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Re-evaluating the impact of urban form on travel patterns in Europe and North-America

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Abstract

The work by Newman, Kenworthy and colleagues on the link between land use, transportation systems and travel patterns and energy use has been received enthusiastically but also criticised strongly. In this paper concerns are expressed about the role accorded to individual travellers and the wider space-time context of cities in the empirical-analytical work by Kenworthy and colleagues. To investigate the seriousness of these concerns, the data collected by Kenworthy and colleagues for European, Canadian and US cities in 1990 have been augmented with information on housing, urban development history and the sociodemographic situation. Regression models are described in which the role of urban form is investigated while account is taken of other relevant factors. The empirical analysis suggests that the space-time context of cities should be taken into account in aggregate-level comparisons of the relations between urban form and transport. Policy recommendations based on the original data may be reconsidered and tailored to the space-time context and population characteristics of cities.

1. Introduction

While numerous researchers have concluded that characteristics of the built environment—commonly referred to as urban form—affect travel behaviour, the debate about the influence of urban form on travel behaviour continues, evolving around questions such as: which aspects of urban form are most relevant to travel behaviour? And how important are built-environment characteristics vis-à-vis other factors known to affect the amount of travel? From a policy perspective, the disagreement and confusion about the relevance of urban form is unfortunate, as it creates uncertainty among policymakers about what strategy to pursue when attempting to make travel patterns more sustainable. Further examination of the link between urban form and travel patterns is therefore warranted, as well as re-examination of previous research about this topic.

An important contribution to the literature about the impact of urban form is the work of Newman and Kenworthy (1989a,b) about land use and travel in 32 major cities in Europe, North-America, Australia and Asia. Their graph about the inverse relationship of population density and energy use for transport has become world famous, and the plea for transit investments and re-urbanisation—concentrating development in the higher-density inner areas and along rail corridors within the metropolitan area—found much response among policymakers in Europe and the USA.

The groundbreaking and influential work by Kenworthy and colleagues has nonetheless been criticized, principally along two lines:

(i) *The theoretical and methodological foundations of the study*. Key objections refer to the omission of other variables known to affect the amount of travel, such as fuel prices, the economic situation, demographic structure, etc.; the neglect of multivariate analysis; and the comparison of cities across the world without adequately accounting for their wider institutional context (Gomez-Ibanez, 1991; Gordon and Richardson, 1989; Mindali et al., 2004; Schwanen, 2002).
(ii) *The policy recommendations*. These have been debated vigorously, resulting in various polemics against and in favour of the ideas of compactness (e.g. Ewing, 1997; Gordon and Richardson, 1989; 1997). Mindali et al. (2004) note that the discussion has evolved around two

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central themes: the potency to increase the role of public transport and walking/bicycling in travel patterns; and households' willingness to reside in higher-density environments.

In 1999 Kenworthy and colleagues offered an update of the original work, in which they presented various extensions of and improvements like the addition of new cities to the data base and the inclusion of a number of indicators on the urban economy (Kenworthy et al., 1999; Newman and Kenworthy, 1999). They continued to consider population density the key driver of the amount of travel in a given city. Hence, their policy recommendations have remained more or less the same, although it was stressed that re-urbanization efforts should be implemented in tandem with pricing measures (Newman and Kenworthy, 1999; 2000; see also Newman et al., 1995). More recently, Cameron et al. (2003, 2004) have provided a multivariate analysis of the relations between travel indicators, the economic situation, population and employment size and metropolitan density.

It thus appears that most criticisms on the earlier work have been taken into account in one way or another. Yet, we believe that there is room for further improvement. More specifically, we think that Kenworthy and colleagues in their empirical-analytical work pay insufficient attention to individual travellers and to the influence of the space-time context mitigating the relations between land use and transport. Although we applaud their efforts and intentions to reduce automobile dependence, we wonder whether land use characteristics, such as density and the centrality of employment and housing, are as important as Kenworthy and colleagues have found in their analyses. Of course, other commentators have made these claims too. Yet, in contrast to earlier critiques, we have extended the Kenworthy et al. analysis of the correlations between land use and travel by accounting for the impact of socio-demographic structure, housing structure, and urban development history in an attempt to assess the relative importance of urban form vis-à-vis other characteristics. In addition, we seek to investigate to what extent the relations between travel indicators and urban form vary between Europe, Canada and the USA.

In the following section we detail our criticisms of the research by Kenworthy and associates, on the basis of which we have set up our own analysis. Section 3 describes the data and procedures followed in the analysis, while Sections 4 and 5 summarize the main results. The paper ends with a conclusion and a brief discussion of some implications for the land use and transport policies advocated by Newman, Kenworthy, their colleagues and others.

