VARIATIONS IN TRAVEL DISTANCE, TRAVEL TIME AND MODAL CHOICE AMONG SMSAs

By Oded Izraeli and Thomas R. McCarthy*

1. INTRODUCTION

Journey to work (JTW) behaviour represents an important dimension of location theory. The location models developed by Alonso (1968), Muth (1969) and others assumed that commuters travel to work sites in the central business district (CBD) of a monocentric city built on a featureless plain. Households choose their optimal location on the traditional basis of utility maximisation subject to a budget constraint. The fundamental trade-off faced by these households is between relatively cheaper land at the city's periphery and the lower transport costs that would result from locating closer to the CBD (where land is, of course, more expensive). Under the assumptions of these models, then, the location decisions of households can be measured by one parameter, distance from the CBD.

In this study, we adopt this basic framework of location theory to investigate not only the important travel distance parameter of JTW behaviour, but also travel time. In particular, we analyse how JTW behaviour, as measured by travel time and travel distance, is affected by a change in city size (as measured by population).

Under the assumption of a monocentric city, the effect of an increase in the population of the city on average travel distance would depend upon the elasticity of the supply of urban land ($E_L$). Excluding the extreme case in which $E_L$ equals zero (for example, an island which totally constrains urban expansion), the increase in population would result in an increase in the average distance travelled to the CBD. This, plus any increased congestion from upward expansion as urban land is used more intensively, would (other things being equal) produce higher average travel time.

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1 The importance of the travel time variable can be seen from the verdict of Gruen (1980), p. 269: "The main finding of this study is that travel time elasticity is substantially greater than the price elasticity".
At some point, one would predict that the development of new centres or subcentres would become attractive. As the city grows in size, businesses are able to realise sufficient agglomeration economies at sites other than the CBD. For households located in cities which are at least of some threshold size to spawn subcentres, travel time would be likely to fall. Thus the conclusion that average SMSA travel time rises with increases in city size becomes questionable if we allow for the development of a multicentre city. Once beyond some threshold city size, we would expect a weaker effect (if any) of city size on JTW behaviour.\(^2\) Finally, it is possible that, beyond this threshold city size, further increases in city size "crowd" not only the CBD but also the sub-centres. Thus a positive and significant relationship between city size and travel distance or travel time might emerge again for cities of very large populations.\(^3\)

Another aspect of JTW behaviour which is investigated in this study is the effect of city size on the means of transport used. Obviously, this decision involves the relative costs of the available transport options. Cost becomes more important because of the energy crisis of the early seventies and the more recent decline in real prices of energy. Therefore this study examines the choice of means of transport, especially mass transit and carpooling.

The next section (section II) discusses the theoretical framework of the monocentric model of urban location as the basis for the empirical analysis which follows in section III. Section II also includes a summary of the hypothesis implied by the monocentric model: section III examines the empirical results to determine the consistency of the data with these hypotheses. Finally, section IV discusses the conclusions and policy implications.

II THEORETICAL FRAMEWORK

The monocentric model

The theoretical framework for our empirical analysis is the monocentric model as developed by Alonso (1968), Muth (1969), and others. In these models, transport costs enter (through the budget constraint) as \(T(k)\) in Alonso’s model and \(T(k, Y)\) in Muth’s model (where \(T\) is transport cost, \(k\) is distance from the CBD, and \(Y\) is income). Both models characterise the household’s decision on location primarily in terms of distance from the CBD. Muth’s inclusion of the income variable modifies Alonso’s model to recognise the opportunity cost of travel time as a part of transport cost. This indirect effect, however, does not fully capture all the effects

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\(^2\) One cannot predict with certainty the effect on travel distance since, even without relocation, the new subcentre might now be closer to the household than the former work site in the CBD. Alternatively, the lower congestion which follows the development of the subcentre may increase travel speed sufficiently to encourage more distant household locations. These empirical questions are explored below.

\(^3\) Even with a high elasticity of supply of urban land, the possible development of additional subcentres is realistically limited by the economic linkage these subcentres share with the original CBD.
of travel time differences. Travel time differences can also affect household location decisions directly through differences in congestion. Muth implicitly assumes that congestion is constant across and between cities, or, more precisely, that the speed of travel is the same for all commuters, no matter what the size of their city or their location in a given city. It is not only possible but highly probable that, in two cities of different sizes, the time necessary to drive a given distance is significantly different because of differences in congestion. Thus, differences in travel time affect location both directly (through congestion differences) and indirectly (through income differences) and become at least as important as distance in determining household location. As differences in congestion are so important conceptually, this paper analyses the effect of city size (as measured by population) on travel time as well as on travel distance.

The Alonso-Muth location model would predict that any increase in a given city's population will cause that city to expand either upward (in taller buildings) or outward, or both. The division between the two directions, up and out, is determined by several factors such as the elasticity of supply of urban land (\(E_L\)) and construction technology and, on the demand side, the income elasticity for housing, the value of time spent on transport, income level and transport facilities (for example, roads, public transport and parking).

The smaller the elasticity of urban land, all other things being equal, the more expansive is the outward expansion of the city by comparison with its upward expansion. An upward expansion would increase density and produce higher congestion. Thus, in the case of low \(E_L\), it is hypothesised that travel distance will be affected very little but that the main effect of an increase in population will be observed as an increase in travel time.

Changes in income have two conflicting effects on location. On the one side, since housing and space are normal (if not luxury) goods, the demand for these goods increases with income. Since the periphery of the city offers land at a relatively lower price, high-income families will be encouraged to move to the periphery and thus expand the city outward. At the same time, a higher income implies a higher opportunity cost of time. Thus total transport costs become higher, and this creates a strong incentive for high-income families to locate centrally so as to minimise commuting time. (Discussion on the relative magnitude of the two effects is beyond the scope of this study. For a more detailed discussion see Muth (1969).) To the extent that the net income effect on location produces an outward expansion of the city, the effect of the income change on the opportunity cost of travel time must be dominated by increase in demand for housing and space. Thus, both travel distance and time would be expected to be positively correlated with income. Between the two travel measures, travel distance is expected to show a much stronger association with income. This is because there are various methods to save on time such as access to expressway, subway or improved traffic control. An increase in travel time which follows an increase in population is also possible because the rising price of land in the CBD makes the opportunity cost of land set aside for transport (streets, parking, etc.) much higher. Thus, if less land is made available for commuting, even greater congestion is created, which further reduces speed and thus travel time.

