th>
<th>PRICE</th>
<th>A^{act}</th>
<th>Y^{work}</th>
<th>PREST</th>
<th>CH</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Medium</td>
<td>0.214</td>
<td>0.040</td>
<td>0.045</td>
<td>2.578</td>
<td>0.3894</td>
<td>-1.365</td>
</tr>
<tr>
<td>Low-Medium</td>
<td>(4.0)</td>
<td>(-1.3)</td>
<td>(1.0)</td>
<td>(1.1)</td>
<td>(2.2)</td>
<td>(-3.1)</td>
</tr>
<tr>
<td>Low-Income</td>
<td>0.281</td>
<td>-0.385</td>
<td>-</td>
<td>3.494</td>
<td>-2.248</td>
<td>-</td>
</tr>
<tr>
<td>High-Income</td>
<td>(2.8)</td>
<td>(-2.0)</td>
<td>-</td>
<td>(5.5)</td>
<td>(-2.4)</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Residential location model parameters of the city of Naples (ratio in brackets)

The b parameters are all of the expected sign. Particularly significant are the transportation attributes, which show the relevance of the transportation supply and the level-of-service among the various zones. The housing stock seems to weight similarly for the two income classes, the other variables are highly different. As a matter of fact, high/medium income residents are willing to pay more for a more accessible and prestigious zone. Such considerations are confirmed by the positive and high values of the active accessibility and prestige parameters and by the negativity of the council houses ratio parameter. On the other hand, low income people do not perceive the same active accessibility, but give a great relevance to the transport level-of-service, giving them the possibility to easily leave their zone for work purpose. Thus, prestige zone parameter has a very negative value for the low income class.

The low significance of location variables (CENTRE, FIRST RING and SECOND RING), which led to their exclusion from the utility function, can be due to the accessibility, transport and prestige variables, which seem to be related to the location of the zone.

Figure 2 shows the scatter diagrams for the high/medium and
low income residential location choice models. There is a
good correspondence between Census data and those
obtained from the model, especially for high/medium workers
\((R^2 = 0.97)\); for low income workers the diagram is more
scattered \((R^2 = 0.43)\), due to the small sample.

![Figure 2: Residential location choice model validation: observed vs estimated data](image)

### 3.2 The model for the city of Rome

Two different levels of zoning have been introduced for the
model of Rome (Cascetta et al., 2000b): one consisting of 463
zones, used for calibration of the model; the other consisting
of the 54 macro-zones, used for the model validation.

Different classes of workers have been identified according to
income level: the high-income and the low/medium-income
groups.

The systematic utility has been assumed a linear combination,
through parameters \(b_i\), of the following “attributes”:

- \(lnSTOCK(\omega)\) is the logarithm of the housing stock in zone \(\omega\);
- \(PRICE(\omega)\) is the price per square meter of the houses in
  zone \(\omega\);
- \(Y_{\text{work}}(\omega,d)\) is the logsum of the mode choice \(m\) between \(\omega\)
  and \(d\) for work purpose and type \(i\) of residents;
- \(PREST(\omega)\) is a dummy variable, equal to 1 if zone \(\omega\) is
  prestigious, 0 otherwise;
- \(CH(\omega)\) is the council houses ratio in zone \(\omega\).
- \(INTRA(\omega,d)\) is a dummy variable equal to 1 if the
  residential zone \(\omega\) and the employment one \(d\) belong to
  the same macro-zone.

In addition to the above attributes, dummy variables (i.e. one
for each of the 54 macro-zones) have been introduced to take
into account, in an aggregate way, all the characteristics
which are common to zones belonging to the same macro-
area (e.g. the historical centre, the central business district and
so on).

The residential location models have been calibrated using
disaggregate data gathered in a vast campaign of interviews
carried out in 1996.