2. Study motivation

Stimulated by other researchers' criticisms, Newman, Kenworthy and colleagues have continuously sought to improve and extend their research since the late 1980s, which has resulted in an impressive body of work about the relations between land use and transportation. We do feel, however, that they could have heeded more directly the criticism that travel patterns in a city are the outcome, as well as a context for, individuals' decisions with respect to housing, employment, household reproduction and leisure in their empirical-analytical work. Where individuals and households could have been accorded a more central place, Kenworthy et al. (1999) instead concentrate on the macro level of systems (see also Newman and Kenworthy, 1999). In some—though certainly not in all—of their publications (Kenworthy et al., 1999; Cameron et al., 2003; 2004), they even go so far as to conceive of cities as organisms behaving according to pretty fixed principles:

'The data [...] in fact illustrate some very systematic and reliable relationships between the various physical planning characteristics of cities which we might term a 'science of cities' [...]. However, in another sense, one might also call it a 'biology of cities' since the analyses [...] suggest that certain unwritten rules seem to be followed with regard to the 'organism of the city', how it functions in transportation and land use terms and how it responds to different policy stimuli, in much the same way that organisms work within certain fairly fixed biological rules.' (Kenworthy et al., 1999: 642)

If this were their view of how cities develop, we would reject it. There may be (strong) correlations between transportation indicators and urban form on the city level, but these do not necessarily reflect causal mechanisms. For causality to be revealed, the micro level of individuals and their households should be considered, ideally in a longitudinal perspective. This criticism is nothing new, as the vast number of studies on the links between travel behaviour and land use have shown. If an individual-level perspective is adopted and socio-demographic factors like gender, income and household structure are taken into account, the magnitude of the influence of land use on travel behaviour tends to be reduced substantially (e.g. Snellen et al., 2002; Stead, 2001). More advanced studies have raised even more doubts about the causality of the relations between land use and travel behaviour. From an individual choice-oriented perspective, it has been argued that attitudes towards travel and land use have to be taken into account and that observed correlations between travel and land use may reflect residential self-selection processes (Kitamura et al., 1997; Schwanen and Mokhtarian, 2005a,b). Geographers drawing on Hägerstrand's constraint-oriented time-geography have also questioned whether compact urban development can result in more sustainable travel patterns. They argue that higher densities and mixed land use by themselves are not enough to make travel more sustainable. The space-time co-ordination of employment, child-care and residential requirements in complex households should be put at the heart of investigations of the relations between land use and travel (Jarvis, 2003; Weber and Kwan, 2003). The point to be made here is that the effects of density and centralization of housing and employment on travel behaviour are reduced, as the conceptualisation of individuals' behaviour becomes more advanced.

Work by geographers and sociologists also emphasizes that relations are contextual and contingent upon local and regional conditions (e.g. Hägerstrand, 1982; Thrift, 1996; Law, 2004). Among other things, this means that a city's development trajectory through time is unique, and that this trajectory together with cultural and institutional factors at a variety of spatial scales—for instance the metropolitan and national level—should be considered when seeking to understand its current situation. Such contextual thinking raises concerns about the usefulness of highly abstracted comparisons of cities in different parts of the world (see also Mindali et al., 2004). While such comparisons may produce appealing statistical outcomes, they raise questions about the comparability of cities as different from one another as Stockholm and Edmonton or San Diego and Amsterdam. We should add that Newman and Kenworthy in their 1999 book do a better job of taking account of cities' space-time context, for instance with their efforts to incorporate elements from postmodernism in their planning approach and their call for localised, grassroots-oriented planning efforts to make cities more sustainable (Newman and Kenworthy, 1999, Chapter 6). One could argue that it is a missed opportunity that they did not extend these attempts to their empirical-analytical work.

Our concerns about the otherwise commendable project by Newman, Kenworthy and colleagues are more than analytical play, for they may have consequences for the policy implications to be drawn from their empirical work. On the positive side, if the link between urban form and travel at the metropolitan level does not reflect (direct) causality and if cities are not really comparable without reckoning for their cultural, historical and institutional context, one wonders whether a single overarching model or vision for the future sustainable city (Newman and Kenworthy, 1999; 2000) is fully instrumental in reducing automobile dependence. Perhaps explicit tailoring of the vision to groups of cities facing broadly comparable contextual conditions makes it more useful in practice. Yet, there is also a more pessimistic note to be made. If it is other factors rather than land use that are more directly related to travel patterns—for instance, a city's population size or its socio-economic profile—the prospects for making cities more sustainable through physical planning are bleaker than Newman and colleagues suggest.

With our empirical analysis we seek to achieve two related goals. First, we aim to gain insight into the relative importance of urban form in explaining (in a statistical sense) variations in metropolitan-wide travel patterns vis-à-vis cities' development history, housing and sociodemographic situation. The focus on these factors reflects our concerns about the omission of cities' space-time context in the empirical analysis by Kenworthy and colleagues. Some of the sociodemographic factors have also been included to account in some ways for the roles that individuals' resources and restrictions play in determining their travel choices.[1] Second, we seek to ascertain to what extent the relations between urban form and metropolitan-wide travel patterns differ across regional contexts. We have therefore allowed the effects of land use variables and other determinants on travel patterns to vary among European, Canadian, and US cities. The reason for looking separately at Canadian cities is that descriptive analysis suggests that they are less car dependent than their US counterparts (Kenworthy et al., 1999).

3. Data and research design

Ideally, we would have used longitudinal, individual-level travel behaviour data in a multitude of cities across the world for this study. However, since such data are not available, we decided to employ and extend the data collected by Kenworthy and colleagues. There are pros and cons to this choice. The most important drawback is that our analysis provides few insights on causal mechanisms, which would require individual-level data at multiple points in time. On the other hand, use of the Kenworthy et al. data augmented with information on cities' development history, housing conditions and socio-demographic situation allows us to gain more detailed insights in the strength of the land use and transportation link in the cities considered by Kenworthy and colleagues. It also makes this study better comparable to their work.