To sum up the predictions for the monocentric city, it is expected that travel
time and travel distance will be positively affected by the increase in city size. For the extreme cases in which $E_L = 0$, distance would be the same for all different city sizes, while travel time would be expected to rise with city size because congestion would increase and less urban land would be available for transport purposes. If $E_L > 0$, it is expected that increases in city size will also have a positive effect on both travel distance and travel time. The higher is $E_L$, the stronger this effect is expected to be on travel distance.

The monocentric city with subcentres

One way to counter the higher transport costs that are the by-product of an increase in a city’s population is through the creation of new subcentres. Since the subcentres are located much closer (than the CBD) to the residential areas of the people who come to work in them, the creation of subcentres should make the effect of city size on travel time and travel distance much weaker than for the monocentric city.

It is possible that the creation of subcentres is subject to a threshold effect: that is, a subcentre is spawned after the city reaches a certain size (population). The effect of added subcentres is to reduce travel distance, as some commuters no longer travel to a CBD work site. We would also expect average time to fall, since CBD congestion is reduced with the development of the subcentre and since average travel distance has been reduced. While a general positive relationship between city size (population) and distance (or time) would be expected to hold, the slope of the function may be very different; this will depend on the number of subcentres in the SMSA.

For travel distance, as the number of subcentres increases, we might expect the slope of the relationship between population and travel distance to become flatter. This indicates that equal increments of population have relatively smaller effects on travel distance in cities which are decentralised (many subcentres) than in a monocentric city.

This result would contrast with the hypothesised relationship between population and travel time for varying numbers of subcentres. The increase in travel time resulting from a change in city size becomes less steep when it results from the number of subcentres in the city. The difference in the two hypothesised relationships stems from the fact that a city with a greater number of subcentres may be relatively more specialised in the functions and interrelationships of the subcentres with the CBD. Households would thus orient themselves with the CBD or with a particular subcentre, and this would lower the average JTW distance. However, assuming that $E_L$ is increasingly lower as physical constraints increasingly limit the potential area of the city, and assuming that the demand for land at the periphery begins to slacken because of increased geographical isolation from the original CBD as the city grows, we would anticipate that congestion in the CBD and subcentres would increase more and more as the city grows. As the population increases, these limits on the areal expansion of the city imply that the average travel time rises with the increased congestion; this offsets to some degree the reduction in travel time resulting from the emergence of subcentres and the consequent reductions in travel distance. Thus, we would expect the
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(positive) slope of the relationship between travel distance and population to
decrease as the number of subcentres increases, and this reduction in slope would
be relatively greater than any change in the slope of the analogous relationship
between travel time and population. According to the amount of increase in
congestion as the expansion of the city becomes physically constrained and as
subcentres actually disrupt commuting patterns to the CBD, the predictive
positive relationship between travel time and population may become flatter
or steeper or may stay the same.

In summary, the positive relationship between city size (population) and travel
time and travel distance is expected to become weaker as the number of sub-
centres in the SMSA increases. This weakened relationship would be reflected by
a generally flatter-sloped function as city size increases. Further, the relative
flattening in the function relating city size to travel distance should be greater
than the flattening of the function relating city size to travel time, since greater
congestion would offset some of the gains in travel time resulting from the lower
travel distances which follow the rise of subcentres.

Another dimension of JTW behaviour involves the use of public transport. Two
lines of investigation are considered here. First, what is the effect of the avail-
ability and use of mass transit on travel time and travel distance? More specific-
ally, has the availability of mass transit any effect on location decisions? Second,
what variables determine the "modal split" — that is, how do we explain the
variance in the proportion of the commuting public which uses public transit?
Note that, in this study, the proportion of the commuting population using public
transit (PPUB) is defined as the sum of the proportion of mass transit (PMASS)
and carpooling commuters (PCARP).

As can be seen in Table 1, the relative importance of public transport in
American cities is small. Even with our broad definition of the proportion of the
city's population using public transit (PPUB), less than one quarter of the pop-
ulation used public transit in 1975 and only one out of five travellers used public
transit in 1977.4

Mass transit requires areas of high density if the large capital investments
implied by rapid rail facilities are to be justified. Because of the positive relation-
ship between city size and density (see Hoch, 1972), it is expected that city size
will have a positive effect on the relative use of mass transit.

Carpooling is more flexible (given the low scale economies implied) and would
be equally suited to all density levels characteristic of cities. Moreover, the in-
creased congestion which is hypothesised to correspond to increases in population
should imply a stronger positive relationship between city size and carpooling.5

During the last quarter of 1973 and into 1974, the drastic interruption of oil
and gas supplies not only drove up the price of gasoline substantially but also
caused great uncertainty on both the availability and the future price of gasoline.
These changes would be expected to encourage commuters to make better use of

