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Trends in Vehicle Kilometres of Travel in World Cities, 1960-1990: Underlying Drivers and Policy Responses.

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Abstract

Increases in private motorised urban vehicle kilometres of travel are shown to arise from population growth, urban sprawl, increased car ownership and decreases in vehicle occupancy. In particular, the worldwide increase in urban mobility since 1960 has been the direct result of increased affluence and the consequent greater accessibility of private motor vehicles, as well as population growth. Urban sprawl has significantly less influence, although it has been significant in USA, Canadian and Australian cities. Despite this, a number of cities have shown that clear policy initiatives can contain the growth of urban private motorised mobility.

Key words: urban mobility, transport planning, urban planning, vehicle kilometres of travel, urban air quality, compact city, urban sprawl, transport modelling

1 Introduction

Private motor vehicular transport is a primary cause of the observed decline in urban air quality and the significance of motor vehicle use is increasing in many urban areas (Anderson *et al.*, 1996). Thus, improved urban air quality requires an understanding of motor vehicle usage and the ability to predict likely changes, particularly in vehicle kilometres of travel (*vkt*), which has been used as a surrogate for vehicular emissions (*eg.*, Lyons *et al.*, 2003). Meyer (2000) highlighted the conceptual interaction of many different variables that result

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in urban travel and, in particular, urban travel by automobile. He argued conceptually that such relationships should be able to be used in most urban areas to describe resulting travel characteristics, with some cultural modifications made to the underlying social and economic characteristics. In general, job growth and associated increasing household income create a market demand for increasing transport. Yet this conceptual argument does not provide a basis for predicting future *vkt* nor understanding the consequences of policy decisions in individual cities. Nor does it necessarily address all the complex factors that underpin observed private motorised mobility in cities. Nevertheless, there is need for a simple model of private motorised mobility that predicts *vkt* to a reliable level, using modest and relatively easily obtained aggregate data at a metropolitan area level. Such a model could form the basis of the assessment of future transportation demand and mobile-source emissions in cities, especially where only rudimentary data are available (Cambridge Systematics Inc., 2003).

Rienstra *et al.* (2000) used past trends to predict the future but recognised that unlimited infrastructure expansion is neither realistic nor feasible. Hence any model of private motorised mobility needs to recognise the constraints imposed by the travel time budget of individuals, saturation of car ownership and the impact of population growth. Notwithstanding the potential difficulties in predicting private motorised mobility as noted by Meyer (2000), Dendrinis and Mullally (1985) have suggested that in spite of micro-level complexity in urban systems, basic insights into urban evolution can be obtained by making relatively few strategically placed macro-level observations of urban growth and form. Furthermore, Longley and Mesev (2000) have argued that the time is now ripe to renew the quest for generalisation across urban systems. In order to do this, complex tasks such as understanding private motorised mobility, need to be reduced to some clear macro-level observations.

This led Cameron *et al.* (2003) to develop a model for private motorised mobility based on the application of dimensional analysis to a selection of key drivers of mobility in cities. Such an approach is based on the premise that a dimensionally homogeneous relationship exists between the controlling parameters of private motorised mobility and argues that dimensional homogeneity is a necessary but not sufficient condition for the validity of any equation so derived (Moon and Spencer, 1949). They developed an equation which, through dimensional homogeneity, is formally independent of the choice of units and is based on the principle that all urban areas exhibit systematic behaviour as noted by Meyer (2000). This echoes the findings of Dendrinis and Mullally (1985), and Cameron *et al.* (2003) extended their ideas specifically into the field of predicting patterns of private motorised mobility to a relatively high level of certainty, through the use of only the key *driving* variables. The potentially complex matter of understanding a city's level of private transport use, is thereby reduced to a small number of reasonably accessible urban data

items.