Because the data by Kenworthy et al. (1999) do not contain socio-economic data (other than the Gross Regional Product) or housing and development history-related factors, we have collected additional information by consulting various statistical organisations in Europe and North America. Due to time and monetary restrictions we had to limit the search for additional data to cities in North America and Europe in the year 1990, and exclude data from cities in Australia and Asia as well as data from the 1960–1980 period from the analysis. After combining the obtained data with those in Kenworthy et al. (1999) and checking their compatibility, we found that sufficient data was available for 31 cities in Europe, Canada and the USA (Table 1). An overview of the statistical agencies contacted and the exact procedures for merging the various data is available in Van de Coevering (2003).

Table 1
Cities in the analysis

European cities	Canadian cities	US cities
Amsterdam	Calgary	Boston
Brussels	Edmonton	Chicago
Copenhagen	Montreal	Denver
Frankfurt	Ottawa	Detroit
Hamburg	Toronto	Houston
London	Vancouver	Los Angeles
Munich	Winnipeg	New York
Paris		Phoenix
Stockholm		Portland
Vienna		Sacramento
Zurich		San Diego
		San Francisco
		Washington

Geographical definitions available in Kenworthy et al. (1999).

[1] Careful interpretation of aggregate-level measures like those here is warranted; relations observed at the aggregate level need not hold at the disaggregate level (a phenomenon known as ecological fallacy (Robinson, 1950)).

Table 2
Potential explanatory variables with mean scores for European, Canadian and US cities

Variable name	Description	European cities	Canadian cities	US cities
Urban form				
Population density metropolitan area[a]	Number of residents/ha for the whole metropolitan area	49.9	28.1	14.2
Population density inner area[a]	Number of residents/ha for the inner area	87.0	43.6	35.6
Population density CBD[a]	Number of residents/ha for the CBD	106.4	38.0	50.0
Population centrality inner area[a]	Proportion of the population residing in the inner area	39.6	27.0	24.1
Population centrality CBD[a]	Proportion of the CBD population in the total population	3.4	1.4	0.8
Employment density metropolitan area[a]	Number of jobs/ha for the whole metropolitan area	31.5	14.4	8.1
Employment density inner area[a]	Number of jobs/ha for the inner area only	84.6	44.6	27.2
Employment density CBD[a]	Number of jobs/ha for the CBD only	345.1	354.6	429.9
Employment centrality inner area[a]	Proportion of jobs in the inner area in the total number of jobs	58.1	44.2	32.8
Employment centrality CBD[a]	Proportion of jobs in the CBD in the total number of jobs	19.7	19.7	10.5
Transport service level				
Road supply[a]	Total road length (km) per 1000 inhabitants	2.4	4.7	6.8
Parking CBD[a]	Number of public parking places per 1000 CBD employees	229.7	408.1	467.8
Transit supply[a]	Total number of public transport service kilometre per inhabitant	92.5	58.0	28.4
Rail density[a]	Total rail track (km) per hectare	3650.9	390.0	152.9
Ratio road to transit supply[a]	Number of public transport service kilometre divided by the number of road kilometre	42467.7	14186.7	5080.2
Ratio transit to car speed[a]	Average speed of transit divided by the average car speed	1.14	0.61	0.57
Housing and development history				
Housing tenure[b]	Proportion of rental dwellings in the total number of dwellings	68.4	42.8	42.0
Dwelling size[b]	Average number of rooms per dwelling	3.3	6.0	5.2
Built before 1945[b]	Proportion of dwellings built before 1945	41.7	12.8	16.2
Built 1945–1970[b]	Proportion of dwellings built during 1945–1970	35.7	38.4	41.8
Built since 1971[b]	Proportion of dwellings built since 1971	22.6	48.8	42.1
Socio-economic situation				
Car ownership[a]	Number of cars per 1000 inhabitants	397.1	524.3	607.8
Gender[b]	Proportion of males in the population	47.9	49.1	49.1
Highly educated	Proportion of inhabitants holding a bachelor/master degree	24.8	18.3	24.1
Share 19–39 year	Proportion of the population aged 19–39	40.4	36.0	36.9
Share 40–64 year	Proportion of the population 40–64	23.6	26.9	25.7
Share 65+ year	Proportion of the population aged 65 or over	16.1	10.4	10.7
Household size	Average number of persons per household	2.1	2.6	2.6
Proportion employed	Proportion of employed persons in the total population	49.3	55.2	49.3
Service employment	Proportion of workers employed in services	51.1	53.0	48.4
Industry employment	Proportion of workers employed in industry	22.2	18.3	21.2
Trade/transport employment	Proportion of workers employed in trade/transport	24.0	25.9	27.5
GRP per capita	Gross regional product (1000 US$) per inhabitant	31.7	22.6	26.8
Population	Natural logarithm of metropolitan area inhabitants	14.2	14.0	15.1

[a] Drawn from Kenworthy et al. (1999).
[b] Additional data obtained from statistical agencies.

