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Patterns of automobile dependence in cities: an international overview of key physical and economic dimensions with some implications for urban policy

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Abstract

Automobile dependence, expressed through comparative levels of car ownership and use and transit service and use, varies widely and systematically across a large sample of international cities. US cities exhibit the most extreme dependence on the automobile, followed by Australian and Canadian cities, with European and Asian cities having very much more transit-oriented cities with greater levels of walking and cycling. These patterns are not strongly related to differences in wealth between cities, but do vary in a clear and systematic way with land use patterns. The total fixed and variable cost of cars per kilometre is also significantly related to the degree of automobile dependence in cities, though not as strongly as land use. The data suggest that the most auto-dependent cities are less wealthy than some other more transit-oriented cities. They have the worst operating cost recovery in transit, have far higher road construction and maintenance costs, spend the highest proportion of their wealth on passenger transportation but have roughly similar journey-to-work trip times and much longer trip lengths. These patterns suggest some important policy implications which stress the need to strategically reshape urban land use, to emphasise investment in non-auto infrastructure and to ensure that any physical planning strategies aimed at reducing automobile dependence work in concert with economic policies directed at increasing the real cost of both car ownership and car use.

1. Introduction

In all metropolitan regions in the world today, the problem of the automobile and its impact on urban societies is a major issue. Whether they are low density, sprawling cities such as Los Angeles or Houston, which are today almost totally dependent on the automobile and well known for their auto-based environmental problems, or high density, more transit-based cities such as

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Bangkok or Manila in the developing world, with their gridlocked traffic and fume-filled air, urban policy is centrally concerned with how to better manage the automobile. However, it is not always accurately known to what extent the problem of automobile dependence has progressed and how cities really differ from each other in their basic transportation patterns. A casual observer in the streets of Bangkok, or just about any other Asian city in the developing region, could be forgiven for thinking that such cities are heavily dependent on the automobile, but they are not, as will become clearer in the analysis to be presented here.

Indeed, without mounting a detailed and time-consuming research exercise, it is very difficult to find easy and reliable answers to even the most reasonable and basic kind of questions on transportation and land use in cities. How much variation is there in urban car ownership and how much are cars actually used by residents of cities in different parts of the world? How significant is public transit in the overall passenger transportation task of different cities? Do the transit systems of most cities suffer large operating losses? How do city densities which help shape transportation patterns differ from one another? In fact, for just about any comparative urban transportation or land use question one might seek a perspective on across a broad international spectrum of cities, there are really no quick, easy or accurate answers from published sources.

The above kind of problems stem from the fact that, unlike for nations, where there is a plethora of data available on virtually every area of human concern (through, for example, the comparative data publications of the United Nations and World Bank), there are really no systematic international urban databases from which can be gleaned a detailed appreciation of the differences in urban transportation systems, land use patterns and economics between cities and some of the possible reasons for these differences.

The overall aim of this paper therefore is to provide an insight into some summary findings of a large comparative study of automobile dependence in cities, whose ongoing goal is to at least partly remedy this obvious lack of comparative urban transportation data. This study, which was partially funded by a grant from the World Bank to the Institute for Science and Technology Policy at Murdoch University, examined a wide range of data for 1990 in 46 cities in the USA, Australia, Canada, Western Europe and Asia, the Asian sample being divided into wealthy Asian cities and much less wealthy, developing Asian cities. The detailed data and findings of this research project, which took some seven years to complete, are to be published in a forthcoming book by Kenworthy et al. (1999). This new study represents an extension and update of the database on 32 cities contained in Newman and Kenworthy (1989).

For the purpose of synthesising some of the results from what is a very much larger and more detailed study, the authors will attempt to provide insights into the following questions:

- How do some key factors describing urban transportation and land use patterns vary between metropolitan regions in the USA, Australia, Canada, Western Europe and in both the wealthy and some developing parts of Asia?
- What are some of the key relationships which exist between urban transportation, land use and economics in this international sample of cities and how do these relationships enhance our understanding of the broad patterns of automobile dependence in cities?
- What general policy insights might we infer from these data?

The data presented in the paper are primarily based on averages of the various data items from the sample of cities in each distinct geographic region. Data on individual cities are not

Table 1
Cities in the comparative study by region and their 1990 population

Cities	Population (1990/91)
American	
Boston*	4,056,947
Chicago*	7,261,166
Denver*	1,787,928
Detroit*	3,912,679
Houston*	3,462,529
Los Angeles*	8,863,164
New York*	18,409,019
Phoenix*	2,122,101
Portland	1,174,291
Sacramento	1,355,107
San Diego	2,498,016
San Francisco*	3,686,592
Washington*	3,559,604
Australian	
Adelaide*	1,023,278
Brisbane*	1,333,773
Canberra	277,930
Melbourne*	3,022,910
Perth*	1,142,646
Sydney*	3,539,035
Canadian	
Calgary	710,677
Edmonton	823,163
Montreal	3,119,570
Ottawa	907,919
Toronto*	2,275,771
Vancouver	1,542,933
Winnipeg	641,850
European	
Amsterdam*	804,711
Brussels*	964,285
Copenhagen*	1,711,254
Frankfurt*	634,357
Hamburg*	1,652,363
London*	6,679,699
Munich*	1,277,576
Paris*	10,661,937
Stockholm*	674,452
Vienna*	1,539,948
Zurich*	787,740
Wealthy Asian	
Hong Kong*	5,522,281
Singapore*	2,705,115
Tokyo*	31,796,702

Table 1 (*continued*)

Cities	Population (1990/91)
Developing Asian	
Bangkok*	7,639,342
Jakarta*	8,222,515
Kuala Lumpur*	3,024,750
Manila*	7,948,392
Seoul*	18,586,128
Surabaya*	2,473,272

systematically provided, as these will be published in full in Kenworthy et al. (1999), though there is a significant selection of regression analyses presented which utilise the full data set. In addition, the minimum and maximum values of the individual variables within each group of cities are presented, along with the names of the cities where these occur, and the standard deviations on each variable within each group.

Some of the key data used in this paper, including all the economic variables, have already been published for each city in a report provided to the World Bank (Kenworthy et al., 1997; http://wwwistp.murdoch.edu.au/). Table 1 lists the cities in this study along with their 1990/91 population. The definitions of these cities, or metropolitan regions, are discussed in Section 2. The data contained in this paper are for the year 1990 or 1991, depending on the national census year of the country involved. The addition of some key economic variables to the earlier work by Newman and Kenworthy (1989) was made possible through a grant from the World Bank mentioned above. This project required collection of a series of 10 specific indicators of transportation efficiency in 37 cities, including key economic and environmental variables, the latter of which are not dealt with in this paper (Kenworthy et al., 1997). The cities marked with an asterisk were included in the study for the World Bank. Beijing was the only city included in the study for the World Bank which is not included in the wider comparisons. It should be noted that Toronto was the only Canadian city included in the study for the World Bank, so that in some of the data presented here, only this city appears, rather than all the Canadian cities.

2. Methodology

2.1. Choice of cities

The choice of cities dates back to the original study by Newman and Kenworthy (1989) in which an attempt was made to select a set of the major cities in each region which would cover a range of population sizes, not excluding smaller cities, but generally weighted towards medium to large cities. Previous work had suggested that city size (population and area) was of less significance in understanding transportation patterns than urban form and the basic structure of the transport system (Thomson, 1977; Newman and Hogan, 1987; Newman and Kenworthy, 1980). Compromises were made between comprehensiveness of the chosen cities and the capacity to carry out the original work, which took some seven years to complete.

The additional cities which form part of this paper were added for various reasons. Toronto was the only Canadian city in the previous study and it has been complemented by six other major Canadian cities. Toronto's land use and transportation patterns were found to be between the auto orientation of the US and Australian cities and the transit orientation of the European cities (Kenworthy, 1991). The unique features of transit and land use integration in other Canadian cities had been noted elsewhere (Cervero, 1986), thus more were included in the comparisons for 1990. Three new US cities (Portland, Sacramento and San Diego) which had recently installed light rail transit systems were added in order to gain some perspective on any changes this may have brought. Canberra was added due to criticisms of the earlier work that there were no small cities in the study and the fact that the data had been prepared as part of a consulting study (Newman and Kenworthy, 1991). Finally, a selection of six cities in the developing Asian region were added in order to begin adapting and applying the comparative methodology to a developing city context in which the transportation systems and issues are very different to those in developed cities (see Barter and Kenworthy, 1997; Barter, 1998). The World Bank also had specific interests in this region and they were an essential component of our study for the bank. The data on these cities are included in the discrete regional comparisons of individual variables because they are of direct interest, though where appropriate they have been removed from statistical analyses to account for the confounding effect of their very low incomes.

The methodology and experience gained from this initial analysis of developing cities is now being applied to 30 cities in many other developing parts of the world (e.g. Africa, India, South America and parts of the Middle East) as part of a large and detailed study of transportation, land use, economic and environmental factors in 100 global cities by the ISTP and SYSTRA (a Paris-based company) for the International Union (Association) of Public Transport (UITP). The project is entitled the Millenium Towns and Regions Database.

2.2. Metropolitan area definitions

Detailed metropolitan area definitions listing all the component parts such as all the counties comprising the US cities are too long for this paper and are provided in Kenworthy et al. (1999), as well as in the report to the World Bank already mentioned. However, the following general comments can be made.