Thus this paper explores the application of the Cameron *et al.* (2003) private motorised mobility equation in terms of the evolution of private *vkt* over a thirty year period across a range of cities, and relates these changes to policy initiatives that have or have not been evoked. It highlights the way in which private motorised mobility has evolved and the relative importance of the different factors in each city in its evolution. It indicates a wide range of possible future directions in private motorised mobility, depending on the policy settings adopted through planning or by default.

2 Urban mobility

Cameron *et al.* (2003) defined a non-dimensional urban private motorised mobility as:

$$\Pi_{mob1} = \frac{(\alpha_k \alpha_o)}{365 \beta_p 50} \quad (1)$$

where α_k is the total annual *vkt* by passenger vehicles, α_o the average passenger vehicle occupancy, and β_p the total population of the metropolitan area. The constant of 365 represents the number of days in a year and 50 kilometres has been taken as representing a theoretical maximum daily private passenger vehicle travel per person in any city, given the constraints of an individual's time budget (approximately 1 hour per day) and typical maximum average speeds of private travel in cities (50 kmh^{-1}) (Kenworthy and Laube, 2001). This provides a simple relative measure of private motorised mobility for any city and through the application of dimensional analysis, Cameron *et al.* (2003) were able to show that urban private motorised mobility could be represented as:

$$\Pi_{mob1} = 0.38(\Pi_{uf}^{-0.26}) \left(\frac{1}{(1 + \exp(-3.4\Pi_{vehicle}))} \right)^{3.4} \quad (2)$$

where

$$\Pi_{uf} = \frac{\beta_p}{50000\lambda_a} \quad (3)$$

$$\Pi_{vehicle} = \frac{\alpha_c}{0.85\beta_p} \quad (4)$$

and α_c is the total number of cars on register, λ_a the actual urbanised area (Kenworthy *et al.*, 1999), rather than the total area within a city’s territorial boundaries. Π_{uf} has been normalised by recognising that over their entire metropolitan area, cities do not normally exceed 50,000 persons per square kilometre (Kenworthy and Laube, 2001) and $Pi_{vehicle}$ was normalised following Dargay and Gately (1999) who assumed that vehicle ownership saturates at 0.85 vehicles per capita.

Table 1 gives a statistical comparison between the observed private motorised mobility and that predicted for an initial set of data (1960-1990), as well as a completely independent set (1995) (Cameron *et al.*, 2003). The statistics listed are the mean absolute difference (*mad*) between measured and modelled values, root-mean-square-difference (*rmsd*) between measured and modelled values, the intercept (*a*) and slope (*b*) of the linear regression between measured and modelled values, and the linear correlation coefficient of measured and modelled values (*r*). This highlights the ability of equation 2 to reproduce the general features of private motorised mobility across a wide range of urban areas.

Incorporating equations 1, 3 and 4, equation 2 can be re-organised to yield urban *vkt* as:

$$\alpha_k = \left(\frac{115552\beta_p^{0.74}\lambda_a^{0.26}S}{\alpha_o} \right) \quad (5)$$

with

$$S = \left(\frac{1}{(1 + \exp(-3.4(\frac{\alpha_c}{0.85\beta_p})))} \right)^{3.4} \quad (6)$$

The term S , defined by equation 6, is a vehicle saturation factor that changes relatively slowly as a function of the number of cars per head of population, but nevertheless represents an infrastructure limit on the growth of the total *vkt*. It is a measure of automobile ownership and illustrates the impact of economic growth through higher vehicle ownership in accord with Ingram and Liu (1998) and Dargay and Gately (1999). Implicit within this model of private *vkt* is the impact of saturation of car ownership as well as population growth.

Given that the significance of motor vehicle use is increasing in many urban areas (Anderson *et al.*, 1996), equation 5 provides an opportunity to review the relative importance which the factors identified have had on changes in urban mobility across a range of cities over a relatively long period (1960-1990). That is, the relative importance of the factors affecting changes in *vkt*

can be seen through differentiation of equation 5 to yield:

$$\frac{\Delta\alpha_k}{\alpha_k} = 0.74\frac{\Delta\beta_p}{\beta_p} + 0.26\frac{\Delta\lambda_a}{\lambda_a} + \frac{\Delta S}{S} - \frac{\Delta\alpha_o}{\alpha_o} \quad (7)$$

where Δ represents the change in a given parameter.