This paper investigates the relations between the following sets of factors on travel patterns (Table 2):

(i) *Urban form*, here represented by two dimensions that have been shown repeatedly to affect travel patterns at the metropolitan level (e.g. Mindali et al., 2004; Schwanen et al., 2004): the land-use intensity and the land-use distribution or centrality. The intensity dimension was operationalised through the population and employment density of the metropolitan area, inner area—that part of a city that has been built prior to World war II—and the Central Business District (CBD). Land-use centrality is represented by the percentage of the total number of inhabitants or jobs that is located in the inner area or in the CBD.

(ii) *The transport service level*: the supply of infrastructure for car travel and public transport. We readily acknowledge that the relation between transport service level and travel patterns is to some extent a chicken-and-egg problem and that the two are co-constitutive. However, one can argue that in the short run the service level has a clear effect on individuals' behaviour (cf. conventional mode choice analysis and also the work by Newman and colleagues);

(iii) *Housing system and development history*: tenure, age of the dwelling stock and dwelling size;

(iv) *Socio-demographic situation*: this label is shorthand for factors associated with the demographic structure (age and gender) and the socio-economic structure (education, income level, etc.)

The following travel indicators drawn from Kenworthy et al. (1999) are analysed in this paper: the average annual number of kilometres by private car per inhabitant as an indicator of the distance travelled by private car; the average annual number of passenger kilometres by transit per inhabitant as an indicator of the distance travelled by public transport; the average (one-way) commuting distance; the average (one-way) commuting time; and the modal split for commuting as reflected by the percentage of commuting trips by private car, by public transport, and walking/bicycling, respectively. These indicators have been selected because of their relevance to land-use and transportation policies. Distance travelled and modal split are directly linked with energy consumption and the sustainability debate. Special attention is given to commuting, which has long played a central role in policy debates due to its close association with congestion problems and its regular and habitual character. Commuting time is taken into consideration because of its association with quality of life and the level of time pressure workers experience.

For the analysis ordinary least squares regression modelling was used. Because the sample of cities is very small, the specification of regression models as parsimonious as possible was required. Rather than including all variables in the models, we chose to detect and include those that had the strongest statistical association with a given dependent variable with the help of the forward stepwise procedure in the SPSS software. This procedure also helped to avoid problems of multicollinearity among the independent variables in the models. Other checks for multicollinearity were also performed. Where multicollinearity was suspected, bivariate correlation coefficients between variables were calculated and one or more variables dropped from the model specification if correlation coefficients exceeded the value of 0.8.

Two types of regression models have been specified:

(i) *Generic models* in which statistically significantly relationships between the potential explanatory variables and the indicators of travel patterns are identified for all 31 cities in our sample, and no account is taken of regional variations in the effects of potential explanatory variables; and

(ii) *Regional models* in which the effects of independent variables on the travel indicators are allowed to differ among Europe, Canada and the USA. For the latter the generic specifications served as the base. Three regional dummy indicators were created—Europe (1 = city lies in Europe; 0 = otherwise); Canada (1 = city lies in Canada; 0 = otherwise); and USA (1 = city lies in USA; 0 = otherwise)—and these were interacted with the explanatory variables included in the generic model specifications. The generic models were then re-estimated with the interactions of the regional dummies and explanatory variables in question also allowed to be included.

A note of caution is in order before the analysis results are discussed. As Table 1 already showed, the number of observations in our sub-sample of cities is small and this might lead to biased results. We have sought to prevent biases as much as possible by carefully checking the distribution characteristics of each variable and by including only effects that appeared to be robust, in the sense that they showed up with consistent signs in alternative model specifications. Visual inspection of residuals was employed to avoid problems of heteroscedasticity.

4. General impacts

4.1. Total distance by private car

After controlling for other factors, two urban form indicators are statistically significantly related to the number of car kilometres per person (Table 3). As expected, inhabitants of cities with a higher population density at the metropolitan level drive travel fewer kilometres by car. The centrality of employment has a comparable though weaker statistical effect: a higher percentage of jobs in the CBD tends to reduce the distance travelled by car.

Of the non-urban form factors, the percentage of workers in the total population is the only variable included in the model. It is negatively related to the distance by car, which may at first

Table 3
Regression models total distance travelled by transport mode

	Total distance by private car per capita			Total distance by public transport per capita		
	B	*t*-statistic	Beta	*B*	*t*-statistic	Beta
Urban form						
Population density urban area	−135.6	−8.06	−0.754			
Employment density inner area				7.23	4.31	0.322
Employment centrality CBD	−121.3	−2.87	−0.265			
Transport service level						
Ratio transit to road supply				0.017	5.82	0.444
Rail density				0.094	4.69	0.335
Parking CBD				−1.08	−4.31	−0.294
Socio-economic situation						
Proportion employed	−165.2	−3.36	−0.270	21.86	2.75	0.142
GRP per capita				−39.79	−3.32	−0.283
Population						
Constant	22124.1	8.69		701.82	1.47	
R^2 adjusted		0.834			0.955	

sight appear counterintuitive. While it is conceivable that this aggregate-level relationship may not hold at the disaggregate level of individual travellers and one should be wary with drawing conclusions about individual behaviour from aggregate-level measures, this result might be explained in terms of time availability and commuting patterns. Many employed persons may have less time available for non-work activities and associated travel because they are tied to their workplace for significant parts of the week. In addition, public transport is better geared towards commuting to/from the workplace, which makes up a large part of the total travel activity of workers. This is because commuting is more concentrated in space and time than non-work travel.