Australian cities are all represented by their respective capital city metropolitan statistical divisions defined by the Australian Bureau of Statistics and these are generally good representations of the functional urban regions.

US cities are generally based on the 1980 Standard Metropolitan Statistical Area (SMSA) definitions which have been retained for data continuity. For example, San Francisco is the five county Bay Area comprising San Francisco, Marin, Alameda, San Mateo and Contra Costa Counties. New York is the full Tri-State Metropolitan Area because data are readily available on this area through the regional planning and coordination agencies which have existed there for many years, whereas Los Angeles is just LA County (the old Los Angeles-Long Beach SMSA) and omits the surrounding five counties due to practical issues of data fragmentation for so many of the variables covered in the research. In practice, we have found that, for example, average per capita car use in LA County and the six county region varies only slightly (Kenworthy and Newman, 1993).

Canadian cities are for the most part the full urban regions as defined locally, although most of the data for Toronto are for the Municipality of Metropolitan Toronto rather than the Greater Toronto Area (GTA) for which the full range of data could not be collected at the time. Later detailed work to include the whole GTA still showed Toronto to have very low car use and high transit use relative to other auto cities in the US and Australia (Kenworthy and Newman, 1994). The new study for the UITP is using the GTA.

European cities are more difficult to generalise about, but the data provided here are for whole metropolitan regions in a majority of cases. There are a few cases, such as in Frankfurt, Munich, Stockholm and London where it was simply not possible to compile all the data for the whole functional urban region due to fragmented administrative arrangements which made data collection over so many parameters virtually out of the question. In these cases, a smaller area definition had to be adopted for the sake of being able to collect the full range of data required for the study. However, in all cases, transit data are for the whole region and appropriate adjustments to population and urbanised areas were made for transit parameters.

Asian cities are mixed in their definition, with the wealthy cities defined according to the genuine functional urban regions for which excellent data are kept, while the developing Asian cities definitions had to be adapted mostly to fit the definitions used in detailed consulting studies, in order to collect the full complement of data. In practice, most of these were very close to the full functional urban region and thus provided a good basis for collecting the aggregated parameters used in this study (Barter, 1998). Only Jakarta had a more constrained definition of DKI Jakarta, rather than the larger Jabotabek area, though the former is commonly employed and was the only possible definition which could provide the full data set being sought.

2.3. The data

The standardised data presented in this paper for 1990/91 such as per capita car use, urban density, transit service and use per capita, gross regional product per capita and so on, have been painstakingly calculated over a period of seven years through collection of a large set of primary data items (e.g. population, urbanised land area, vehicle kilometres of travel in cars, transit vehicle kilometres of service and passenger boardings for each city etc.). This has involved a detailed comparative approach based on direct contact with authorities in each city through on-site visits to offices, and through subsequent telephone calls, faxes and e-mail communications to clarify the data provided. The 1990 data have been carefully checked and cross-checked using experience built up over 20 years of research in this area and carefully examined in relation to the expected range in values for specific variables in particular groups of cities and trends from previous years to highlight any obvious problems which needed to be rectified. In the vast majority of cases, all original source material has been collected. In no cases have questionnaires just been sent out and the resulting returns accepted at face value.

The work has been financially supported partly through funds from the World Bank, and through extensive indirect support provided by five full time Ph.D. students, all on full time scholarships with their associated travel funds, which allowed virtually all cities to be visited for data collection (e.g. see Laube, 1998).

The reader can gain a better insight into the methodologies and metropolitan area definitions for many of the cities by reference to Newman and Kenworthy (1989), but this has been greatly expanded in Kenworthy and Laube et al. (1999) in a lengthy chapter of that book, including detailed data sources for each city. It is thus impossible in a paper of this length to elaborate too much on methodologies and sources of data. However, in each case as data are presented, an effort is made to give the rudiments of its definition and general sources in notes to the tables.

2.4. Analyses

The main aim of this paper is to present the broad patterns of automobile dependence found in the data and this is done through a series of tables and focused discussions using a limited selection of the main data. However, it is useful to see how some of the selected key variables are related to each other and to do this some simple bivariate regressions are presented. *No assumption of causality between variables is intended or made when presenting or discussing these results*. For the purposes of this overview analysis, it is sufficient to show that certain basic relationships either exist or do not exist between key variables across the international sample. More detailed multivariate analysis can explore this in greater depth with the full set of variables available in Kenworthy et al. (1999). Such an exercise is a separate paper in its own right and is thus beyond the scope or requirements of this summary article.

3. Results

In order to provide answers to the basic questions proposed in the introduction to this paper, the paper first systematically examines some of the key physical and economic indicators used to characterise cities in terms of automobile dependence and to see how these vary on an international scale. It then attempts to explore some relationships between these factors in an effort to better understand the patterns of automobile dependence. Finally, some general policy insights are drawn from the research contained in the paper.

4. Transportation patterns in cities

This section attempts to overview some key transportation patterns in cities, including the respective wealth levels in cities, since these are often thought to be critical in understanding the development of automobile dependence in urban environments (Lave, 1992; Gomez-Ibañez, 1991; Gordon and Richardson, 1989). The issue of wealth and its relationship to the patterns of automobile dependence is pursued later in the paper. Specifically, this section examines international patterns of vehicle ownership, vehicle use, transit service and use, transit share of motorised travel, and some important journey-to-work factors such as mode split, trip times and trip distances.

4.1. Vehicle ownership, use and wealth

Table 2 provides a summary of the vehicle ownership and use data for the international sample of cities, together with their respective average Gross Regional Product (GRP) per capita. The

Table 2
Vehicle ownership, use and wealth in cities, 1990

Cities	Total vehicles per 1000 persons	Cars per 1000 persons	Total vehicle kilometres per capita	Private passenger vehicle kilometres per capita	Gross Regional Product per capita (US$1990)
American	*751*	*604*	*12,336*	*11,155*	*26,822*
Minimum	New York 557	New York 483	New York 9181	New York 8317	Phoenix 20,555
Maximum	Denver 1037	Portland 763	Sacramento 15,194	Sacramento 13,178	Washington 35,882
Standard deviation	119	87	1772	1470	4383
Australian	*595*	*491*	*8034*	*6571*	*19,761*
Minimum	Sydney 530	Sydney 448	Sydney 7051	Sydney 5885	Perth 17,697
Maximum	Perth 678	Adelaide 537	Perth 8861	Perth 7203	Sydney 21,520
Standard deviation	58	39	591	434	1594
Canadian	*598*	*524*	*7761*	*6551*	*22,572*
Minimum	Montreal 455	Winnipeg 412	Toronto 6051	Montreal 4746	Not collected
Maximum	Toronto 706	Calgary 630	Calgary 9201	Vancouver 8361	Not collected
Standard deviation	104	85	1257	1387	Not available
European	*452*	*392*	*5026*	*4519*	*31,721*
Minimum	Copenhagen 341	Copenhagen 283	Paris 4100	Paris 3459	London 22,215
Maximum	Frankfurt 526	Frankfurt 478	Frankfurt 6636	Frankfurt 5893	Zurich 44,845
Standard deviation	63	62	767	707	6036
Wealthy Asian	*217*	*123*	*2950*	*1487*	*21,331*
Minimum	Hong Kong 78	Hong Kong 43	Hong Kong 1459	Hong Kong 493	Singapore 12,939
Maximum	Tokyo 374	Tokyo 225	Tokyo 3795	Tokyo 2103	Tokyo 36,953
Standard deviation	149	93	1295	869	13,542
Developing Asian	*227*	*102*	*2337*	*1848*	*2642*
Minimum	Manila 86	Surabaya 40	Manila 901	Manila 732	Surabaya 726
Maximum	Kuala Lumpur 403	Bangkok 199	Kuala Lumpur 4944	Kuala Lumpur 4032	Seoul 5942
Standard deviation	125	65	1488	1263	1975

The data collected are registered vehicles by class of vehicle, including all commercial/freight vehicles and are usually obtained from vehicle registries or motor vehicle censuses as in Australia.

Vehicle kilometres data or VKT represent total annual travel by all vehicles, by class of vehicle on all roads. Data are most often obtained from land use-transportation planning models in each city or from other types of surveys, such as those conducted in consulting studies or the Australian Bureau of Statistics' Survey of Motor Vehicle Use in Australian cities.

Gross Regional Product per capita represents the total value of economic activity within the metropolitan region, or in some cases a broader job market area, divided by its own specific population. The data are usually derived from economic agencies or national statistical organisations. The data here represent the averages for a slightly smaller group of 37 cities for which these data were collected for the World Bank (see Table 1). GRPs were converted to 1990 US dollars using the Standard Drawing Right from the IMF. Purchasing Power Parities (PPP), developed by Summers and Heston (1988) have been used in recent years by the World Bank when publishing gross domestic product (GDP) data. The result is more stable rates and adjustments between capital-intensive and capital-extensive economies. There are, however, methodological problems in this approach, since the determination of buying power necessarily involves a selection of a range of goods whose price is then compared to calculate the exchange rate. The selection of goods introduces a weighting factor in favour of the goods chosen and thereby a value judgement by those choosing the goods. This is of particular relevance in the area of transportation and urban form. If the representative choice of goods used to calculate PPPs includes a car and a detached single-family house, areas with high taxation on cars for environmental reasons, and high densities, entailing a high premium on a detached home, will have their currency's purchasing power artificially undervalued. The methodology can't take into account that a car and a detached home may be lower on the list of consumer desires in cities which are not low density and car-dependent.