4 This finding is consistent with previous studies on the subject. (See Mills (1980) and Neenan
(1981)).

5 A further stimulus for carpooling as city size increases is the increased parking fees in the
CBD as land prices rise with population growth. SMSA stands for Standard Metropolitan Statis-
tical Area.
<table>
<thead>
<tr>
<th>Variable</th>
<th>1975</th>
<th>1976</th>
<th>1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPUB</td>
<td>23.28</td>
<td>21.52</td>
<td>20.69</td>
</tr>
<tr>
<td></td>
<td>(4.16)</td>
<td>(7.07)</td>
<td>(5.43)</td>
</tr>
<tr>
<td>PMASS</td>
<td>6.62</td>
<td>5.52</td>
<td>5.18</td>
</tr>
<tr>
<td></td>
<td>(4.46)</td>
<td>(8.28)</td>
<td>(4.56)</td>
</tr>
<tr>
<td>PCARP</td>
<td>16.65</td>
<td>15.99</td>
<td>15.50</td>
</tr>
<tr>
<td></td>
<td>(2.83)</td>
<td>(2.88)</td>
<td>(2.04)</td>
</tr>
</tbody>
</table>


mass transit or carpooling as an alternative to the private car. Further, we would expect a gradual centralisation of households as families adjusted to the higher transport costs by locating closer to their job sites (or as employers moved closer to concentrations of labour). The 1973 embargo would be expected to make both mass transit and carpooling more attractive because of (1) the usual substitution and income effects of the gasoline price change and (2) the effect of the higher density (higher residential concentration) that follows increased centralisation. Further, real income fell as a result of the 1974–75 recession, touched off in large part by the supply shock of the oil embargo. This should be matched by a rise in the demand for public transit, as public transit is generally viewed as an inconvenient mode of transport, and thus an inferior good. Consequently, lower real incomes should encourage commuters to shift to public transit as they accept inconvenience for the sake of savings in transport cost.

The general effect on public transport facilities (especially mass transit) on household location is to increase density along the transit routes. As mass transit encourages centralisation by concentrating people around transit lines, we would expect a negative relationship between the proportion of the population using public transport (PPUB) and travel distance. Total travel time, on the other hand, might easily show a positive relationship with PPUB, since actual travel time ("line haul" time for Mills, 1980, p. 145) plus waiting time (Mills's "suburban collection" and "downtown distribution" time) should be higher for mass transit commuters than for private car commuters. Thus, the greater the proportion of commuters using mass transit, the higher the average travel time. This prediction
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would be further reinforced through the density/congestion characteristic of any
city with well developed public transit facilities; that is, the more densely devel-
oped the city, the greater the congestion and thus the lower the speed of all forms
of commuting.

III. EMPIRICAL ANALYSIS

Data sources

A complete list of data sources is given in Table 2. The main source of informa-
tion for this study is the Annual Housing Survey for the years 1975, 1976, and
1977. For each of these years, the Bureau of Census collected detailed data for
twenty different SMSAs through household interviews. Among other variables,
the Annual Housing Surveys present for the first time aggregate (SMSA-wide)
data for heads of households on median travel time, median travel distance, and
means of transport, as well as on distributions for the travel time and travel
distance variables. These distributions are used in the analysis to calculate a
weighted average travel time and a weighted average travel distance. We use
the natural log of these two variables as the principal dependent variables in the
analysis.

The sample size is treated in the empirical analysis as a cross section which
implicitly ignores structural changes occurring during the three-year period
over which the data were collected. This assumption is justified by the high
degree of aggregation (SMSA level) and by the observation that significant
locational changes would be slow to occur, so that possible changes in the
structure of the urban economy are unlikely to create significant empirical
biases. Finally, in case bias due to the temporal inequality of the sample might
be a problem, regression results are presented both with and without dummy
variables to hold the year of observation constant when appropriate (D76 and
D77 in regression tables. D75 is the omitted category).

Empirical results

Travel distance and travel time

To test the hypothesis implied by the monocentric city model that city size has
a strong and positive effect on travel distance (except where $E_L = 0$) and on travel
time, we used a multivariate log-linear regression analysis. The dependent variables
are the log of the weighted means of travel distance and travel time for the total
population of the SMSA. The results of the OLS regressions are reported in
Table 3.

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6 The sample size for the analysis is 61 SMSAs. The only SMSA to be repeated in the sample
is Madison, Wisconsin, which was surveyed in both 1975 and 1977.

7 The weighted averages for travel distance ($TD$) and travel time ($TT$) are based upon the
SMSA-wide frequency distribution(s) of the number of heads of families whose JTW character-
istics fell into a given range of the distribution(s).
### TABLE 2

**List of Variables, Definitions and Sources**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TT(LTT)</strong></td>
<td>Weighted mean travel time for the SMSA. <em>(LTT is the natural log of this variable.)</em></td>
<td><em>Annual Housing Survey</em> 1975-77</td>
</tr>
<tr>
<td><strong>TD(LTD)</strong></td>
<td>Weighted mean travel distance for SMSA. <em>(LTD is the natural log of this variable.)</em></td>
<td><em>Annual Housing Survey</em> 1975-77</td>
</tr>
<tr>
<td><strong>SP</strong></td>
<td>Speed of travel, calculated as <em>TD</em> divided by <em>TT</em> (see below).</td>
<td><em>Annual Housing Survey</em> 1975-77</td>
</tr>
<tr>
<td><strong>POP, (LPOP)</strong></td>
<td>Population (total) of the SMSA. <em>(LPOP is the natural log of this variable.)</em></td>
<td><em>County and City Data Book, 1977</em></td>
</tr>
<tr>
<td><strong>EDUC</strong></td>
<td>Median completed years of schooling of the population in SMSA.</td>
<td><em>Annual Housing Survey</em> 1975-77</td>
</tr>
<tr>
<td><strong>INC, (LINC)</strong></td>
<td>Median family income. <em>(LINC is the natural log of this variable.)</em></td>
<td><em>Annual Housing Survey</em> 1975-77</td>
</tr>
<tr>
<td><strong>PCARP</strong></td>
<td>Percentage of heads of households which carpool to work</td>
<td><em>Annual Housing Survey</em> 1975-77</td>
</tr>
<tr>
<td><strong>PPUB</strong></td>
<td>Percentage of heads of households using public transport (= <em>PMASS + PCARP</em>)</td>
<td><em>Annual Housing Survey</em> 1975-77</td>
</tr>
<tr>
<td><strong>REG</strong></td>
<td>Price of regular gasoline; usually the State average for May of the year during which the respective SMSA was surveyed</td>
<td><em>American Automobile Association Publication</em> 1975-77</td>
</tr>
<tr>
<td><strong>AGE</strong></td>
<td>Weighted mean age of housing stock in SMSA</td>
<td><em>Annual Housing Survey</em> 1975-77</td>
</tr>
<tr>
<td><strong>DENST</strong></td>
<td>Population density: thousands of people per square mile of area of SMSA</td>
<td><em>State and Metropolitan Area Data Book, 1979</em></td>
</tr>
<tr>
<td><strong>TEMP</strong></td>
<td>Mean SMSA temperature for the month of January</td>
<td><em>County and City Data Book, 1977</em></td>
</tr>
<tr>
<td><strong>PI</strong></td>
<td>Percentage of the SMSA population living in the central city</td>
<td><em>County and City Data Book, 1977</em></td>
</tr>
<tr>
<td><strong>D75, D76, D77</strong></td>
<td>Year dummy variables: value of 1 if observation is from the respective year, zero otherwise</td>
<td></td>
</tr>
<tr>
<td><strong>PD1</strong></td>
<td>Population dummy variable for small SMSAs (<em>POP &lt; 625,000</em>)</td>
<td></td>
</tr>
<tr>
<td><strong>PD2</strong></td>
<td>Population dummy variable for medium SMSAs (<em>625,000 &lt; POP &lt; 1,600,000</em>)</td>
<td></td>
</tr>
<tr>
<td><strong>PD3</strong></td>
<td>Population dummy variable for large SMSA (<em>POP &gt; 1,600,000</em>)</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 3