4.2. Total distance by public transport

The statistical relations between land use and total distance by public transport appear to be smaller than for distance by car. The employment density for the inner area is the only urban form indicator included in the model, indicating that larger distances are travelled by public transport in metropolitan areas with more jobs per hectare in the core (Table 3). This is presumably because the spatial concentration of functions leads to a concentration of traffic flows, which makes transit more attractive. The influence of public transport infrastructure, which is of course usually related to land use factors, is captured by two variables which are both positively correlated with the distance by public transport: the ratio of public transport to road supply—the most important determinant in the model—and rail density. Further and in line with expectations, the distance by public transport also increases as public parking supply in the CBD is lower.

Two additional factors are included in this model. The Gross Regional Product (GRP) per capita and the percentage of employed persons in the total population both have a statistically significant influence on the distance by public transport. A higher GRP reduces the number of public transport kilometres. Under the assumption that for door-to-door trips (including access, waiting and egress times) the average travel speeds for the car tends to be higher than for intra-urban transit, the effect for the GRP is consistent with observations by Schafer (1998) that a higher level of economic prosperity leads to more use of fast transport systems. The positive influence of the share of workers is in line with the remarks in the previous subsection and suggests that substitution exists between transport modes: a higher percentage of workers results in less car but more public transport kilometres per capita, supporting the notion that transit is more competitive for commuting than for other travel purposes.

4.3. Commuting distance

The regression model for the average commuting distance in Table 4 points out that the percentage of jobs in the CBD is the only urban form variable to be statistically significantly related to commuting distance. A higher percentage of jobs in the CBD leads to a shorter average commuting distance, thereby suggesting that metropolitan areas have shorter commuting distances as they have a stronger monocentric orientation. This result is not consistent with the co-location hypothesis, which states that commutes tend to be shorter on average in polycentric metropolitan areas as a result of individuals' and firms relocation behaviour (Gordon et al., 1989; Levinson and Kumar, 1994). Note, however, that the co-location hypothesis focuses on commuting time rather than distance, for it is time that is of prime interest to both employees and employers. The (ambiguous) empirical evidence for the co-location hypothesis that is available is stronger for commuting time than for distance (Schwanen et al., 2004 for a detailed discussion).

Population size is positively correlated with the average commuting distance. This may reflect that the maximum distance between an individual's residential and workplace location can be longer in larger cities. The model also reflects one of the most frequently recurring findings in the commuting literature, namely that males tend to have longer home-to-work trips than women. Consequently, we find that at the aggregate level a higher percentage of males in the population leads to longer commute distances. This finding has often been explained by referring to the household responsibility hypothesis arguing that women work closer to home than men, because the former are still responsible for the bulk of household and childcare tasks (Turner and Niemeier, 1997).

Table 4
Regression models average commuting distance and time

	Average commuting distance			Average commuting time		
	B	*t*-statistic	Beta	*B*	*t*-statistic	Beta
Urban form						
Employment centrality inner area				0.071	1.98	0.297
Employment centrality CBD	−0.22	4.42	−0.453			
Transport service level						
Rail density				$-0.62^{E}-04$	−4.40	−0.544
Socio-economic situation						
Car ownership				−0.017	−4.20	−0.585
Gender	1.57	4.58	0.451			
Proportion employed				0.23	3.00	0.339
Population	1.25	3.62	0.333	2.41	5.25	0.615
Constant	−79.05	−4.32		−12.89	−1.35	
R^2 adjusted	0.776			0.770		

Other explanations include women's lower wages, the spatial segmentation of the labour market, and the fact that women hold other types of occupation than men (Hanson and Pratt, 1995; Macdonald, 1999).

4.4. Commuting time

Table 4 suggests that the concentration of employment in the inner area is the only urban form factor that is significantly and positively related to the average commuting time. In other words, the more monocentric an urban area is, the longer is the average commuting time—a finding that is diametrically opposed to those for the average commuting distance in the previous subsection. Two interrelated explanations may be given (Levinson and Kumar, 1997; Schwanen et al., 2004). First, in cities with a strong concentration of employment in the metropolitan core the average travel speed may be lower as a result of congestion and parking problems, and this lower speed may offset a shorter distance and result in a longer average commuting time. This is a key element of the co-location hypothesis, since it is this longer commute time that may motivate firms and households to look for a location in the (outer) suburbs. Second, in monocentric cities public transport and walking/bicycling are often used more frequently, which also reduces the average travel speed in a city.

A comparison of the standardised beta coefficients in Table 4 indicates that population size is most strongly correlated with commuting time, indicating that larger metropolitan areas have longer average commute times. This is more or less consistent with the findings regarding commute distance presented above. The model further suggests that a higher public transport service level is associated with a lower average commuting time. While it is tempting to conclude from this that extending transit services may reduce congestion, we are wary to do so given that the direction of the causality is not very clear in this instance. More detailed analysis is required focusing on individual behaviour in a longitudinal perspective.