There were no data available for total vehicle kilometres of travel in Montreal, but based on the other data it is likely it would have been the minimum in the Canadian Cities.

GRP per capita of actual urban regions, not national economic data, is used here to specify the respective levels of wealth between cities (see note 3 to Table 2).

Vehicle ownership and use display the strong ascendency of the automobile in US cities compared to other cities around the world; US cities are 70% higher in car use than their nearest rivals, the Australian and Canadian cities, 2.5 times higher than the wealthier European cities and 7.5 times higher than the wealthy Asian cities. However, this gap between US cities and other cities in their automobile dependence is not as strongly expressed in the actual ownership of vehicles, as it is in their use. Table 3 shows in each case that US cities exceed total vehicle and car ownership rates by much lesser margins than they do use. For example, US cities have 1.5 times more cars per capita than in urban Europe and nearly five times more than wealthy Asian cities, but car use differences are much higher.

This is not meant to underplay the large differences that still do exist between US cities and other cities in absolute rates of vehicle ownership (clearly these are significant too, especially when compared to European or Asian cities), but vehicle use not ownership is the primary factor in determining outcomes such as congestion, fuel use and emissions, and the former clearly has a more significant pattern of variation than just ownership of vehicles.

These data tend to show that while cities may reach the financial capacity for high levels of car ownership, the actual need to use the cars differs greatly. For example, the data suggest that US cities may be building in more compulsory car use than other cities through very auto-dependent land use patterns and a general lack of viability of other modes because travel distances are long and activities are not concentrated enough for effective transit or non-motorised modes (see later). In addition, the hostile public realm of many parts of US cities can discourage people from using modes that expose them to threatening physical and social elements (Garreau, 1991; Calthorpe, 1993; Kunstler, 1993; Kenworthy and Newman, 1993).

An important point to note from Table 2 is the extent to which developing Asian cities, with much lower levels of wealth than their neighbours in Singapore, Tokyo and Hong Kong, already have higher levels of car use. With only 12% of the GRP per capita of wealthy Asian cities, we have explored in detail some reasons for this relatively high car use, which appear to relate most strongly to an absence of economic restraints on car ownership and use, poor transit options (almost no rail systems) and an emphasis on large-scale road building to solve congestion problems in the developing Asian cities (Ang, 1996; Phang, 1993; Poboon, 1997; Kenworthy et al., 1995; Tanaboriboon, 1993).

Table 3
Ratios of vehicle ownership and use in US cities compared to other cities

Cities	How many times US cities exceed other cities in total vehicle ownership	How many times US cities exceed other cities in total vehicle use	How many times US cities exceed other cities in car ownership	How many times US cities exceed other cities in car use
Australian	1.26	1.54	1.23	1.70
Canadian	1.26	1.59	1.15	1.70
European	1.66	2.45	1.54	2.47
Wealthy Asian	3.46	4.18	4.91	7.50
Developing Asian	3.30	5.28	5.92	6.04

The issue of wealth and its relationship to automobile use will be pursued later in the paper.

4.2. Transit service and use

To complement this picture of automobile use, it is important to also understand the patterns of transit provision and use. Table 4 summarises the average values for a number of key transit service provision and use variables within each major regional grouping of cities, together with standard deviations and the respective minimum and maximum values.

4.2.1. Transit service and transit trips

Not unexpectedly, the data show the US cities again to be the most automobile dependent, with not only scant transit service provision but also very low transit use. Residents of US cities only make one transit trip every six days or so, whereas, their nearest rivals in the Australian cities, make one trip every four days. It is, however, only in the Canadian cities where transit begins to look respectable with one trip every two days or so. From there it rises to much higher levels in European and developing Asian cities and peaks in the wealthy Asian cities at an average of about 1.4 trips per day by every man, woman and child. Manila's very high transit service is due to its extensive jeepney service using low capacity vehicles.

Although the developing Asian cities do very well in transit use in an international perspective, the discontinuity between them and their wealthier Asian neighbours is again apparent. The level of transit service per person in developing Asian cities is only marginally less than in the wealthy Asian cities, though the usage rate is 1.5 times higher in the wealthy Asian cities, due in all probability to the inferior type of transit service in developing Asian cities, dominated by run-down buses stuck in congested traffic. The type of transit services in developing Asian cities, which generally exclude high quality, high capacity urban rail systems, do not seem to be competing effectively with the automobile, despite residents of these cities generally having much lower incomes than in Singapore, Tokyo and Hong Kong (see Kenworthy et al., 1994, 1995).

4.2.2. Rail service

The above claims are borne out to a degree by the rail service per hectare data which show a very systematic relationship with transit usage across the international sample. The low transit using cities have poor rail service coverage which systematically increases along with transit use up to the wealthy Asian cities and then drops away dramatically in the developing Asian cities, in parallel with the big fall in overall transit use in these cities. Note the exceptional rail service density in Zurich and the fact that Zurich is the second highest transit using city in the sample, just behind Hong Kong.

4.2.3. Relative transit share

A perhaps more revealing factor about the importance of transit in cities is the proportion of all motorised passenger kilometres accounted for by transit – in other words, how much of actual passenger travel is captured by transit systems?

Table 4 shows that US cities have a tiny 3% of total motorised travel on transit. Australian and Canadian cities do a little better with 8% and 10%, respectively, while European cities have some

Table 4
Transit service provision and transit use in cities, 1990

Cities	Transit service kms per person	Rail service intensity (service km per urban ha)	Transit trips per person	Percentage of total motorised passenger kms on transit (%)
American	*28*	*153*	*63*	*3.1*
Minimum	Phoenix 10	Den., Det. Hou., LA, Pho. 0	Phoenix and Sacramento 15	Phoenix and Sacramento 0.8
Maximum	New York 63	New York 760	New York 155	New York 10.8
Standard deviation	16	226	47	2.8
Australian	*60*	*287*	*92*	*7.7*
Minimum	Adelaide 46	Canberra 0	Perth 54	Perth 4.3
Maximum	Sydney 94	Sydney 905	Sydney 160	Sydney 15.8
Standard deviation	18	340	37	4.2
Canadian	*58*	*390*	*161*	*10.2*
Minimum	Winnipeg 41	Ottawa, Winnipeg 0	Calgary 94	Winnipeg 6.2
Maximum	Toronto 98	Toronto 1469	Toronto 350	Toronto 23.6
Standard deviation	19	539	94	6.4
European	*92*	*3651*	*318*	*22.6*
Minimum	Frankfurt 48	Frankfurt 1283	Copenhagen 164	Frankfurt 12.1
Maximum	Zurich 148	Zurich 15,864	Zurich 515	Vienna 31.6
Standard deviation	36	4128	102	7.5
Wealthy Asian	*114*	*4914*	*496*	*64.1*
Minimum	Tokyo 89	Singapore 1722	Singapore 457	Singapore 46.7
Maximum	Hong Kong 140	Hong Kong 7863	Hong Kong 570	Hong Kong 82.3
Standard deviation	26	3078	64	17.8
Developing Asian	*108*	*639*	*334*	*40.2*
Minimum	Kuala Lumpur 50	Surabaya 0	Surabaya 174	Kuala Lumpur 20.0
Maximum	Manila 258	Seoul 3479	Manila 481	Manila 61.9
Standard deviation	79	1393	136	16.4

Transit trips are actual annual passenger boardings or unlinked trips on all transit modes and transit operators within each metro region. Most operators, as well as key umbrella organisations such as APTA report boardings, not linked transit trips. The Asian cities include not only the government run systems, but also the privately operated paratransit modes such as microbuses, minibuses and jitneys in some cities.

Vehicle kilometres of service are the annual revenue service kilometres on the same basis. For rail modes, "wagon" or car kilometres are used, not train kilometres (ie a six car train travelling 1 km is reported as 6 car kilometres). This is standard practice in transit reporting systems to reflect the greater capacity of rail modes.

The rail service kilometres per urban hectare are a measure of rail service intensity and are derived by adding all the annual car kilometres of service by all rail-based modes in each city and dividing by the urbanised hectares of land. Rail service kilometres are a component of the transit service kilometres in the previous variable.

The above data, in a majority of cases, come from annual reports of each transit operator or in some cases in the Asian region, from consulting reports. In US cities Section 15 reports from the former UMTA, now FTA, are used.

The percentage of total motorised passenger kms on transit is the annual passenger kilometres per capita on transit as a percentage of total motorised passenger kilometres per capita (ie the sum of private and public transportation passenger kilometres per capita). Private transportation passenger kilometres are derived by multiplying the vehicle kilometres in cars by the annual 24 hour/7 day vehicle occupancy, provided generally from transportation departments through surveys. Transit passenger kilometres are derived by multiplying annual boardings by the average trip length of each boarding. The calculation is done in steps for each transit mode and data come as a rule from surveys by transit operators or by inferences made by them about trip distances derived from other information such as ticket sales.

23% of motorised travel on transit and the wealthy Asian cities almost two-thirds of all motorised passenger movement on transit (64%). Hong Kong has a massive 82% of all motorised passenger travel on transit. As with transit trips per capita, this systematic improvement in the role of transit in cities follows an increasing orientation to rail within the transit systems (see also Section 4.3). The drop in developing Asian cities to 40% of motorised travel on transit follows the other patterns discussed and appears to be related to what might be called a "rail gap" in these cities compared to their wealthy neighbours (Kenworthy, 1996).