Log-Linear Regression Equations for Travel Distance and Travel Time

<table>
<thead>
<tr>
<th></th>
<th>Log Travel Distance</th>
<th>Log Travel Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>LPOP</strong></td>
<td>0.090*</td>
<td>0.093*</td>
</tr>
<tr>
<td></td>
<td>(0.020)</td>
<td>(0.020)</td>
</tr>
<tr>
<td><strong>DENST</strong></td>
<td>0.034*</td>
<td>0.036*</td>
</tr>
<tr>
<td></td>
<td>(0.019)</td>
<td>(0.019)</td>
</tr>
<tr>
<td><strong>LINC</strong></td>
<td>0.288*</td>
<td>0.361*</td>
</tr>
<tr>
<td></td>
<td>(0.130)</td>
<td>(0.146)</td>
</tr>
<tr>
<td><strong>EDUC</strong></td>
<td>-0.128*</td>
<td>-0.132*</td>
</tr>
<tr>
<td></td>
<td>(0.057)</td>
<td>(0.057)</td>
</tr>
<tr>
<td><strong>AGE</strong></td>
<td>-0.010*</td>
<td>-0.010*</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
<tr>
<td><strong>PPUB</strong></td>
<td>-0.490</td>
<td>-0.597</td>
</tr>
<tr>
<td></td>
<td>(0.368)</td>
<td>(0.382)</td>
</tr>
<tr>
<td><strong>TEMP</strong></td>
<td>-0.0004</td>
<td>-0.001</td>
</tr>
<tr>
<td></td>
<td>(0.0013)</td>
<td>(0.001)</td>
</tr>
<tr>
<td><strong>REG</strong></td>
<td>-0.598</td>
<td>-0.089</td>
</tr>
<tr>
<td></td>
<td>(0.475)</td>
<td>(0.644)</td>
</tr>
<tr>
<td><strong>D76</strong></td>
<td>-0.015</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>(0.033)</td>
<td>(0.033)</td>
</tr>
<tr>
<td><strong>D77</strong></td>
<td>-0.061</td>
<td>-0.065</td>
</tr>
<tr>
<td></td>
<td>(0.049)</td>
<td>(0.038)</td>
</tr>
</tbody>
</table>

*Significant at the 5 per cent level or better (two-tailed test). Standard error in parenthesis.
For a complete list of variables and sources see Table 2.
Columns 1 to 3 in Table 3 present the regression results for travel distance, and columns 4 to 6 for travel time. In general, our set of independent variables explains the variations in travel time much better than the variations in travel distance. The value for the adjusted coefficient of variation, $\bar{R}^2$, in the travel time regressions is about 0.72, while the travel distance equation is about 0.45. As explained earlier, this result would be expected, since travel distance is only one component of travel time. Further, as has been shown by many researchers, households are more aware of the time dimension of the JTW than either the travel distance or the direct money cost.\(^8\)

The performance and interpretation of most of the explanatory variables are generally similar in each set of regressions in terms of the direction and significance of the coefficients. There are only two variables which change signs between the two sets of regressions: the proportion of the population using public transport ($PPUB$) and temperature ($TEMP$). In the travel distance equations $PPUB$ is negative but of only weak significance, but in the travel time regressions $PPUB$ is positive and significant. $TEMP$, on the other hand, never achieves statistical significance. (Each of these results is discussed below.) We now analyse the effect of each of the independent variables on travel distance and travel time.

**City size**

The variable of primary interest is city size as measured by the SMSA population (in log form, $LPOP$). The coefficient of $LPOP$ is always positive and significant. The magnitude of the elasticity of travel distance with respect to population is about 0.09. This means that an increase of 10 per cent in population produces slightly less than a 1 per cent increase in the average length of the work trip. To illustrate by example the size of this response, as we move from an SMSA such as Grand Rapids, Michigan ($POP = 570,000$), to an SMSA such as Atlanta, Georgia ($POP = 1,800,000$) with a population more than three times as great, the average length of the work trip rises by about 19 per cent.\(^9\) As the mean travel distance in Grand Rapids is 9.0 miles, the predicted value for Atlanta would be 10.7 miles. (The actual mean travel distance for Atlanta is 11.4 miles.)

Travel time is increased by 0.8 per cent by a 10 per cent increase in population (see cols. 4, 5 and 6). If we again use the same two SMSAs for the sake of illustration, the additional travel time in Atlanta due to its higher population over that of Grand Rapids is 2.8 minutes, or only a 17.2 per cent increase.\(^{10}\) Let us

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\(^8\) Bish and Nourse (1975, p. 361) sum this up as follows: "Consistent conclusions from attempts to identify cross elasticities of demand among modes with respect to price and travel time are that . . . the effect of changes in travel time is always stronger than effects from changes in price".