The price per square meter of the houses is assumed to be a
sum of two components:

\[
PRICE(\omega) = P_{\text{bas}}(\omega) + \gamma_1 \cdot x(\omega)^2
\]

where \(P_{\text{bas}}(\omega)\) is the “fixed” component depending on
exogenous factors characterising the real estate market of the
zone, and \(x(\omega)\) is the “variable” component depending on the
demand for floorspace in a given zone, here computed by
means of the ratio of the residents, \(Res(\omega)\), and the square
meters of houses, \(sq(\omega)\), in zone \(\omega\):

\[
x(\omega) = \frac{Res(\omega)}{sq(\omega)}
\]

The parameters \(\gamma_1\) and \(\gamma_2\), estimated together with the other
parameters of the model, are equal respectively to 1.03 and
1.78 for high-income workers class and 0.32 and 1.88 for
low/medium-income workers class. Estimates of the other
model parameters, calibrated through the Maximum
Likelihood method, for the two selected groups of workers
are reported in table 2. Note that the parameters relative to the
above introduced 54 macro-area dummy variables, whose
estimates range from \(-0.80\) to \(+0.80\), are not reported in the
following.

<table>
<thead>
<tr>
<th></th>
<th>(\text{LnsSTOCK})</th>
<th>(\text{PRICE})</th>
<th>(\text{INTRA})</th>
<th>(\text{Y}_{\text{work}})</th>
<th>(\text{PREST})</th>
<th>(\text{CH})</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>0.245</td>
<td>-0.520</td>
<td>-0.477</td>
<td>0.197</td>
<td>-0.649</td>
<td></td>
</tr>
<tr>
<td>income</td>
<td>(11.2)</td>
<td>(-3.1)</td>
<td>(6.9)</td>
<td>(1.9)</td>
<td>(-1.8)</td>
<td></td>
</tr>
<tr>
<td>Medium-Low</td>
<td>0.297</td>
<td>-0.716</td>
<td>0.482</td>
<td>0.118</td>
<td>-0.335</td>
<td></td>
</tr>
<tr>
<td>income</td>
<td>(27.7)</td>
<td>(-6.6)</td>
<td>(4.8)</td>
<td>(11.8)</td>
<td>(-1.9)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Residential location model parameters
of the city of Rome (\(\text{t-ratio in brackets}\))

As it can be seen, all the parameters have the expected sign
and all the attributes considered in the model are statistically
significant.

Although the housing stock coefficient as well as the
coefficient relative to the inclusive value of the mode choice,
\(Y_{\text{work}}(\omega,d)\), have almost the same value for the two categories
considered, the other variables are highly different, and in
general, different behaviour in housing location choice
emerges for high and medium-low income workers. For
instance, the dummy variable \(\text{INTRA}(\omega,d)\) is positive and
significant only for low income workers. This means that the
distance from the workplace zone is a factor affecting
residential location choice for low income workers more than
for high income ones. This is mainly due to the more flexible
working-time for the former, which implies work trips not
necessarily in the peak period, when the transportation system
is usually congested. On the other hand, the prestige of a zone
is significant only for high-income group.

In order to evaluate the results of the estimation phase,
the system of models have been applied to the more
detailed zoning, consisting of 463 zones; however the
results are analysed for the aggregate 54 macro-zones
(see Figure 3).

The percentage error between observed and estimated
workers for the 54 macro-zones ranges from \(-8\%\) to \(+8\%\).

The scattered diagrams, depicted in Figure 3, show a bigger
dispersion for low income (\(R^2=0.68\)) than for high-income
workers (\(R^2=0.95\)): a more disaggregate segmentation of low
income could probably improve the estimates.
4 Economic Activity Location Model

In the model proposed, allocation of population depends upon the distribution of employment, and so forecasts of employment location, whether exogeneously prepared or endogenously estimated, are an essential component. The ways in which the model describes employment and the general process implicit in its representation of employment location are in the following reported. A distinction needs firstly to be made between employment and jobs or workplaces (Webster et al., 1988). All the models present in the literature are commonly called employment location models. Actually it would be more accurate to call them jobs and/or workplaces such as factories or office buildings, and to use the term employment location models only where such jobs or workplaces are actually filled by the labour force.