We also find that the average commuting time is longer as the level of car ownership is higher and in metropolitan areas with a larger share of workers in the total population. The former result may reflect higher levels of economic wellbeing (not captured by the GRP per capita), or that in cities with higher levels of car ownership road congestion is more prevalent which may decrease travel speeds and hence lengthen travel times. The latter might be related to the fact that public transport is used more and the private car less as the share of workers increases (see Sections 4.2 and 4.3). Travel times for public transport trips are often longer than for car trips, because public transport is used more for longer-distance trips and because transit usage incurs transfer, waiting, access and egress times (Krygsman, 2004). Alternatively, the level of congestion may be higher in areas where the share of workers is larger, and this may adversely affect travel speeds.

4.5. Modal split for commuting

Table 5 presents the results for the regression models for the modal split for commuting. As explained before, three models are specified for the percentage of commuting trips by car, by public transport and by walking/bicycling, respectively. Consistent with expectations, a higher population density is associated with a smaller share of the car and more walking/bicycling. In addition, the share of public transport becomes larger as the resident population is more strongly

Table 5
Regression models modal split for commuting

	Share of the private car			Share of public transport			Share of walking/bicycling		
	B	*t*-statistic	Beta	*B*	*t*-statistic	Beta	*B*	*t*-statistic	Beta
Urban form									
Population density metropolitan area	−0.39	−5.21	−0.334				0.088	1.99	0.196
Population centrality inner area				0.24	3.14	0.192			
Employment density inner area				0.26	8.82	0.607	−0.130	−6.36	−0.579
Transport service level									
Ratio of transit to road supply				1.84^{E}-04	3.41	0.253			
Parking places in CBD				−0.011	−2.55	−0.154			
Housing and development history									
Housing tenure (share of rental dwellings)	−0.32	−4.67	−0.242				0.47	11.57	0.912
Built before 1945	−0.44	−6.17	−0.335						
Socio-economic situation									
Employment in trade/ transport	0.93	3.52	0.156				−1.17	−7.84	−0.501
Household size	11.31	3.48	0.168						
Percentage employed	−0.70	−4.61	−0.179						
Constant	89.88	5.41		1.71		0.45	21.50	4.83	
R^2 adjusted	0.967			0.945			0.923		

concentrated in the inner areas of a metropolitan area. These areas came into existence prior to World war II and tend to be less oriented towards car use and more accustomed to the use of public transport and walking/bicycling. Moreover, the provision of public transport services is more profitable as the demand for travel is more concentrated spatially. This last argument may also explain why the share of commuters using public transport rises with the job density in the inner areas. However, the beneficial effect of employment concentration on public transport is reached at the expense of less walking/bicycling, as the coefficient for job density in the central areas indicates. Perhaps a stronger degree of employment concentration means that home-to-work distances become too long to cover on foot or by bicycle for larger numbers of commuters who therefore resort to transit modes.

Consistent with the results for total distance by public transport, the results for the transport service level factors are as expected. A good provision of public transport relative to road infrastructure and a lower number of public parking places in the CBD stimulate the share of public transport commutes.

The share of walking/bicycling rises and that of the car decreases with the percentage of rental units in the total number of dwellings. We checked whether this result was due to the inclusion of Amsterdam, a city where the proportions of both walking/bicycling and rental dwellings are much higher than elsewhere. This appeared not to be the case, since the coefficient remained statistically significant after Amsterdam was excluded from the analysis. One explanation for the positive impact of the share of rental dwellings might be that in cities with more rental units the average income may be lower, which may in turn imply a larger use of inexpensive modes of travel. In addition, rental dwellings are frequently older than owner-occupied ones and more often built as medium or high-rise developments than owner-occupied units. Thus, in the former case the share of rental dwellings acts as a proxy indicator of income and in the latter it suggests that a city's history is relevant to contemporary travel patterns. The latter explanation is in line with the result that the share of commuting by car decreases as the share of pre-1945 dwellings increases. As argued before, this may reflect that neighbourhoods built before World war II are less geared towards car use.

Socio-economic variables also exert a significant influence on the modal split for commuting. Car use rises and walking/bicycling decreases with the share of the labour force employed in the trade/transport sector. This may be attributed to the fact that firms in that sector are typically located in low-density areas on the outskirts of metropolitan areas, often along highways. Such locations are well accessible by cars but not by public transport and certainly not by walking/bicycling. Distances between residential areas and peripheral workplace locations are too far for the use of walking/bicycling. In addition, household size and car use are positively correlated. This might reflect that larger households more often consist of one or more children. As Dowling (2000); Collins and Kearns (2001) have shown, the car is better suited for travelling with children than transit or walking/bicycling because of it space-time flexibility and because of the safety and security it provides. Consistent with the results for the distance travelled by car, the share of the car is lower as the percentage of workers in the total population increases.

4.6. Discussion

The analysis does not directly undermine a physical planning approach to reduce automobile dependence. Urban form variables are relevant to all dimensions of travel patterns considered. Interestingly, however, the land use characteristics of the inner area—that part of the city built prior to World war II—seem to be more directly associated with aggregate-level travel patterns than metropolitan-wide population density. The latter is mainly relevant to total vehicle kilometres travelled and the shares of the car and bicycling/walking in the modal split for commuting. From the effects of the inner-area variables one could conclude that historical conditions matter to travel patterns. This is also borne out by the effects of housing tenure and building period on the modal split for commuting.