\(^9\) This heroically assumes that the estimated elasticity is constant over this wide interval. It is well known that an elasticity is appropriately applied only at the mean; we use this estimate for demonstration purposes only.

\(^{10}\) In fact the difference in travel time between Grand Rapids and Atlanta is much larger than the 2.8 minutes predicted in the text (16.5 minutes for Grand Rapids and 24.2 minutes for Atlanta); but this is due to other variables besides population, the results for which are discussed later.
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divert our investigation to the question whether the slope (elasticity) of travel
distance or travel time is changed over different city sizes.

Our theoretical discussion suggests that the positive relationship between travel
distance or travel time and population should become weaker as city size in-
creases, especially the relationship between travel distance and city size. This
results from the predicted development of subcentres within the SMSA. That is,
the larger the city, the greater the likelihood that a subcentre or multiple sub-
centres will be spawned.\textsuperscript{11} We would therefore expect that the coefficients on
the population variable in our regression analyses would be smaller for a sub-
sample of large SMSAs than for a group of medium or small SMSAs (especially
for travel distance).

To deal with this question, we divided our sample into three groups based on
differences in population.\textsuperscript{12} Group I contains all SMSAs with a population less
than or equal to 625,000. Group II contains all SMSAs with a population greater
than 625,000 but less than or equal to 1,600,000. Group III includes SMSAs with
populations greater than 1,600,000. The empirical test of the above hypothesis
has used the dummy variable test for both the interrupt and the slope (see Dutta,
1975, pages 172–8). The regression estimation is:

\[
\begin{align*}
\text{LTD} &= 1.982 - 0.569PD1 - 0.524PD2 + 0.050LPOP + 0.080LPOP_1 + 0.069LPOP_2 \\
&= (0.716) (0.776) (0.053) (0.109) (0.107) \\
R^2 &= 0.28 \\
\text{SSR} &= 0.71861
\end{align*}
\]

\[
\begin{align*}
\text{LTT} &= 1.968 + 0.936PD1 + 0.619PD2 + 0.153LPOP - 0.154LPOP_1 - 0.094LPOP_2 \\
&= (0.658) (0.713) (0.049) (0.100) (0.098) \\
R^2 &= 0.57 \\
\text{SSR} &= 0.60671
\end{align*}
\]

These equations can be interpreted as follows:

For the sample of small SMSAs (\(PD1 = 1\))

\[
\begin{align*}
\text{LTD} &= 1.413 + 0.130LPOP \\
\text{LTT} &= 2.904 - 0.001LPOP
\end{align*}
\]

For the sample of medium SMSAs (\(PD2 = 1\))

\[
\begin{align*}
\text{LTD} &= 1.458 + 0.119LPOP \\
\text{LTT} &= 2.587 + 0.059LPOP
\end{align*}
\]

\textsuperscript{11} Because we have no objective measure of the number of subcentres in each SMSA in our
sample, we assume that the number of subcentres is positively correlated to population (city
size) and thus captured through \(POP\) in the regression analysis.

\textsuperscript{12} The somewhat arbitrary divisions were based upon two considerations: first, after ranking
the 61 SMSAs by population, we chose to make the breaks at those points where the per-
centage increase in population was largest along the spectrum of city sizes. This choice was subject
to a second consideration, that of choosing roughly equal sample sizes for the three sub-
categories. Surprisingly, there was little trade-off necessary between these considerations. The
only large percentage change that was not used would have separated the largest 5 SMSAs from
the rest of the sample. Obviously, that sample size would be too small. The resulting subsample
sizes are somewhat uneven and the estimates are statistically weak for the smallest group
(\(n = 16\)) in particular; but the breakpoints in the larger sample were based on obvious gaps in
the population distribution. A perfect evening out of the sample sizes would have been too arti-
fi.cial.
For the sample of large SMSAs ($PD3 = 1$)

\[
LTD = 1.982 + 0.050 \, LPOP
\]  

(7)

\[
LTT = 1.968 + 0.153 \, LPOP
\]  

(8)

As can be seen from the above results, there are obvious differences between the three groups in spite of their weak statistical quality. Figures 1 and 2 illustrate these differences.

In Figure 1, the positive (though often statistically insignificant) trend of travel distance with respect to increases in population becomes weaker as we move from group I (S) to group III (L). In contrast, the travel time results show the opposite trend. The interpretation of these results is that relatively small SMSAs accommodate an increase in population by spreading the area of the city to the relatively close, inexpensive land at the periphery. Thus travel distance may increase (as shown by the positive coefficient of the population variable in equation 3), but travel time remains roughly the same (or perhaps even falls slightly). This is because the increase in congestion may be minimised by the opportunity to develop road systems of at least the minimum efficient scale to handle the increase in traffic; or perhaps a population threshold is reached at which subcentres develop.\(^{13}\)

This relationship changes with the size of the city. As we move to groups II (medium) and III (large SMSAs), the population coefficient for travel distance falls, and for travel time the coefficient increases and becomes positive. Group III has the smallest increase in travel distance for a 1 per cent increase in population (with a coefficient of 0.050), but the greatest increase in travel time for a 1 per cent increase in population (elasticity equal to 0.153). This result tends to support the hypothesis presented in the theoretical section that large SMSAs are increasingly constrained in the expansion of their land areas by supply constraints (rivers, mountains, etc.) as well as demand constraints (low demand for land at the periphery due to isolation from the economic centre of the city, the CBD). Further, the greater number of subcentres associated with large SMSAs helps to accommodate increases in populations. Thus travel distance is only modestly affected (low coefficient, weak statistical significance). Travel time on the other hand begins to increase more dramatically in the large SMSAs, since little new land is available for more subcentres or improved transport networks, and therefore the density of population and development increases to produce slower commuting (that is, \(E_L\) is low for large cities).\(^{14}\) Further, the increase in population density allows a greater proportion of the population to shift to mass transit. We test this hypothesis later in this section. The higher waiting

\(^{13}\) The interpretation of the results here is highly speculative, since most of the estimated coefficients are statistically insignificant.