Most of the models differentiate between so-called “basic” and “non-basic” types of employment. This categorisation stems from economic base theory, where “basic” employment refers, for the most part, to the sectors which are largely externally driven, while “non-basic” employment contains the more locally-driven types. This distinction reflects notions of local markets and suppliers, and the presumed sensitivity of location to these as well as other factors. Thus, “basic” employment contains all primary sectors and most secondary sectors, while “non-basic” employment contains some secondary sectors and all the tertiary sectors.

The models proposed allocate workplaces rather than employment. Although they use the same structure for all types of workplaces, each structure contains equations referring to two different location processes. In all cases, the functions allocate a change of workplaces to zones according to a locational utility function, which contains accessibility as one of its components.

To simulate these location choices a behavioural approach consistent with Random Utility Theory is followed. Activity location choice location models have been calibrated based on aggregate Census data for the city of Naples and the city of Rome. The results are presented and discussed in the following subsections.

4.1 The model for the city of Naples

Three different activity location choice models have been calibrated: one for the wholesale sector, one for the retail sector and one for the service sector. The parameters have been estimated on an aggregated database using Census data. The procedure consists of the logarithmic of the probability ratio between two zones to transform Logit expressions into linear ones solving them with the GLS method (see Table 3). The attributes of the systematic utility of the economic sectors selected for the generic zone d are in the following reported:

- \(\ln FL(d)\) is the logarithm of the available floorspace in zone \(d\);
- \(A_{n\text{op}}^{\text{pass}}(d)\) is the passive accessibility of zone \(d\) to the employed in the retail sector;
- \(MI(d)\) is the number of motorway junctions within and nearby zone \(d\);
- \(PRICE(d)\) is the price per square meter of the floorspace in zone \(d\);
- \(A_{n\text{op}}^{\text{pass}}(d)\) is the passive accessibility of zone \(d\) to population;
- \(POP(d)\) is the population living in zone \(d\);
- \(EMP^{\text{out}}(d)\) is the number of employed in the services sector in zone \(d\);
- \(CENTRE(d)\) is a dummy variable, equal to 1 if zone \(d\) belongs to the centre, 0 otherwise;
- \(FR(d)\) is a dummy variable, equal to 1 if zone \(d\) belongs to the first ring, 0 otherwise.

All the \(\beta\) parameters are of the expected sign. In particular, the location dummies (CENTRE and FIRST RING) are significant, while they were not considered in the residential location models, because not relevant. Again the transportation variables are significant, but in this case what mainly counts is the available floorspace by sector. The CENTRE dummy variable is positive for all the sectors and, as expected, the highest weight is relative to the retail sector. Its low value for the services sector is probably due to the presence of a CBD, out of the centre, which concentrates a large number of activities. Coefficients relative to passive accessibility to population or employed are statistically significant. Moreover the number of junctions can be assumed as an indicator of accessibility of the zone with respect to the external zones, where the goods come from.

<table>
<thead>
<tr>
<th>(\ln FL)</th>
<th>PRICE</th>
<th>(A_{n\text{op}}^{\text{pass}})</th>
<th>POP</th>
<th>(EMP^{\text{out}})</th>
<th>(X_{n\text{op}})</th>
<th>CENTRE</th>
<th>FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0.476)</td>
<td>(0.476)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>(0.500)</td>
<td>(0.500)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>(0.500)</td>
<td>(0.500)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
</tbody>
</table>

Table 3: Workplaces location model parameters of the city of Naples (\(\beta\)-ratio in brackets)

In the validation process, the results obtained are satisfactory for all the models and mainly for the service sector (\(R^2 = 0.99\)). For the wholesale \(R^2\) is equal to 0.87 and for the retail sector \(R^2\) is equal to 0.97 (see Figure 4).
4.2 The model for the city of Rome