To some extent, the relevance of historical conditions raises questions about newer cities and/or those that have expanded greatly since 1945. Can policies aimed at increasing densities and the mixing of land uses in such cities successfully recreate the conditions in older cities and will this indeed reduce driving in favour of public transport and bicycling/walking? Answering such questions is beyond the scope of this paper and would require more in-depth qualitative and quantitative research approaches. The results do make clear, however, that multiple conclusions about the feasibility of physical planning can be drawn (even) from the Kenworthy et al. data, ranging from very positive views like those by Newman and colleagues (Newman et al., 1995; Newman and Kenworthy, 1999) to more pessimistic ones.

As expected, indicators of socio-economic situation in a city are also statistically significantly related to metropolitan-wide travel patterns. For the average commute distance and time and the share of the private car in the modal split for commuting, these are more important than urban form variables, even at this aggregate level of analysis. From a policy perspective the relevance of these factors is somewhat difficult to explain, because the share of employed persons in the total population and population size are difficult to influence with policies. These results act as a useful reminder that there are limits to what can be realized by physical planning; there are numerous other factors that may result in an increase in distance traveled and vehicle use that may offset or overshadow the transportation benefits of physical planning.

5. Regional variations

In this section, we seek to arrive at a more subtle understanding of the differences in metropolitan-wide travel patterns, by analysing to what extent the outcomes presented so far differ for Europe, Canada and the USA. As described before, we have created a set of regional dummies, interacted those with the variables in the model specifications described in

Section 4, and allowed these interactions to be included in the model specifications. Before discussing the results, we would like to remind the reader once more that the results should be interpreted with caution due to the small number of cities when segmenting the analysis by world region/country. Table 6 summarises the results. Only the total effects (the sum of the average or main effect for a factor as represented by its overall regression coefficient and the region-specific interaction or the additional regression coefficient for the same variable but for one region only) of those variables for which the impact varies between Europe, Canada and the USA are shown; the coefficients for the other explanatory variables in each model strongly resemble those in the specifications discussed in Section 4, and are therefore omitted. Note that no indications of statistical significance are provided in Table 6. Because all region-specific interactions for which the total effects presented there are statistically significant (at $\alpha = 0.05$), the total effects can also be considered as such. Van de Coevering (2003) provides more information on the models.

The analysis indicates that regional differences appear to exist for three of the five travel indicators investigated (Table 6): the total distance by private car; the total distance by public transport; and the modal split for commuting. Put otherwise, with the current data no statistically significant differences could be detected in the determinants of commuting distance and time among European, Canadian and US cities.

Table 6
Variations in the effects of explanatory variables between Europe, Canada and the USA

	European cities	Canadian cities	US cities
Total distance travelled by private car			
Population density metropolitan area	−105.93	−105.93	8.47
Proportion employed	−88.18	−88.18	−37.33
Total distance travelled by public transport			
Employment density inner area	1.77	11.33	11.33
Share of the private car in the modal split for commuting			
Population density metropolitan area	−0.29	−0.29	−0.04
Housing tenure (share of rental dwellings)	−0.35	−0.35	−0.24
Household size	11.21	11.21	13.43
Proportion employed	−0.51	−0.51	−0.39
Trade/transport employment	0.76	0.76	0.97
Share of public transport in the modal split for commuting			
Population centrality inner area	0.24	0.24	0.10
Employment density inner area	0.23	0.23	0.12
Share of walking/bicycling in the modal split for commuting			
Population density metropolitan area	0.05	−0.15	−0.85
Employment density inner area	−0.13	−0.17	−0.07
Housing tenure (share of rental dwellings)	0.29	0.14	0.11
Trade/transport employment	−0.85	−1.06	−1.15

The numbers in the table represent the sum of the average (main) effect of a given explanatory factor and an interaction term of that variable with dummies for Europe, Canada and/or USA. Only explanatory factors of the effects vary between European, Canadian and US cities are presented. The other explanatory variables in each model are identical to those in Tables 3–5.

Turning to the results for the total distance by private car, we see that the impact of metropolitan population density differs between the USA on the one hand and Europe and Canada on the other. The model shows that metropolitan density is only marginally relevant for the explanation of differences among US cities in the Kenworthy et al. data. In addition, the expanded model suggests that the influence of the percentage of workers in the total population on the distance by car is smaller in the USA. It thus appears that the average distance by car depends to a lesser degree on urban form and socio-demographic situation in the USA than in Europe and Canada. Two interrelated explanations for these findings may be given. First, the reliance on and the predisposition towards the private car are higher in the USA than in Europe (e.g. Salomon et al., 1993). Second, as can be seen from Table 2, the average metropolitan population density is more than three times lower and the proportion of the metropolitan population residing in the inner areas 1.6 times lower in the USA than in Europe. These statistics aptly describe the lower acceptability of high-density living to the general public in the USA in the 1990s (Gordon and Richardson, 1989; 1997; Mindali et al., 2004).

With regard to the total distance by public transport, the model suggests that the Canadian cities deviate from those in Europe and the USA. In particular, we find that the positive correlation between employment density and distance by public transport is only very weak in Canada. No explanation is readily available; this result may stem from the fact that only seven Canadian cities are included in the Kenworthy et al. data.