4.3. Journey-to-work patterns

A significant focus of a lot of urban transportation planning is the journey-to-work because of its links to the important peak period when both road and transit system capacity are most limited. Accordingly, Table 5 summarises the modal split for the journey-to-work, journey-to-work trip times and journey-to-work trip distances in the international sample of cities.

4.3.1. Modal split for the journey-to-work

Table 5 provides the percentage of workers using transit and foot and bicycle to work, the balance being those using private transportation. The data very clearly follow the patterns already established, with the most auto-dependent cities in the US and Australia having relatively small use of non-automobile modes to work (14–19%), systematically increasing through the regional groupings of cities to the wealthy Asian cities with 80% of people getting to work by transit, foot or bicycle. There is again a drop in the developing Asian cities to 56%, reflecting an inferior position for these non-auto modes relative to their wealthier counterparts, though still healthy by international standards (almost identical to the European cities).

An interesting point from the table is that where transit use to work is at a minimum in Europe (in Amsterdam and Copenhagen), walking and cycling to work are at a maximum. The same pattern is seen in the developing Asian region in the case of Surabaya.

4.3.2. Journey-to-work trip times

With such large differences in the means of travel to work it might be expected that there would be considerable differences in journey-to-work times across such a wide range of cities. The data however show that journey-to-work trip time remains roughly at the 30 min mark across all of the cities. The relatively small differences hardly seem significant when compared to the massive difference in use of cars between cities, and the fact that car use continues to be facilitated in many cities through road investment programmes largely predicated on providing time savings. The phenomenon is best understood by reference to historical studies on time budget theory which show that people everywhere have consistently chosen to spend on an average around half-an-hour travelling to work (Manning, 1978; Pederson, 1980; Zahavi and Ryan, 1980). The UK's SACTRA report (Standing Advisory Committee on Trunk Road Assessment) found "the average amount of time spent on journeys to work has remained stable for some six centuries" (SACTRA, 1994, p. 40).

One of the problems with attempting to reduce travel time, or for that matter fuel use and emissions by expanding road capacity is the phenomenon of induced traffic. This has been the subject of considerable debate and more recently the topic of in-depth research which has shown

Table 5
Characteristics of the journey-to-work in cities, 1990

Cities	Percentage of workers using transit (%)	Percentage of workers using foot and bicycle (%)	Journey-to-work trip time (min)	Journey-to-work trip distance (km)
American	*9.0*	*4.6*	*26.1*	*15.0*
Minimum	Phoenix 2.1	Detroit 2.0	Denver 22.3	Boston 10.1
Maximum	New York 26.6	Boston 7.4	New York 30.6	Houston 19.1
Standard deviation	7.5	1.5	2.8	2.6
Australian	*14.5*	*5.1*	*26.4*	*12.6*
Minimum	Perth 9.7	Perth 4.1	Perth 22.5	Sydney 11.5
Maximum	Sydney 25.2	Canberra 6.0	Sydney 30.3	Perth 13.7
Standard deviation	5.8	0.7	5.5	1.6
Canadian	*19.7*	*6.2*	*25.3*	*11.2*
Minimum	Edmonton 11.0	Calgary and Toronto 5.3	Na	Na
Maximum	Toronto 30.1	Winnipeg 8.0	Na	Na
Standard deviation	7.1	1.0	Na	Na
European	*38.8*	*18.4*	*28.2*	*10.0*
Minimum	Amsterdam/ Copenhagen 25.0	Frankfurt 8.5	Zurich 20.4	Brussels 5.6
Maximum	Stockholm 55.0	Amsterdam 35.0	Paris 35.0	Copenhagen 13.9
Standard deviation	8.7	8.5	4.4	2.3
Wealthy Asian	*59.6*	*20.3*	*38.6*	*10.0*
Minimum	Tokyo 48.9	Hong Kong 16.9	Singapore 33.1	Singapore 9.0
Maximum	Hong Kong 74.0	Singapore 22.2	Hong Kong 44.0	Hong Kong 10.9
Standard deviation	12.9	2.9	7.7	1.3
Developing Asian	*37.8*	*18.4*	*32.8*	*7.4*
Minimum	Surabaya 21.0	Bangkok 10.0	Surabaya 20.5	Surabaya 5.2
Maximum	Seoul 59.6	Surabaya 23.5	Seoul 41.2	Seoul 11.2
Standard deviation	15.8	4.8	7.9	2.2

Primary data are gathered on the actual number of trips by each mode for the journey-to-work. The data come from national population censuses and transportation survey results.
Journey-to-work trip length and time were only collected systematically for the slightly smaller sample of 37 cities used in the study for the World Bank. Hence, Toronto is the only Canadian city for which these data are available in this study. The US sample excludes Portland, Sacramento and San Diego for these two variables and in Australia they exclude Canberra. The data for journey-to-work trip distance and time were collected in each city from either census data which contain a question from which these data may be derived or from transportation surveys. The data are averages across all modes, including walking and cycling and reflect the correct modal split weightings.

the extent to which new roads generate extra traffic, rather than relieving congestion (Goodwin, 1994; SACTRA, 1994; Goodwin, 1997; Hansen and Huang, 1997). Our own research has shown why building high speed roads does not save fuel or reduce emissions (Newman and Kenworthy, 1988). Historically, other authors have shown how rail systems can also induce city spread and lengthen trip distances, thus tending not to save travel time (for example in Los Angeles; see Wachs, 1984). Today, many efforts to install new rail systems are accompanied by strategies to focus development around stations in mixed use, high density nodes in an effort to minimise sprawl and reduce car use (Bernick and Cervero, 1996; Cervero, 1998). Some cities have been very successful at minimising rail-induced city spread (e.g. Stockholm, Cervero, 1995).

On the available evidence, the economic use of time is likely to remain at around the same level, no matter what transportation policies are implemented.

4.3.3. Journey-to-work trip lengths

Unlike journey-to-work trip times, trip lengths more or less systematically increase with increasing auto dependence. This is borne out by calculating the overall journey-to-work trip speed for each city. This shows that journey-to-work trip speed drops consistently as cities become denser (see later), less automobile oriented and more oriented to transit and non-motorised modes. US city residents travel to work at an average speed of 35 km/h, Australians at 30 km/h, Torontonians at 27 km/h, Europeans at 22 km/h, residents of Singapore, Tokyo and Hong Kong at an average of 16 km/h and residents of less wealthy Asian cities at 14 km/h. The inevitable conclusion is that increased speeds are not used so much to save time as they are to travel further, while maintaining a more or less stable 30 min average journey-to-work trip time.

5. Some key economic data associated with the transportation patterns

Table 2 has already presented data on the comparative wealth levels of cities in this sample. Table 6 provides some additional key economic data associated with urban transportation in these cities, some of which can then be used in Section 6, along with land use and wealth data, to explore relationships between urban transportation patterns and other factors. First, a brief synopsis of the international patterns for each item is provided.

5.1. Economics of operating transit

Rather than focusing on transit's actual contribution to moving people, some debates focus more on what transit costs the community in terms of its operating subsidy. The debates are often couched in negative terms, with poor cost recovery being used as a reason why good transit can no longer be afforded and why it should be wound back. Cervero (1998) provides interesting discussions on this, showing the value of quality transit systems and the fact that some transit systems make operating profits. Table 6 reveals that the proportion of transit's operating costs recovered from the farebox follows very closely the level of auto dependence in the cities. The most bus-based, low density, car-dependent cities in the US and Australia have the worst operating cost recovery (e.g. Perth, Phoenix and Houston have a mere 28%, Detroit has only 23% and Denver only 19%). In such cities, even if fares are set reasonably high, it is difficult to have a high cost recovery because of the inherently higher cost structures of such systems (e.g. high labour input per passenger kilometre, low occupancy per service unit etc). At the other end, despite common perceptions that "transit never makes a profit", seven out of the 37 cities do in fact run at an operating profit. These are all the Asian cities apart from Bangkok and Seoul where the recovery rate is still very high at 93% and 97%, respectively.