Two different activity location models have been calibrated: one for the services and one for the commerce (wholesales plus retail). The calibration has been carried out using Census data of the urban area of the city of Rome. The attributes of the systematic utility of the non-basic economic sectors selected for the generic zone $d$ are in the following reported:

- CENTRE ($d$) is a dummy variable, equal to 1 if zone $d$ belongs to the centre, 0 otherwise;
- $A_{act, pop}^d(d)$ is the passive accessibility of zone $d$ to population;
- $POP(d)$ is the population living in zone $d$;
- $EMP_{act}(d)$ is the number of employed in the basic sectors in zone $a$;

The calibration results are reported in table 4. Passive accessibility is here computed through equation 9 where the constants $\gamma_1$ and $\gamma_2$, calibrated together with the other model parameters, are equal to 0.85 and 1.22 respectively.

<table>
<thead>
<tr>
<th></th>
<th>$A_{act, pop}$</th>
<th>POP</th>
<th>EMP_{act}</th>
<th>CENTRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
<td>0.137</td>
<td>0.011</td>
<td>-</td>
<td>1.585</td>
</tr>
<tr>
<td>(1.6)</td>
<td>(2.8)</td>
<td></td>
<td>(3.0)</td>
<td></td>
</tr>
<tr>
<td>Commerce</td>
<td>0.105</td>
<td>0.075</td>
<td>0.049</td>
<td>1.397</td>
</tr>
<tr>
<td>(1.9)</td>
<td>(2.6)</td>
<td>(2.4)</td>
<td>(2.1)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Workplaces location model parameters of the city of Rome (t-ratio in brackets)

All the estimates are statistically different from zero and have the expected sign. As it can be noted, the parameters $\beta_{act,pop}$ are positive, meaning that the more accessible a zone is to residents the more it is convenient to locate there an activity. While the values of $\beta$'s relative to accessibility are comparable for "Services" and "Commerce", this is not true for those relative to population. The $\beta_{pop}$ is almost seven times bigger for "Commerce" than for "Services", as if the distribution of commercial activity resembles very closely the distribution of population among the zones. Furthermore, the number of employed in the basic sector activities of the zone are not significant for "Services" sector. Finally, location in a central area is very convenient both for services and commercial activities due to the historical and social factors typical of such area.

In order to evaluate the results of the estimation phase, the system of models have been applied to the more detailed zoning, consisting of 463 zones, however the results are shown for the aggregate 54 macro-zones. The percentage error between macro-zones ranges from -4% to +4% as shown in Figure 5.

5. Comparative Analysis

It is important to be clear why it is useful to make comparisons between models. The most obvious reason is to ensure that, given a choice between two or more models, the most appropriate is selected for a particular task. This raises a number of questions, such as how the appropriateness can be determined. Some possible criteria will be identified below. Another reason for comparing models is to assist in the design of better models, as it may be possible to use elements of different models in developing new and better ones. A third reason for making such a comparison is as a learning exercise, as it is usually easier to analyse a system by comparing it with another one, rather than trying to study it in isolation.

5.1 Comparison criteria

In the context of the comparison of the empirical aspects of two models applied to two similar case studies, a number of specific criteria can be identified (Mackett, 1990):

- method of representation of population and other sectors
- method of representation of space
- exogenous data specification
- simulated market mechanisms
According to such criteria a comparison between the model of the city of Naples and the model of the city of Rome follows.

**Method of representation of population and other socio-economic sectors**
This criterion essentially aims at identifying how disaggregate the model is in terms of urban system representation (i.e. how many economic sectors, how many population categories, etc.). As it can be seen from table 5, the overall level of urban activities is higher for the city of Rome.

Both models outlined are disaggregate, although they present a different residents segmentation. The model of the city of Naples disaggregates the population into “high-medium” and “low” income groups, while that of the city of Rome into “high” and “medium-low” classes. It will be seen in the following section that this affects some parameter estimates.