The three models for the modal split for commuting contain the most regionally varying impacts. For all variables with a negative impact on car use—the share of workers in the total population, metropolitan population density, and the share of rental dwellings—the total effect is smaller in the USA than in Europe and Canada. In contrast, the positive impacts of the share of the trade/transport sector in the total employment and the average household size on car use are larger in the USA. This again seems to reflect the larger dependence on and predisposition towards the private car in the USA and the generally weaker preference for urban living there than in Europe and Canada. The pattern of a smaller influence of metropolitan structure is also apparent from the results for the share of commuting trips by public transport. For both the employment density in the inner areas and the centrality of the population the positive effect is statistically significantly smaller in the USA than in Europe and Canada.

For the share of walking/bicycling in the modal split for commuting the results are somewhat different. Table 6 indicates that differences occur among the USA, Europe and Canada for this variable. Consistent with the results for commuting by car and public transport, we see that the negative impacts of metropolitan population density and the share of workforce employed in the trade and transport sector is stronger in the USA than in Europe and Canada, whereas the positive impact of the share of rental dwellings is smaller. These results suggest that walking/bicycling are least favoured in the USA. The only variable that yields different results is the employment density of the inner area, for which the negative impact is largest in Canada and smallest for the USA. In the model for the public transport share the (positive) impact is smaller in the USA than in Europe and Canada. Taken together, these results seem to suggest that the employment density of the inner area is less relevant to the modal split for commuting in the USA. Perhaps the difference between Canada and the USA reflect that transit services relative to densities are better in Canada.

6. Conclusions and discussion

While Kenworthy and colleagues have made a very important contribution to our understanding of the relations between urban form and travel patterns, it could be argued that the role of individual travellers as well as the space-time context of cities has remained underexposed in their empirical-analytical work. In an attempt to assess the seriousness of those limitations, we have augmented the 1990 data collected by Kenworthy and associates for cities in Europe, Canada and the USA with information on housing, development history and the socio-demographic situation, and assessed how these factors, alongside land use and transport infrastructure, are related to travel patterns. We have also investigated to what extent the correlations between land use, transport infrastructure and the aforementioned factors on the one hand and travel patterns on the other differ among European, Canadian and US cities.

As expected, urban form and transportation infrastructure are not the only factors to be statistically related to metropolitan-wide travel patterns. Various socio-demographic and housing and history-related variables are associated with inter-metropolitan differences in travel patterns. At the same time, however, characteristics of urban form appear to remain relevant to all dimensions of travel patterns investigated in this paper once other factors are taken into consideration. For three of the five travel indicators investigated, we have found that the magnitude (and sometimes even the sign) of the effects of one or more determinants varies statistically significantly between European and US cities. Canadian travel patterns resemble those in Europe, when the total distance by car and public transport and the shares of the car and public transport in the commuting modal split are concerned; they take an intermediate position between Europe and the USA with respect to walking/bicycling for commuting.

Before discussing some implications of the results, some cautionary remarks are in order. The sample of cities in the current study is small, even smaller than in Kenworthy et al. (1999); Cameron et al. (2003), so the findings should be considered as preliminary rather than definitive. Assessments such as the one reported here should thus be repeated for much larger samples of cities. Improvement can also be made in dealing with the space-time context of cities: additional data on individual cities and their characteristics are required. But even then researchers should be careful to infer causality from aggregate-level statistical analysis.

We end this paper by discussing some implications for the future sustainable city vision/model, which can be reached in four steps (Newman and Kenworthy, 1999): (i) revitalisation of the inner city; (ii) concentration of new development around the present rail system; (iii) discouragement of further urban sprawl; and (iv) extension of the transit system with cross-suburban and orbital rail lines and building new urban villages around them. Our results that the strength of the statistical correlations between land use and travel patterns at the aggregate level appear to differ across regional contexts after other factors are taken into account make us wonder whether it is appropriate to represent the land use-transport relations through a single vision/model of the future sustainable city.

Would not it be more appropriate to replace the singular and coherent vision/model with a series of visions/models tailored to regional contexts and putting more emphasis on specific steps in different regional contexts? In Europe a strong focus on the traditional urban core, high densities, development in rail corridors may be more fruitful than in the USA. There, a stronger emphasis on suburban locations, lower densities and a somewhat larger role for the private car (in addition to rail) seem to be required for policies to be successful. Rather than on (re)centralisation of housing and employment, the US model/vision should accentuate the provision of sufficient and affordable housing in mixed-use medium-density neighbourhoods in the suburbs with good (road) access to suburban employment opportunities in edge cities or more spread out over the metropolitan area. The Canadian model would occupy the middle ground between the European and US versions.

Physical planning policies can provide people with more opportunities for switching modes or reducing the lengths of their trips, but they may not be sufficient for realizing substantial changes in aggregate travel patterns. While the need to supplement physical policies with pricing measures has been emphasized elsewhere (e.g. Newman and Kenworthy, 1999), it is also important that the 'right' type of travellers is attracted to more mixed and denser neighbourhoods. Recent work has suggested there is some empirical evidence from the San Francisco Bay Area that the transport benefits of such neighbourhoods are reduced at least partially, if travellers are attracted who actually prefer living in lower-density environments and/or hold strong pro-car attitudes (Schwanen and Mokhtarian, 2005a,b). Although more research along these lines is certainly required, it is fair to say that individual travellers with their preferences and constraints should be given an explicit place in visions/models of how future sustainable cities should look like. It can only be hoped that extensions like those outlined here will make land use policies more effective and our cities more sustainable.

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