The transit operating cost recovery debate tends to focus on how to reduce government costs. It often concludes that it would be much cheaper to provide only buses in cities as these have lower

Table 6
Selected economic data on the transportation systems of cities, 1990

Cities	Transit operating cost recovery (%)	Annual road expenditure per capita ($US, 1990)	Annual road expenditure per capita adjusted for wealth ($US, 1990 per $1000 of GRP)	Total costs of cars per km ($US, 1990)	Total costs of cars per km adjusted for wealth (millionths of GRP per km)	Percentage of GRP spent on operating all modes of passenger transportation (%)
American	*35*	*264*	*9.84*	*0.29*	*11.1*	*12.4*
Minimum	Denver 19	Los Angeles 175	San Francisco 6.36	Los Angeles 0.25	Washington 8.3	Washington 9.7
Maximum	Washington 50	Phoenix 399	Phoenix 19.41	Denver 0.36	Denver 14.8	Phoenix 16.4
Standard deviation	12	67	3.78	0.03	2.3	2.4
Australian	*40*	*142*	*7.18*	*0.37*	*18.8*	*13.2*
Minimum	Melbourne 24	Melbourne 89	Melbourne 4.22	Brisbane 0.30	Sydney 16.2	Sydney 10.4
Maximum	Sydney 55	Sydney 188	Brisbane 8.89	Adelaide 0.41	Perth 22.7	Perth 16.8
Standard deviation	14	38	1.90	0.04	2.7	2.6
Toronto	*61*	*150*	*6.65*	*0.28*	*12.2*	*7.4*
European	*54*	*135*	*4.26*	*0.48*	*15.4*	*8.1*
Minimum	Brussels 27	Vienna 72	Vienna 2.56	London 0.36	Zurich 10.3	Paris 5.0
Maximum	London 93	Zurich 185	Copenhagen 5.54	Stockholm 0.80	Stockholm 24.0	Stockholm 12.8
Standard deviation	18	41	1.11	0.12	3.4	2.1
Wealthy Asian	*119*	*88*	*4.13*	*0.63*	*32.7*	*4.8*
Minimum	Tokyo 105	Singapore 63	Tokyo 2.94	Tokyo 0.29	Tokyo 7.8	Tokyo 3.1
Maximum	Hong Kong 136	Tokyo 109	Hong Kong 6.64	Hong Kong 0.79	Hong Kong 56.1	Singapore 7.2
Standard deviation	16	24	1.85	0.26	24.3	2.1
Developing Asian	*113*	*35*	*13.31*	*0.21*	*115.2*	*15.9*
Minimum	Bangkok 93	Surabaya 10	Kuala Lumpur 4.50	Surabaya 0.10	Kuala Lumpur 45.0	Seoul 8.5
Maximum	Kuala Lumpur 135	Seoul 72	Manila 21.10	Manila 0.30	Manila 276.6	Kuala Lumpur 18.9
Standard deviation	18	28	5.97	0.07	89.8	3.8

Toronto was the only Canadian city for which these economic data were collected.
Although Beijing was part of the study for the World Bank, it is not included in the developing Asian cities here because full data were not available for the broader transportation data reported in previous sections (i.e. the previous sections excluded Beijing too).
The transit operating cost recovery data are derived from the financial operating cost and fare revenue data obtained from all operators for all modes in each city. The data do not include capital items or servicing of capital debt. Most data are direct from annual reports, while some in developing cities are derived from research published in consulting studies.
The data on road expenditure represent all spending by all levels of government and the private sector on all classes of roads for construction and maintenance averaged over a three period, generally 1989, 1990 and 1991 or 1990, 1991 and 1992. The data are from finance departments, road agencies and local government sources. This is perhaps the most difficult data item of all to obtain comprehensively in any city.
The total fixed and variable costs of cars per kilometre were retrieved in most cases from national automobile associations. In most cases, a Toyota Corolla was used as a reference make of car, while in some European cases, the Volkswagen Golf was used. In both cases, the variety of car with a 1600 cc engine was chosen. For the US, the results of the extensive cost study commissioned by the Conservation Law Foundation (1994) and supplied by the American Automobile Association were used. In all cases, the capital and other fixed costs per kilometre, which are always provided based on an assumption of total annual kilometres driven, were adjusted for the actual annual kilometres driven in every car in the cities concerned (based on data in the present study). Fixed costs assume an average vehicle life of 10 years. Variable costs include all fuel purchases, registration, insurance, maintenance and so on and also all tolls paid in cities on roads and bridges. The data do not include any time costs of travel or parking.
The total operating costs of passenger transportation are calculated by combining the data on private and public transportation use in each city with the specific direct fixed and variable costs of cars per kilometre and transit operating costs per kilometre in each city, and then expressed as a percentage of total GRP. Transit cost includes the subsidy to transit, or the profit as the case may be, because it takes the full operating costs of the transit system in each city or the full operating revenue, whichever is largest.

capital and sometimes lower maintenance requirements. However, these data suggest that buses are only effective in recovering operating costs in situations where there are large number of captive users, as in developing Asian cities such as Manila where transit operates at a 122% cost recovery. It would appear that buses in developed cities, no matter how cut down the systems become to make them more efficient, do not recover a high proportion of operating expenses. Rather, the city becomes less effective in transit delivery, leading to a downward spiral in use and farebox revenue.

The more fundamental way to recover transit operating costs in developed cities would appear to be to gradually develop a more transit-oriented urban system, where urban structure better supports transit use. The role of rail systems in influencing and facilitating this appears to be very important (Cervero, 1995, 1998; Bernick and Cervero, 1996).

5.2. Road expenditure

Data collected on infrastructure supply patterns in this study show that in terms of road length per capita, the patterns again essentially follow that of automobile dependence with US and Australian cities having 6.8 and 8.3 m of road per capita, respectively, followed by Canadian cities with 4.7, European 2.4, wealthy Asian 1.8 and developing Asian 0.7 m per capita (these are total centreline lengths, covering all road types down to residential streets). It is important to see these international patterns of road supply in relation to their economic costs. The data in Table 6 provide this, both as straight per capita figures in US$1990 and as expenditure per US$1000 of GRP to take account of the vastly different levels of wealth in the cities.

Simple per capita road expenditure basically follows the pattern of automobile dependence in the sample of cities. There is a higher level of maintenance spending in North American and Australian cities due to their larger amount of roads per capita, but considerable road building is still occurring in these auto-based cities. When the data are standardised to take account of wealth, the pattern is essentially retained, except that in the developing cities, road spending is very much higher than in any other group of cities (1.5 times US spending). Manila is spending US$21.10 per US$1000 of GRP, or over twice the relative level in the US, as it and other developing cities attempt, without success, to build their way out of escalating congestion problems.

5.3. The cost of cars

The cost of buying and running a car, especially the cost of fuel, is often thought to be a major determinant of car ownership and use (e.g. Kirwan, 1992). The present study collected all the fixed and variable costs of cars in each city according to the method summarised in footnote (5) of Table 6. These data represent a more complete picture of the true cost of cars in each city than just gasoline price. The data are expressed both in raw figures and normalised for the different levels of wealth in each city. This is achieved simply by dividing the raw cost figures by the GRP per capita and expressing the result as millionths of GRP per vehicle kilometre.

The data in general show, and not surprisingly, that cities with lower car costs do tend to be more automobile dependent. However, there are some obvious anomalies. First in the raw costs data, Toronto has essentially the same car costs as US cities and yet Toronto's car use is 50% that of the US cities. The raw cost of cars in developing Asian cities is the lowest of all, but of course these cities have almost the lowest level of car use of all cities (just marginally more than their wealthy Asian neighbours). When car costs are adjusted for wealth, the pattern again shows cities with lower car costs generally to be more auto dependent, though there are still discrepancies. Again, the costs of cars in Toronto and US cities are almost the same, but car use varies widely. Relative to wealth, the total cost of cars per kilometre is actually cheaper in European cities than in Australian cities and yet car use in European cities is some 31% lower than in Australian cities. Developing Asian cities are shown here to have very high costs of cars, 3.5 times that of the wealthy Asian cities and yet car use is actually marginally higher. These data are pursued further in Section 6.

5.4. The costs of operating passenger transportation in cities

The last data item in Table 6 attempts to express the relative costs of operating both the private and public passenger transportation systems in cities by taking the total direct costs of both private and public transportation and expressing this as a proportion of each city's GRP (ie how much of a city's wealth is expended on passenger transportation?). Footnote (6) explains the method. In an era when the cost of all services within society are coming under the economic microscope, regardless of real or perceived benefits, it is useful in its own right to see cost data for transportation more clearly expressed.

The data suggest that in general within the developed cities, the proportion of wealth expended on passenger transportation declines as automobile dependence declines (for example, it is about 12–13% in US and Australian cities and 5% in wealthy Asian cities). This breaks down in the developing Asian cities where GRPs are very low and some 16% of wealth is spent on passenger transportation. Again these data are pursued more in Section 6.

6. Relationships between transportation, land use and economic factors

This section takes the foregoing data, combines it with some key land use data on the cities and examines some of the simple bivariate relationships which emerge. The international comparison of cities in this study collected a wide array of data on land use in each of the cities including the population or urban density of the whole city, its employment density and the same data for the CBD, inner and outer areas. It also examined the degree of centralisation of each metropolitan region by examining the proportion of population and jobs in both the CBD and inner areas (Kenworthy et al., 1999).

For the purpose of analysis in this paper, the data will be restricted to the key urban form factor we have examined in previous work, that is the urban density of each city (see Newman and Kenworthy, 1989). Urban density is a critical factor in understanding transportation patterns through its influence on trip length and the viability of transit and non-motorised modes. The urban density data are defined and summarised in Table 7.

6.1. Car ownership, car use and wealth

Using the GRP data presented in Table 2, it is possible to examine average annual car use per person in the groups of cities against GRP per capita (Fig. 1). This reveals that North American

Table 7
Urban density in the international sample of cities, 1990

Cities	Urban density (persons per hectare)
American	*14.2*
Minimum	Houston 9.5
Maximum	Los Angeles 23.9
Standard deviation	3.9
Australian	*12.3*
Minimum	Canberra 9.6
Maximum	Sydney 16.8
Standard deviation	3.0
Canadian	*28.5*
Minimum	Calgary and Vancouver 20.8
Maximum	Toronto 41.5
Standard deviation	7.9
European	*49.9*
Minimum	Copenhagen 28.6
Maximum	Brussels 74.9
Standard deviation	12.8
Wealthy Asian	*152.8*
Minimum	Tokyo 71.0
Maximum	Hong Kong 300.5
Standard deviation	128.2
Developing Asian	*166.4*
Minimum	Kuala Lumpur 58.7
Maximum	Seoul 244.8
Standard deviation	61.9

Densities are all based on actual urbanised land area which excludes all regional scale open space, undeveloped land, forests, agricultural land and water bodies. Total land area is not used. Urbanised land includes all road and streets, all developed land and all local open spaces. Data are obtained for each metropolitan region from detailed land use data.

and Australian cities have considerably higher car use per capita than European and Asian cities, higher than would be expected, just considering the level of wealth.