\(^{14}\) In moving from group I to group III, the creation of new subcentres implied by population growth seems to have much more success in keeping average travel distance from growing as fast as average travel time. This is possibly the result of a diseconomy of scale in the supply of transport facilities produced by the division of SMSAs into many subcentres instead of one centrally located CBD. On average, the increase in the actual mean of travel distance between group I and group III SMSAs is 19.2%, while the increase in the actual mean of travel time is 42.2%.
times implied by that modal choice would contribute to higher travel times overall in large cities.

Density
The density variable (DENST) is defined as total population per square mile for the SMSA. DENST might be expected to be highly correlated with city size (see for instance Hoch, 1972), but only minor collinearity problems are evidenced by the results presented in Table 3. DENST clearly adds independent information in explaining our JTW measures. As predicted, the coefficient of DENST is positive and significant in all the regressions. For travel distance, the positive result indicates that people find the disadvantages of “crowding up” (higher crime rates, more noise, dirt, congestion) to outweigh the advantages (economies of scale in construction, shorter travel distances), and therefore move outward. Given that  \( E_L \) is greater than zero, this means that the new population causes the city to “spill out” towards its periphery, as both the monocentric model and the sub-centre model would predict.

For the travel time results, the positive coefficient reflects two basic forces. First, since higher densities encourage households to live further away from their places of work, the added distance itself increases travel time. Second, the positive association between density and congestion might lead to a reduction in the speed of travel: thus travel time could rise because of worsening traffic. Alternatively, if locating further from the job site allows the worker to travel on better roads or forces him/her to drive instead of using the more time-intensive alternative of mass transit, travel speed might even increase in spite of the increase in congestion due to higher densities. In such a case, travel time would not increase by more than an amount implied by the greater travel distance. The elasticities of travel distance and travel time with respect to density implied by our results are about 0.29 and 0.24 respectively. (No statistically significant difference is manifested.) Thus, it seems that the changes in travel time substantially reflect changes in travel distance.

Income
The income variable (in its log form, LINC) is defined as median household income for the SMSA. Economic theory suggests that the effect of income on travel time and distance is likely to be complicated. Since the amount a worker can earn as income reflects the opportunity cost of that worker’s time, it is expected that the worker will try to cut the time spent in commuting as his/her income increases.\(^{15}\) At the same time, however, a rise in income encourages most households to increase their consumption of housing in general and of “space” or land in particular. Thus, households with rising incomes may tend to buy bigger houses at locations more distant from the job site (as land is cheaper outside the CBD). The net effect of a change in income on both time and distance is difficult.

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\(^{15}\) Shorter travel times need not imply shorter travel distances. Differences in mode of transport and in road quality and conditions might mean that a longer trip from one household location might be made in less time than a shorter trip from another. Still, most locations with increased travel distances are likely to produce higher travel times.
FIGURE 1

Travel Distance and City Size
FIGURE 2

Travel Time and City Size
to predict, as these two effects suggest opposite responses. The higher opportunity cost of commuting time suggests closer, "quicker" locations, while the increased demand for housing and space suggests more distant locations with higher travel times.

The empirical analysis shows that, for the average household, the second effect, (larger houses, more land) is stronger than the incentive to minimise travel time. The coefficient of LINC is always positive and significant for all Table 2 regressions. Further, the elasticities are generally comparable; this indicates that changes in travel time attributable to changes in income are proportionate, and generally seem to reflect the changes in travel distance which follow changes in income.

**Education**

The education variable, EDUC, measures the mean number of completed years of formal education for the SMSA population. As a standardising variable, education is expected to reflect two general attributes of the population. First, the more educated the population, the more efficient will be the exchange of and response to information. For instance, with the dramatic rise in fuel prices that followed the 1973 oil crisis, we would expect households to adjust, perhaps by buying more fuel-efficient cars or relocating closer to the job site. Thus, the more educated the population, the quicker the response is expected to be to changes in the urban environment. The empirical results do indicate that EDUC has a negative and significant effect on both travel time and travel distance, thus confirming our hypothesis. Since the oil crisis, the more informed have apparently acted to save on transport cost by reducing travel time and travel distance.

The second characteristic which may be reflected through the EDUC variable is the occupational mix of the city's population. More educated populations contain relatively larger numbers of professional workers, whose employers may be relatively more flexible with respect to employment location. Thus, besides being more informed shoppers when buying or renting housing, the relatively more educated populations may have more convenient job sites. The negative coefficient for EDUC may in part reflect this accommodation by employers toward white collar workers.

**Age of the housing stock**

The weighted average age of the housing stock of the SMSA (AGE) was calculated from an age distribution of housing stock presented in the Annual Housing Survey(s) of the U. S. Bureau of the Census. The AGE measure is intended to capture differences in urban structure, particularly the "inertia" or history of the SMSA. In older cities the transaction costs associated with adjusting to changing economic conditions are relatively greater than the newer cities which have an infrastructure better designed to accommodate the automobile. Thus the increased congestion resulting from population growth may be more severe in older SMSAs, since these "established" cities adjust to newer transport technologies more slowly or less efficiently. Further, the age of the housing stock should reflect the higher degree of centralisation found as an accident of history in older cities.

The AGE variable enters negatively in all regressions; but an acceptable level
of statistical significance is reached only for the results on travel distance. Age is not significant in the travel time regressions. The travel distance estimates reflect strongly the hypothesised centralisation and inertia of older cities; the weakness of the travel time results is probably due to the higher congestion and consequent slower speeds that are associated with their crowded, inefficient highway systems. Thus, the time-saving effect of shorter average travel distances is countered by lower speeds.