<table>
<thead>
<tr>
<th>WORKERS*</th>
<th>ECONOMIC SECTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic</td>
</tr>
<tr>
<td></td>
<td>Commerce</td>
</tr>
<tr>
<td></td>
<td>Services</td>
</tr>
<tr>
<td>NAPLES</td>
<td></td>
</tr>
<tr>
<td>High-Med</td>
<td>182,000</td>
</tr>
<tr>
<td>Law</td>
<td>58,385</td>
</tr>
<tr>
<td></td>
<td>133,598</td>
</tr>
<tr>
<td>Total</td>
<td>240,385</td>
</tr>
<tr>
<td></td>
<td>308,622</td>
</tr>
<tr>
<td>ROME</td>
<td></td>
</tr>
<tr>
<td>High-Med</td>
<td>221,976</td>
</tr>
<tr>
<td>Medium-L</td>
<td>747,632</td>
</tr>
<tr>
<td></td>
<td>178,982</td>
</tr>
<tr>
<td>Total</td>
<td>969,608</td>
</tr>
<tr>
<td></td>
<td>1,032,173</td>
</tr>
</tbody>
</table>

*Residing in the study area

**Figure 5: Workplaces location model validation: observed vs. estimated data**

**Method of representation of space**
In literature, several models (i.e. those following the microeconomic theories of land-use) treat the space as a continuous variable. In doing so, however, they fail in representing the variety and richness of the urban and regional geography, since many restrictions are imposed.

A step forward to overcome these limits, has been represented by the disaggregation of space into zones. Zoning can have a different level of detail, i.e. a coarser or finer grain. A larger number of zones provides a more precise representation of the real system and a lower incidence of intra-zonal trips, whose effects on the physical network cannot be simulated. On the other hand, a large number of zones increases the computational burden of any model. In practice, achieving a reasonable compromise between these two conflicting requirements depends once again on the particular type of project (Cascetta, 2001).

Both models use a conventional zoning system. The number of zones is 463 in the case of Rome and 145 in the case of Naples.

**Exogenous data specification**
“Land-use” means, in all integrated land-use/transport models, activities, i.e. population and/or households, and employment. In some models, many other land use variables are modelled, including buildings and land or floorspace values. Most of the models in literature can predict the responses of land-uses and transport to changes in land-use policy. The models range from very complex urban systems in which the influence upon land-use is only one effect among many, to those which can be used to analyse land-use impacts as if only accessibility was changing. Actually other models exist and they are:

- those which cannot represent real cities (e.g. those in which all employment is assumed to be at a single central point);
- those which cannot represent explicitly different places within the city (i.e. “macro” models of the whole urban system);
- those which cannot represent transport systems explicitly (e.g. those that measure space only as distance) and
- those which deal only with one sub-system of land-use, e.g. housing or employment or retailing.

The models selected in this research focus on the components which directly interact with the transportation system and take separate those which typically determine the evolution of the urban system, e.g. migration and/or competition for the same floorspace. In particular, they require the specification of housing stock and of the total number of employment in the study area. Moreover since they simulate the residential location choice of workers/employed an exogenous model to infer information about the other population categories (students, retired, housekeepers, ...) is needed. A first specification of the housing price is required, however, in the model of Rome this can be modified according to the request of housing floorspace. Concerning the transportation system, the model of Naples requires the specification of the generalised travel cost between zones, while, on the other hand, the model of Rome needs the network characteristics, since the transportation system is explicitly simulated.

**Simulated markets mechanisms**
Urban land-use transport models incorporate the most essential processes of spatial development including all types of land uses. According to Wegener, urban systems represented in land-use transport models can be divided into nine subsystems according to the speed by which they change. The urban fabric consisting of infrastructure networks and land use patterns is subject to the very slow change over time. Workplaces and housing change relatively slow while the employment and residential population adjust their spatial behaviour fairly quickly to changing circumstances. Goods transport or travel destinations are the most flexible phenomena of urban spatial development. They can be modified almost instantly according to changes in congestion or fluctuations in demand. A ninth subsystem, the urban environment, is more complex regarding its temporal behaviour.