The data show that the large US cities in this sample have:

- 1.66 times higher car use than the major Australian cities but are only 1.36 times higher in GRP;
- 2.17 times higher car use than metropolitan Toronto but are only 1.19 times higher in GRP;
- 2.41 times higher car use than the average European city but actually have only 0.85 the level of GRP per capita;
- 7.3 times higher car use than the wealthy Asian cities but have only 1.26 times the level of GRP per capita.

If we examine this in more detail and correlate GRP with per capita car use, the above observations are confirmed. First, by eliminating the developing Asian cities from the analysis due to

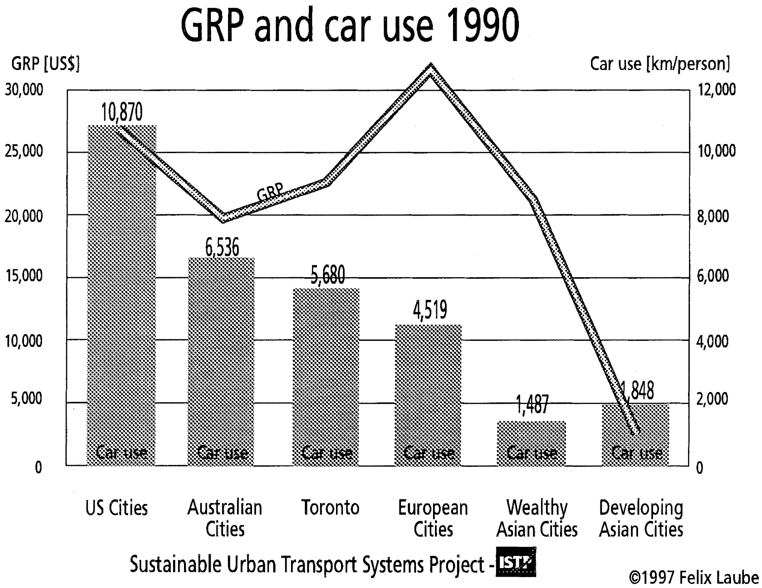

Fig. 1. Car use versus wealth in cities, 1990.

their very low wealth, we find that amongst the developed cities in North America, Australia, Europe and Asia there is virtually no relationship between wealth and car use ($r^2 = 0.070$ and $r = +0.264$). This is shown in Fig. 2. Furthermore, even car ownership only bears a very weak relationship ($r^2 = 0.159$ and $r = +0.399$).

With the developing cities included, however, the relationship of car use with wealth improves considerably due to their very low wealth and very low car use ($r^2 = 0.445$ and $r = +0.667$). Nevertheless, there is still a lot of scatter in the relationship, as shown in Fig. 3.

6.2. Car ownership, car use and land use

If we contrast the relationship between land use and car ownership and car use against the above relationships with wealth by correlating urban density with these factors, we find much stronger statistical patterns.

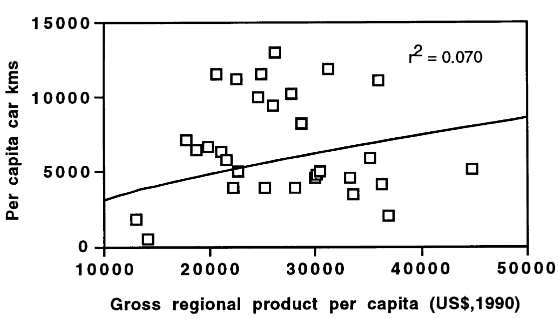

Fig. 2. GRP per capita versus car use per capita in developed cities, 1990.

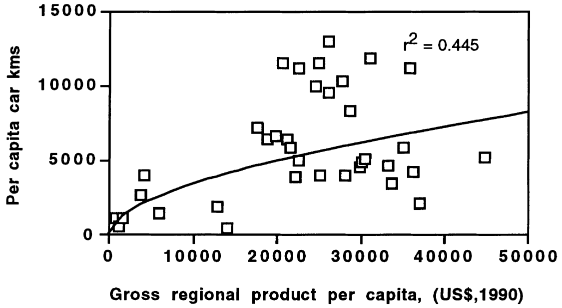

Fig. 3. GRP per capita versus car use per capita across developed and developing cities, 1990.

6.2.1. Developed cities

First, if as above, we consider just the developed cities, the correlation of urban density with car use shown in Fig. 4 reveals an r-squared of 0.753 ($r = -0.868$). It might be argued that the high density city of Hong Kong is distorting this result. However, if it is removed, the relationship is still almost as strong ($r^2 = 0.706$ and $r = -0.840$). The line of best fit, however, becomes exponential as opposed to the power function in Fig. 4, although the power function is still highly significant ($r^2 = 0.671$ and $r = -0.819$). As with car use, car ownership in developed cities is also strongly correlated with urban density ($r^2 = 0.768$ and $r = -0.877$).

6.2.2. Developed and developing cities

If we repeat the same correlations including the developing cities, as in Fig. 5, we find the relationship between car use and urban density to be somewhat strengthened ($r^2 = 0.821$ and $r = -0.906$). This also ratifies the inclusion of the very high density city of Hong Kong in the previous analysis, since a number of developing cities with high density leading up to Hong Kong fit the relationship well. Looking at urban density versus car ownership, an even slightly stronger relationship is found ($r^2 = 0.838$ and $r = -0.915$).

In summary, the relationships between car use, car ownership and land use, as characterised by metropolitan scale urban density, are indeed very strong with little evident scatter, both within just the developed cities and even more so when developing cities are included; as density increases, both car ownership and use decline. By contrast, the relationship between city wealth and

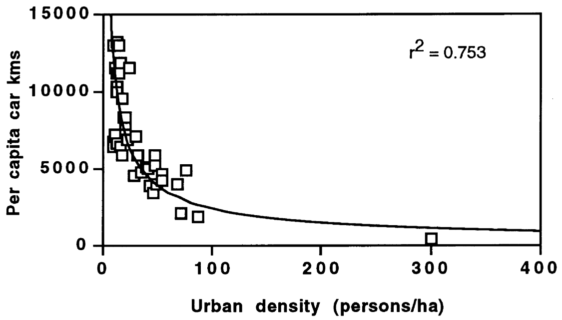

Fig. 4. Urban density versus car use in developed cities, 1990.

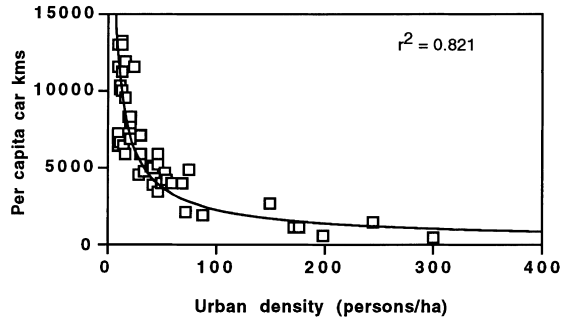

Fig. 5. Urban density versus car use in developed and developing cities, 1990.

car use and car ownership within the developed cities is very tenuous and characterised by a large amount of scatter in the data. Not surprisingly, this is improved when developing cities are included, though the relationship is still nowhere near as strong as with urban density (cf. Figs. 3 and 5).

6.3. Transit use, wealth and urban form

On the other side of the equation, it is sometimes assumed that transit use necessarily declines and becomes more marginal as societies become wealthier and more auto oriented (e.g. Lave, 1992). Intuitively from the data in this study, such a position would be hard to sustain with Zurich, the wealthiest city, also having close to the highest transit use per capita (Tables 2 and 4). Correlating the relative share of transit in the transportation task from Table 4 (percent of total motorised passenger kilometres on transit) with city wealth yields virtually no significant statistical relationship at all. With only the developed cities, the best fit provides an *r*-squared of only 0.033 (i.e. almost totally random data). Including developing cities, which have low wealth and relatively high transit use, the fit is marginally better with an *r*-squared of 0.180, but the scatter is still enormous (Fig. 6).

Looking at the same relationships with urban density, the analysis shows a very strong correlation in both the developed city sample ($r^2 = 0.744$ and $r = +0.862$) and that which includes the

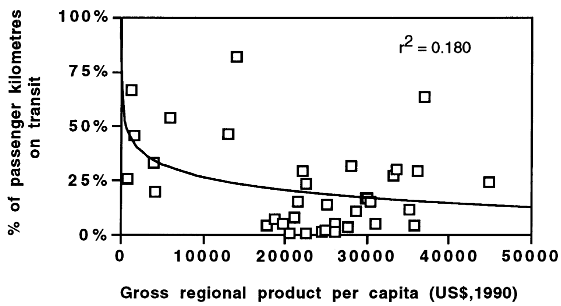

Fig. 6. GRP per capita versus the proportion of total motorised travel on transit in developed and developing cities, 1990.