Public transport
The percentage of the population which uses public transport, PPUB, enters the travel distance regressions negatively but insignificantly, at a level of (5 per cent). This probably reflects the fact that public transport is most efficient and most available in densely populated areas. The failure of PPUB to become significant is in part due to the (appropriate) inclusion of the DENST and AGE variables, which already account for this effect.

The results are quite different in the travel time regressions. Here, PPUB enters positively and significantly. This result reflects the slower speeds of public transport.16

Temperature and the price of gasoline
These two variables are related only in their failure to show any significant effect on either travel time or travel distance. For temperature (TEMP) it was expected that a bad climate (which is defined here as a low mean temperature during the month of January) would encourage centralisation, since people might prefer to drive shorter distances, but increase travel time, as driving speed in wintry conditions would be lower. However, neither result is manifested in Table 3. In fact the signs are the opposite to our expectation.

The price of gasoline (REG) variable enters most regressions with the expected negative sign but at an insignificant level.

One problem which arises in the measurement of the REG variable is that no local deflators are available for all (or even most) of the SMSAs in our sample. Consequently, REG is not a measure of real gasoline prices. A further problem is that a true centralisation process which might follow such a dramatic increase in transport costs would be likely to take several years. Thus, the 1975–77 observations in our sample are too close to the supply shock to which households are expected to adjust.

The year dummy variables, D76 and D77
The inclusion of year dummy variables should correct for the fact that our sample is a mixture of time series and cross-section observations. The coefficients of D76 and D77 are always negative. For the travel distance equations the coefficient of

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16 The reader is reminded that PPUB is the sum of the proportion of the population which uses mass transit (buses and rapid rail), PMASS, and the proportion which commutes via carpools, PCARP. Since all these conveyances involve greater time costs for collecting and distributing riders in addition to the time costs of travelling a given distance, travel time overall is likely to be higher (as the results confirm).
the variable $D76$ is insignificant, whereas $D77$ shows only a weak statistical significance for a two-tailed test (that is, $t = 1.24$ in column 2 and 1.71 in column 3). The increased magnitude and significance of the year dummy coefficients suggests that there may be a slow trend toward centralisation in response to higher energy prices. In the travel time regressions only the coefficients of the variable $D76$ are significant. The coefficients are also negative, suggesting that there is a centralising trend, even though a very slow one.

The choice of means of transport

As was shown in Table 1, public transport is used by a small and apparently decreasing number of commuters. In 1975 an estimated 23.3 per cent of all households used some form of public transport (either carpooling, 16.7 per cent, or mass transit, 6.6 per cent). By 1977 this proportion had dropped to 20.7 per cent (15.5 per cent carpooling and 5.2 per cent mass transit). The purpose of this section is to examine briefly the household choice of mode of transport.

Theory suggests that commuters will assess the relative prices of different transport options and choose that option which is cheapest in terms of dollars, time, and other associated disutilities (such as crowding on a bus or subway, or the frustration of traffic jams when commuting by car). Further, these relative prices will in part be determined by the relative efficiency of each mode of transport. For example, the large economies of scale associated with rapid rail transit imply that both the average and the marginal cost of a given trip will be lower if the ridership is large. (Thus, fares and the relative price of rapid rail will be attractive.) Clearly, this productive efficiency must in turn depend upon the structure of the city. A truly monocentric city would favour the development of an efficient, low-cost rapid rail system, since both the density of households and the density of job sites allow for the easy collection and distribution of workers. In contrast, the monocentric city discourages automobile commuting, since travel times would be high in the relatively congested CBD. Also the auto commuter would face higher parking fees, because the price of land is higher in the monocentric city.

On the other extreme, an SMSA with many subcentres may produce the opposite relative prices for modal choice. The decentralisation of jobs and people makes rapid rail inefficient and therefore costly, while the spreading out of the SMSA through its subcentres may make access by automobile convenient and efficient. Thus, urban structure should play a significant role in determining modal choice.

In order to examine these hypotheses empirically we performed multiple regression analysis, using three alternative measures of modal choice as dependent variables. The first dependent variable specification is $PPUB$, the percentage of working households in the SMSA using public transport, which is broadly defined to include carpooling and mass transit commuting. The second and third specifications break $PPUB$ into its components; that is, we use $PCARP$, the percentage of SMSA commuters using carpools, and $PMASS$, the percentage of SMSA commuters using mass transit (bus and/or rail), as dependent variables. Table 4 presents the results for all three specifications.
### Table 4

**Regression Equations for Means of Transport Choice**

<table>
<thead>
<tr>
<th></th>
<th>( PPUB ) (1)</th>
<th>( PCARP ) (2)</th>
<th>( PMASS ) (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( POP )</td>
<td>-0.000004 (0.000006)</td>
<td>-0.000006* (0.000003)</td>
<td>0.000010* (0.000003)</td>
</tr>
<tr>
<td>( SP )</td>
<td>-0.471* (0.097)</td>
<td>-0.150* (0.078)</td>
<td>-0.319* (0.090)</td>
</tr>
<tr>
<td>( AGE )</td>
<td>0.001 (0.001)</td>
<td>-0.001 (0.001)</td>
<td>0.0017 (0.0010)</td>
</tr>
<tr>
<td>( DENST )</td>
<td>0.021* (0.006)</td>
<td>-0.003 (0.004)</td>
<td>0.024* (0.005)</td>
</tr>
<tr>
<td>( EDUC )</td>
<td>0.026 (0.017)</td>
<td>-0.010 (0.013)</td>
<td>0.035* (0.015)</td>
</tr>
<tr>
<td>( PI )</td>
<td>-0.030 (0.024)</td>
<td>-0.022 (0.020)</td>
<td>-0.008 (0.022)</td>
</tr>
<tr>
<td>( INC )</td>
<td>0.001 (0.003)</td>
<td>0.0037 (0.0024)</td>
<td>-0.002 (0.003)</td>
</tr>
<tr>
<td>( REG )</td>
<td>-0.057 (0.199)</td>
<td>-0.056 (0.153)</td>
<td>†</td>
</tr>
<tr>
<td>( TEMP )</td>
<td>0.0005 (0.0004)</td>
<td>†</td>
<td>0.0004 (0.0004)</td>
</tr>
<tr>
<td>( D76 )</td>
<td>† (0.014)</td>
<td>-0.004 (0.008)</td>
<td>0.003 (0.009)</td>
</tr>
<tr>
<td>( D77 )</td>
<td>-0.023 (0.014)</td>
<td>-0.015 (0.012)</td>
<td>-0.008 (0.010)</td>
</tr>
</tbody>
</table>