In the model of Naples, the typical markets of the urban system are not simulated. On the other hand, in the model of Rome equilibrium among housing and activity location is
looked for. In doing so, two typical urban mechanisms are simulated: one the one hand the competition for residing in a limited number of (more attractive) zones between individuals, on the other hand, the competition for floorspace between urban activities (i.e. housing and economic activity). The former is a typical market mechanism of demand/supply interaction which, in the case of housing market, results in the determination of the housing price level. The latter is a typical urban phenomenon which induces modification in the main urban-pattern of the zones of the area (i.e commercial, residential, industrial,...).

5.2 Analytical comparison

5.2.1 Parameters
The parameters comparison of the systematic utility is made on the basis of the similar attributes, by using the t-student statistics on the single coefficients. The null-hypothesis $\text{Ho:} b_{\text{NAPLES}} = b_{\text{ROME}}$ is tested through the statistics:

$$t = \frac{\beta_{\text{NAPLES}} - \beta_{\text{ROME}}}{(\text{Var} \beta_{\text{NAPLES}} + \text{Var} \beta_{\text{ROME}} - 2 \text{cov} \beta_{\text{NAPLES}} \beta_{\text{ROME}})^{1/2}}$$  \hspace{1cm} (4)

where $X$ is the generic attribute of the systematic utility common to the two models.

If the value of $t$ is bigger than 1.96 the null hypothesis can be rejected with a degree of confidence of 5% which implies $\beta_{\text{NAPLES}} = \beta_{\text{ROME}}$.

Table 6 shows the results obtained for the residential location choice model by comparing the estimates relative to some of the parameters listed in section 3.

As it can be seen, the null-hypothesis cannot be rejected (meaning that the estimates are not different for the two models) except for the estimates of the inclusive value $Y_{work}$ and $PRICE$ (see the values of $t$ pointed out by asterisk). These results are not surprising, but easily understandable if we consider that the categorisation of residents, and thus the perception of travel generalised costs and housing prices, may be different.

<table>
<thead>
<tr>
<th>$Y_{work}$</th>
<th>CH</th>
<th>PREST</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Medium/High</td>
<td>3.83*</td>
<td>-0.80</td>
<td>0.38</td>
</tr>
<tr>
<td>Low/Low-Medium</td>
<td>3.81*</td>
<td>0.79</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4: Workplaces location model parameters of the city of Rome (t-ratio in brackets)

Moreover, another possible cause of the statistical difference between the attributes of the inclusive value, $Y_{work}$, resides in the fact that the transportation supply and, thus, the level-of-service attributes are significantly different for the two cities. This implies different perception of the distance from the workplace.

On the other hand, for neighborhood attributes, such as $\text{CH(o)}$ and $\text{PREST(o)}$, the residents segmentation seems to be irrelevant and the estimates of the relative parameters can be assumed to be statistically not different.

In Table 7 are reported the results obtained by comparing some of the parameters listed in section 3. It is worth noting at this stage that for the comparison of these parameters the model of Naples has been adapted to that of Rome. In particular, it is meant that the commerce sector has been considered as a whole, i.e. as an aggregation of the wholesale and retail sectors.

As it can be seen, the null-hypothesis can not be rejected except for the estimate of the attribute $CENTRE$ (see the value of $t$ pointed out by asterisk). This result is not surprising if it is considered that the centre of Rome is the hub of all the national (parliament) and international (embassies) political activities. These are themselves a stimulus for the location of a large number of connected services; whereas the services activities in the city of Naples are mainly located in the CBD, which is not located in the centre.

5.2.2 Elasticity

The residential location models have then been compared in terms of elasticity with respect to those attributes for which, in the statistical test, the null hypothesis cannot be rejected.