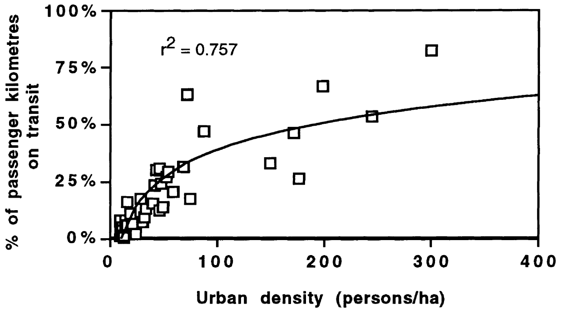

Fig. 7. Urban density versus the proportion of total motorised travel on transit in developed and developing cities, 1990.

developing cities is almost the same ($r^2 = 0.757$ and $r = +0.870$). Fig. 7 shows just the latter relationship.

In summary, the same general pattern emerges with transit use in cities as with car use. The urban form of the city, as expressed by density, has a much stronger relationship with the level of transit use than does city wealth; as density rises, transit use also rises in quite a systematic way.

6.4. Car ownership, car use and the cost of cars

It is frequently suggested that the costs of private transportation are a major factor in how much it is used and that charging higher prices, (especially for fuel), which better reflect true costs to society, is the key way to reduce car use (for discussions on this see for example: Kirwan, 1992; Gomez-Ibañez, 1991; Brotchie, 1992; Newman et al., 1995). Using the detailed city data on the fixed and variable costs of cars summarised in Table 6, it is possible to examine automobile dependence in relation to what people have to pay for private passenger transportation. Table 8

Table 8
Correlations between the cost of cars and car ownership and use in cities, 1990

	Developed cities	All cities
Total cost of cars per kilometre with:		
Car ownership		
r^2	0.316	0.049
r	−0.562	+0.222
Car use		
r^2	0.458	0.049
r	−0.677	−0.221
Total cost of cars per kilometre adjusted for wealth with:		
Car ownership		
r^2	0.652	0.709
r	−0.807	−0.842
Car use		
r^2	0.561	0.652
r	−0.749	−0.808

summarises these results by correlating the total fixed and variable costs of cars per kilometre (adjusted and unadjusted for wealth) against car ownership and car use, both for the whole city sample and just for developed cities.

The analyses reveal that:

(1) When the raw cost of cars per kilometre, (unadjusted for wealth) is used in the whole sample of cities, there is no significant relationship with either car ownership or car use.
(2) When the same correlations are made, but this time with the car costs adjusted for city wealth, there is a strong relationship with both car ownership and car use, both factors declining as costs increase (65–71% of variance accounted for).
(3) If the much poorer developing cities are removed from the analyses and only developed cities are considered, then unlike in the whole sample, the raw cost of cars does have a significant relationship with both car use and car ownership, though there is considerable scatter with the percentage of variance explained by the relationship being only 32–46% (Fig. 8 shows the correlation with car use).
(4) Finally, if the adjusted costs of cars per kilometre are correlated with car ownership and use in the developed city sample only, the relationship is strengthened relative to that in (3) above with 56–65% of variance explained (Fig. 9 shows the correlation with car use).

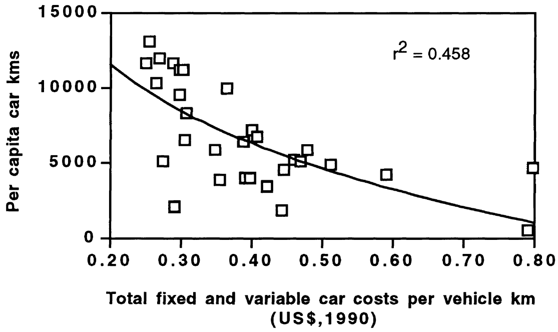

Fig. 8. Cost of cars versus car use in developed cities, 1990.

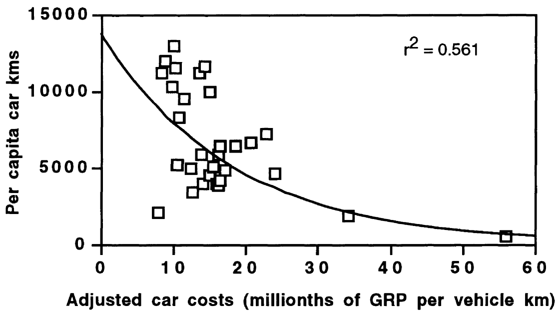

Fig. 9. Adjusted cost of cars versus car use in developed cities, 1990.

It can be concluded from this analysis that the cost of cars needs to be adjusted to take account of city wealth in order to produce consistent and meaningful results in relationship to car ownership and car use. When this is done the total cost of cars per kilometre bears a strong relationship to both car ownership and use across the entire city sample, though a little less so within just the developed city sample. Overall, although these relationships are significant and clearly important, they are not as strong as the relationships between car ownership, car use and urban density (see Section 7).

6.5. Transit use and car costs

It might be expected that the cost of cars would bear a strong relationship to transit use. Examining the percentage of total motorised passenger kilometres on transit in relation to both the adjusted and unadjusted cost of cars in cities, it is found that both within the developed cities and to a lesser extent across all the cities, high car costs are positively associated with transit use (except the unadjusted costs across the entire sample where the r-squared is only 0.072). The relationship is the strongest with costs adjusted for wealth. Across all the cities, the relationship has an r-squared of 0.345 ($r = +0.588$) and for the developed cities only the r-squared is a little better at 0.386 ($r = +0.621$). Although significant, the relationship of transit use with urban density is much stronger (see Fig. 7).

6.6. The total costs of operating passenger transportation

The last column of Table 6 provides an important measure of the overall operating costs of urban passenger transportation by showing what proportion of a city's wealth is accounted for by expenditures on the operation of private and public transportation. Using the data presented here, does this factor bear any relationship to automobile dependence, transit use, the cost of cars or urban density across an international sample of cities? Table 9 attempts to provide insights into this question.

The following conclusions can be drawn.

(1) The low wealth of the developing cities means that they tend to have an artificially high proportion of that wealth spent on transportation and thus relationships with all five factors in Table 9 are necessarily weak (r-squared values do not exceed 0.261).

Table 9
Correlations between the proportion of wealth spent on operating passenger transportation systems and various other factors, 1990

Correlation of the percentage of GRP spent on the operation of passenger transportation with:	Developed cities		All cities	
	r^2 value	r value	r^2 value	r value
Car use per capita	0.597	+0.773	0.100	+0.317
Percentage of total passenger km on transit	0.708	−0.841	0.223	−0.473
Unadjusted cost of cars	0.076	−0.276	0.261	−0.510
Adjusted cost of cars	0.043	−0.207	0.226	+0.475
Urban density	0.620	−0.788	0.068	−0.260

(2) This is not the case in the developed cities where wealth levels are similar and thus comparable. Within this sample, the data suggest that the higher the automobile dependence in a city, the higher proportion of its wealth tends to be spent on operating its passenger transportation systems. Car use per capita is positively correlated with overall passenger transportation operating costs with an r-squared of 0.597 (Fig. 10) and the proportion of travel on transit is strongly negatively correlated with an r-squared of 0.708, as shown in Fig. 11.

(3) Neither of the car cost variables is at all significantly related to the overall proportion of wealth spent on operating passenger transportation in the developed cities.

(4) As urban density increases within developed cities, the overall proportion of wealth spent on operating passenger transportation declines, as shown in Fig. 12 ($r^2 = 0.620$). In other words, sprawling low density cities appear to be paying more for passenger transportation. It should be noted that removal of Hong Kong, which is of very high density, does not change the shape or strength of this relationship in any greatly significant way ($r^2 = 0.586$).

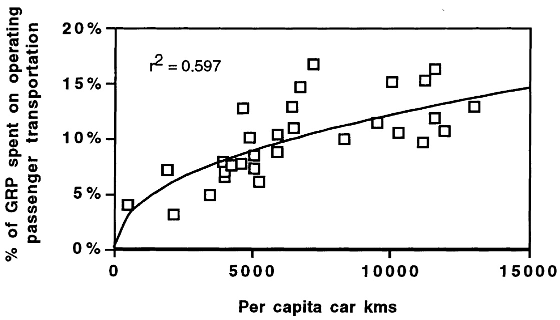

Fig. 10. Car use per capita versus the proportion of GRP spent on operating passenger transportation in developed cities, 1990.

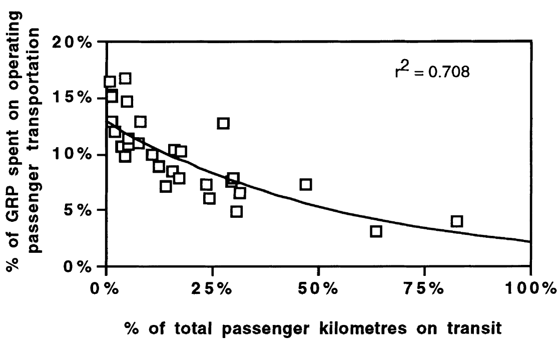

Fig. 11. The proportion of travel on transit versus the proportion of GRP spent on operating passenger transportation in developed cities, 1990.