\( CON \): 0.097 \( 0.395 \) -0.296
\( R^2 \): 0.71 \( 0.16 \) 0.80
\( S.E.E. \): 0.031 \( 0.024 \) 0.027
\( N \): 61 \( 61 \) 61

*Significant at the 5 per cent level or better (two-tailed test). Standard errors are in parentheses.
†The coefficient was so insignificant that regression package did not load it.
For definition of the variables and data sources see Table 2.
The estimates in Table 4 indicate that the choice to use carpool is poorly explained by the independent variables \( R^2 = 0.16 \), while the choice to use mass transit is reasonably well explained by these variables \( R^2 = 0.80 \). Further, the overall PPUB equation estimated in column 1 seems to reflect most closely the results estimated for PMASS in column 3. A general result then is that the split between private auto and public transport is not the only modal choice of interest. Once a choice in favour of public transport has been made, there is still the separate decision which form to adopt, carpooling or mass transit. Since the Table 4 results suggest that these are very different choices, we will focus here on columns 2 and 3 to highlight the differences.

The first important difference relates to city size. As can be seen for the population variable (POP), the decision to carpool is more likely in small cities as opposed to large SMSAs. This is consistent with the hypothesis that economies of scale in mass transit must be exploited to make mass transit cheap and available. Thus, a threshold effect is reflected by the positive sign on POP in column 3. For carpooling, the bigger cities produce more congestion and, as a result, raise the price of carpooling in comparison with mass transit.

In all three regressions, travel speed (SP) enters negatively. This is the expected result, since a more efficient flow of traffic indicates lower time costs, either because the road system is better or because travel distances have been made shorter by the development of subcentres. In either case, the relative price of commuting by private car is lower, so commuters shift away from all forms of public transit, especially mass transit with its many attendant inconveniences. (The negative coefficient of the speed variable in the PMASS regression is twice as strong as that in the PCARP regression.)

The mean age of the housing stock variable, AGE, produces opposite signs in the PCARP regression and the PMASS regression. Though neither is significant at the 5 per cent level for a two-tailed test, the positive coefficient on AGE satisfies the 5 per cent level of significance for a one-tailed test (which is appropriate when the sign of the coefficient is predicted a priori). As expected, the older, more centralised cities are better structured to produce mass transit efficiently, and they probably discourage commuting by private auto, as congestion in the CBDs of these older cities raises the relative price of both private cars and carpools. (Hence the negative sign in column 2.) Thus, urban structure does affect modal choices in transport.

Another interesting contrast between the choice to carpool and the mass transit choice is reflected by the estimates of the population density coefficients (DENST). As predicted for PMASS, more densely structured cities will encourage the development of efficient mass transit. This prediction is supported by the empirical analysis. The opposite would be true for carpooling, as congestion rises with density. The estimate is insignificant, but a sign reversal on the DENST coefficient lends weak support to this expectation. Once again, urban structure affects the choice of transport mode.

The education variable (EDUC) provides still another contrasting result. In the PMASS regression, EDUC enters as positive and significant, while an insignificant but negative coefficient is estimated for PCARP. The EDUC variable is most likely capturing differences in the occupational mixes between cities. That is,
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SMSAs with a more educated population are probably characterised by a strong CBD with a higher proportion of professional workers whose job site is in the CBD. In contrast, SMSAs with relatively larger blue-collar populations may be better characterised by industrial subcentres in the outskirts. If this tendency holds, the more educated SMSA populations will be correlated with an urban structure conducive to efficient mass transit. Hence, the result is a positive and significant sign for the EDUC variable in the PMASS regression but a negative though insignificant sign in the PCARP estimate.

For several variables the coefficient was insignificant. Among these we found the percentage of the SMSA population living in the central city (PI), the household income (INC), the price of regular gasoline (REG), the climate variable (TEMP) and the year dummy variables D76 and D77.

IV. SUMMARY

The analysis has shown that the mean SMSA travel distance and travel time of urban commuters are positively and significantly influenced by city size. This result is consistent with predictions made by the monocentric model of urban development, especially as modified to recognise the development of subcentres of urban economic activity. The lesson for urban economists is that household location models based on a single distance parameter must hold the speed of urban travel constant if the implicit conceptual equality between travel time and travel distance assumed by these models is to be attained. This is especially important because households seem to regard travel time with greater sensitivity than travel distance when choosing a location.17 Other variables shown to influence journey to work behaviour significantly are population density, income, education, age of housing stock, and percentage of the population riding public transit. Finally, a weak trend toward centralisation was identified on the basis of the negative and sometimes significant “year” dummy variables in the travel time and travel distance regressions.

The regressions for household choice of means of transport produced widely differing results between the factors influencing mass transit ridership and those affecting the decision to carpool. The picture which emerges suggests (as might be expected) that mass transit is the choice of those in larger, older, and more densely settled urban areas, while carpooling is more appropriate to smaller urban areas.

These regressions in particular show that the modal choice for commuters is strongly affected by the structure of the SMSA (age, density and size). Further, a very important factor in the shift to public transit is the speed of urban travel, which, when slow, tends to encourage both carpooling and mass transit ridership. The price of gasoline did not perform well and does not contribute to an explanation of modal choice, probably because of its poor specifications as a variable (statewide data and no use of a deflator).

17 See footnotes 1 and 8.
REFERENCES