In every respect, random utility models can be considered demand functions in the econometric sense. In fact, choice probabilities can be seen as the mean values of the fractions of a certain market segment (a group of decision-makers with the same characteristics) using each alternative. Also, these fractions are expressed as function of the attributes of the available alternatives. In the context of this interpretation, it is possible to extend to random utility models the microeconomic concepts of direct and cross elasticities of demand functions with respect to infinitesimal or discrete variations of the variables in the utility function.

Direct elasticity is defined as the percentage variation of the demand for a certain commodity (in this case, of the choice probability of alternative j) divided by the percentage variation of a variable (attribute) relative to the same commodity $X_{kj}$:

$$E_{kj}^\theta = \frac{\Delta p_{ij}}{p_{ij}} \frac{\Delta X_{kj}}{X_{kj}}$$  \hspace{1cm} (5)

Analogously, cross elasticity is defined as the percentage variation of the demand for a certain commodity $j$ divided by the percentage variation of a variable $k$ relative to another commodity $h$, $X_{kj}$.
$$E_{r}^{\beta_{j}} = \frac{\Delta P_{j}}{\Delta X_{i}} \frac{\Delta Y_{j}}{X_{i}}$$ (6)

In the above definitions, the variations of attributes and demand are assumed to be finite. In this case, we speak of arc elasticity, which is calculated as the ratio of incremental ratios over an "arc" of the demand curve. Point elasticities are defined for infinitesimal variations and can be expressed analytically (Cascetta, 2001).

In the context of this research, a comparison between the residential location choice elasticities of the model of Naples and of that of Rome, calculated with respect to the generalised travel cost, $Y_{work}$ and housing price, $PRICE$, has been carried out.

The arc direct-elasticity of residential choices with respect to housing price have been calculated, for a given zone $o$, by modifying the price of houses of +10% only in that zone (in the case of the model of Rome just the fixed component $P_{fix}(o)$ has been modified) and by computing the difference of the probability of residing in zone $o$. The arc direct-elasticity of residential choices with respect to the generalised travel cost, for a given zone $o$, has been calculated modifying all the values of $Y_{work}$ from zone $o$ to all the others zones $d$ of the study area of +10%, and then by computing the difference of the probability of residing in zone $o$.

<table>
<thead>
<tr>
<th></th>
<th>$Y_{work}$</th>
<th>$PRICE$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naples</td>
<td>Low/Low-Medium</td>
<td>0.95</td>
</tr>
<tr>
<td>Rome</td>
<td>High-Medium/High</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Table 7: Results of the t-student statistics test for the Commerce and Services location models

As it can be seen from Table 8 the values obtained by the two models are comparable for the generalised cost, not for the price. This is due to the fact that in the model of the city of Rome the price mechanism is explicitly simulated while in the model of the city of Naples housing prices are considered to be fixed with respect to demand of floorspace.

6. Conclusions And Further Research Issues

In this paper two residential and activity location choice models consistent with Random Utility Theory have been presented. The models outlined have been developed and calibrated based on disaggregate (survey) and aggregate (Census) data for two similar case studies: the city of Rome vs. the city of Naples. Model specifications and calibration results are outlined and discussed.

In order to validate the followed behavioural approach a comparison between the models, based on empirical criteria, t-student statistic and elasticity, has been carried out.

The results of such comparison yield interesting considerations and show the way for further research. For the activity location model, calibrated model parameters are highly comparable. As for the residential location choice model, calibrated model parameters are comparable for neighbourhood attributes (e.g. prestige, council houses ratio), while they are not comparable for level-of-service attributes (e.g. logsum) and dwelling unit attributes (e.g. price). The results of elasticities imply: for LOS attributes conversely to parameters are highly comparable, while for dwelling unit attributes (i.e. Price) it requires further analysis.

The authors hope that the comparison proposed will encourage further debate about appropriate forms of integrated land-use/transport models for future works and appropriate calibration methods of such models.

7. Acknowledgements

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