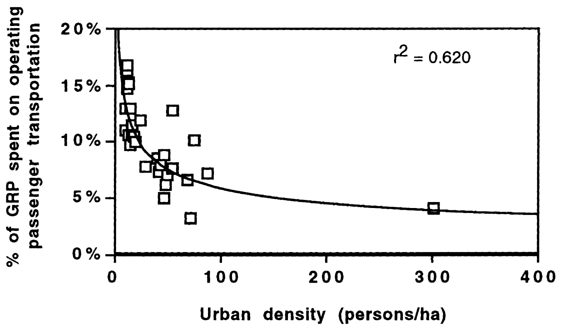

Fig. 12. Urban density versus the proportion of GRP spent on operating passenger transportation developed cities, 1990.

7. Summary and conclusions with implications for urban policy

The data in this paper suggest some clear and systematic patterns of variation in the key physical parameters which describe the degree of automobile dependence in cities. US cities clearly lead the world in dependence on the automobile. The pattern of auto dependence then fairly systematically declines through Australian, Canadian, European and wealthy Asian cities, with a jump upwards in the developing Asian cities, despite lower levels of wealth and land use characteristics which are inherently suitable for high levels of transit and non-motorised mode use.

Some of the key points and policy conclusions which appear to flow from the research in this paper are:

(1) *The wealth of cities does not alone provide reliable or consistent evidence in explaining the degree of automobile dependence in different cities.*

Many analyses tend to suggest that it is simply inevitable for automobile dependence to grow in cities as people become more wealthy and as cars become more affordable. Likewise, transit is seen more and more as the weary battler as people develop greater financial capacity to afford private transportation. This whole process of the takeover of urban transportation by the automobile and the decline of transit is seen by some as an "irresistible force" (Lave, 1992). Of course, growing wealth is a powerful force in shaping the possibilities and choices offered to cities in the development of their transportation systems and is always a force to be reckoned with, as any city would readily recognise.

This paper, however, refutes the idea that automobile dependence is simply "inevitable", since within the developed cities with comparable wealth levels, car use per capita, car ownership and transit use bear little relationship with wealth and even when developing cities are included the scatter is large and the r-squared values quite low. Quite clearly some wealthy cities, particularly in Europe and Asia, have the automobile much more under control and are achieving good results in transit and its competitive position with respect to the automobile. Public policy in such cities appears to be able to shape the urban system into a much less auto-dependent form (Pucher and Lefèvre, 1996).

(2) *In contrast to city wealth, urban form, in particular higher urban density, is consistently associated with lower levels of car ownership and car use, higher levels of transit use, and lower total costs of operating urban passenger transportation systems.*

Correlations between urban density and these factors provide very strong *r*-squared values, unlike the scatter found in the same relationships with wealth. Higher urban density would thus appear to be a positive factor in minimising automobile dependence and its associated direct economic costs.

For Asian cities, which already have among the highest urban densities in the world, the challenge would appear to be to ensure that the form of future development remains strongly oriented to transit and non-motorised modes. This has to be achieved under increasingly strong pressure to build western style low density, heavily zoned areas in response to growing car and motor cycle ownership. By contrast, lower density, more automobile-dependent cities need to find ways of strategically increasing densities. This can occur in their central and inner areas and around transit nodes in order to facilitate both transit and non-motorised mode use, as well as in outer areas so that new development becomes more centred and transit-oriented using concepts drawn, for example, from the New Urbanism (Katz, 1994; Calthorpe, 1993; Energy Victoria et al., 1996). The growth of cities outwards needs to be curtailed, perhaps with the assistance of greenbelts and urban growth boundaries (Wake, 1997).

Although overall metropolitan density will rise only slowly, this does not negate the need to consider this important factor. Others have clearly shown the way in which automobile dependence varies consistently within cities at different urban densities (e.g. Holtzclaw, 1990, 1994 for the San Francisco region and INRETS, 1995 for the Paris region). Even within the Los Angeles county, transit use varies from a low of 9 trips per capita in the lowest density areas up to 175 trips per capita in the highest density sectors (Kenworthy and Newman, 1994). The latter usage is higher than the New York region's per capita transit use. Through awareness of the importance of urban density, an urban region can gradually reshape its transportation patterns by strategically developing areas and centres that are denser, more mixed in land use and more oriented to transit and non-motorised modes (see, for example, Cervero, 1998). Such a process does not involve wholesale redevelopment of suburbs and can happen relatively quickly, as for example in Vancouver.

(3) *The cost of cars in terms of the total fixed and variable costs per kilometre is an important policy factor to consider in any efforts to reduce automobile dependence.*

Correlations of car costs with car ownership and use show that as costs increase the former decline. Likewise, transit's role within the transportation system is higher where car costs are greater. The strength of the relationship between car costs and automobile dependence is, however, not as strong as that between urban form and automobile dependence. In addition, unlike urban density, car costs are not at all strongly related to the proportion of a city's GRP spent on operating passenger transportation.

In terms of policy, it would appear that physical planning strategies to reduce automobile dependence, such as targetted increases in urban density, need to work in concert with economic policies that seek to charge more for car ownership and use in cities, and vice versa. Singapore, as well as Hong Kong and Tokyo are good examples of cities where the costs of car ownership and use have been set high for many years and physical planning strategies have emphasised development patterns oriented to transit, walking and cycling (Barter, 1998). Mustering the political will, however, to set significantly higher charges for car ownership or car use through any of the mechanisms potentially available to governments, remains elusive in a majority of cities. Notwithstanding this very real practical problem in attempting to reduce auto ownership and/or use through pricing mechanisms, it would appear that neither the land use nor economic policy arenas can afford to ignore the other, and if they work together considerable synergy for reducing automobile dependence would appear to be possible.

(4) *There appear to be no obvious gains in economic performance from developing auto dependence in cities, particularly as it is manifested in US and Australian cities.*

There is no relative gain in GRP per capita and the costs of operating the overall passenger transportation systems assume a higher proportion of a city's GRP in more auto-dependent cities. Furthermore, trip times to work are roughly the same everywhere, while trip distances to work are significantly longer, recovery of transit operating costs is much worse and road expenditure for construction and maintenance is higher due to greater per capita road provision in auto-dependent cities.

(5) *European and wealthy Asian cities appear to have both the most economically cost-effective and sustainable urban transportation systems.*

However, in terms of their own local sustainability goals, as well as global sustainability imperatives, they all still need to do better in terms of car use, which is growing in most of these cities, though not at the same rate as in US cities (see Newman and Kenworthy, 1999).

(6) *Rapidly developing Asian cities have considerably less economically cost-effective and sustainable urban transportation systems than would be expected from their levels of wealth, and especially when compared to their wealthier Asian neighbours.*

The main reasons for this appear to relate to a combination of: inferior transit systems based on buses caught in severe traffic congestion rather than rail systems as in Singapore, Tokyo and Hong Kong; a transportation infrastructure programme which emphasises major road building; a rapidly deteriorating situation for non-motorised transportation and a lack of any economic disincentives to car use as in the wealthy Asian cities (Ang, 1996; Phang, 1993; Kenworthy et al., 1994, 1995).

The positive side, however, is that developing Asian cities still have highly transit-oriented urban forms with strong corridors of development which are ideal for high capacity transit systems. The value of mass transit systems in dense urban environments has been demonstrated in the cases of Singapore, Hong Kong and Tokyo. All the data here would strongly suggest that for future urban growth, developing Asian cities will need to move towards higher quality transit which is competetive with the automobile, if they are to achieve more economic benefits, as well as some obvious environmental and social benefits for their cities. Together with the creation of conditions which are much more amenable to the use of non-motorised transportation, developing Asian cities appear to have the potential to be rapidly transformed into more sustainable patterns.

(7) *Cities with a higher level of rail service within their transit systems generally have better utilised transit and lower automobile dependence.*

The data in this study on rail service levels and overall transit use make it difficult to ignore the significance which rail systems appear to have in enhancing the role of transit in cities. For example, looking just within the US cities sample at those with and without rail systems, it is found that those with rail systems have some 117 annual transit trips per capita, while those that have only buses have 30 trips per capita. This is not to undermine the critical role which buses play in any transit system, including those with strong rail systems. However, transportation strategies in both developed and developing cities aimed at reducing automobile dependence need to carefully consider the potential of rail to provide a strong, permanent, reliable and highly visible backbone to a transit system which is well-equipped to provide services competitive with the automobile. Data collected as part of this study show that it is only in the European and wealthy Asian cities, where rail plays the largest role in transit systems, that the overall operating speed of transit exceeds that of general road traffic due to the superior speed of the rail systems (Kenworthy et al., 1999).

(8) *Non-motorised transportation is significant in both economic and environmental terms in that walking and cycling contribute almost nothing to the cost picture for urban transportation compared to motorised modes and involve almost negligible environmental costs.*

Cities which implement plans for improving the contribution of non-motorised transportation are likely to see immediate and long term benefits. Such strategies can include traffic calming and pedestrianisation schemes, dedicated on and off-road bicycle schemes, better storage facilities for bikes, more direct, safe connections for pedestrians and cyclists, and so on (Whitelegg, 1993; Pucher, 1998; Pucher and Lefèvre, 1996).

In summary, this international comparison suggests that increasing automobile dependence and declining transit and non-motorised mode use in cities are not inevitable. Rather, they appear to be responsive to public policy which seeks to minimise such trends through effective land use planning, transportation infrastructure and service delivery policies directed more towards non-auto modes and through economic policies which set higher charges for auto ownership and use.

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