Equation 7 suggests that increases in private *vkt* arise from population growth ($0.74\frac{\Delta\beta_p}{\beta_p}$), urban sprawl ($0.26\frac{\Delta\lambda_a}{\lambda_a}$), increased car ownership ($\frac{\Delta S}{S}$) and decreases in vehicle occupancy ($\frac{\Delta\alpha_o}{\alpha_o}$). The predicted changes in *vkt* from equation 7 are shown in Figure 1 against the observed changes from Kenworthy *et al.* (1999). Within an individual city the observed changes are a consequence of policy initiatives, whether deliberate or unforeseen, or a more *laissez faire* approach to urban planning.

All cities tend to experience greater mobility as the urban population increases, but this does not necessarily have to translate to greater values of private *vkt* if policy initiatives are utilised to compensate for the increased population by a commensurate decrease in the other factors listed in equation 7.

In order to examine the factors that underpin trends in private motorised mobility in cities from 1960 to 1990, seven metropolitan areas have been chosen as case studies. Figure 2 depicts the absolute values of car *vkt* in these metropolitan areas for four decadal years and confirms that all experienced growth in private motorised mobility over this period, though the rate of growth varied between cities and for different decades. It should be noted that data are missing for some years where it was not available.

The cities were firstly chosen to ensure representation across the different geographic regions covered by the *vkt* data (Asia, Europe, North America and Australia). The aim here was to test the model over a wide range of city types from high density, public transport-orientated Asian cities to sprawling, auto-dependent regions, where it might be expected that different factors would be at work in determining trends in private motorised mobility. Within this general context, preference was given to cities that had noteworthy or unusual policies that might be expected to distinguish them from other cities (*eg.* Singapore's traffic restraint policies), thus permitting clearer judgements about whether model results coincided with these clear policy strategies.

Table 2 provides an overview of some key characteristics of each of the seven cities in order to show the very wide range in land use and transport conditions encapsulated in the case studies. For example, annual private car use ranges from 930 passenger kilometres per capita in Hong Kong up to 15,100 in Phoenix and density in the same cities ranges from 32000 persons per sq km down to 1000 persons per sq km respectively.

To highlight the relative role of the factors outlined in equation 7, figures 3-9 depict the relative changes in each of these variables over decadal periods normalised by the term on the left hand side of equation 7. Thus the normalised terms will add to 1 for an increasing vkt and -1 for a decreasing vkt .

3 Asian cities

As engines of economic development many developing cities are showing, or have shown in the past, steady, but at times rapid growth in personal affluence (GDP per capita) that brings with it well recognised parallel growth in automobile ownership and use (Ingram and Lui, 1998; Dargay and Gately, 1999; World Bank, 2000; Schipper *et al.*, 2001). The result of this scenario is that many cities in developing regions are encountering increased automobile ownership and use, and particularly high levels of automobile commuting. The implications of this increased automobile ownership and use are infrastructure congestion and loss of urban environmental amenity through excessive air and noise pollution. A range of traffic management strategies, planning policies and fiscal instruments has been widely considered and implemented by a number of city governments and regulatory authorities in developing regions as measures to constrain increased urban automobile ownership and use. The following case studies of Singapore and Hong Kong between 1960 and 1990 cover a period of rapidly growing wealth in these formerly developing cities. They demonstrate some examples of the impact of implementing constraints on an increasing demand for urban automobile ownership and use.

3.1 Case study - Singapore

Singapore's expanding economic development and growth rate of its *GDP* per capita from \$S1,306 in 1960 to \$S33,500 in 1995 has seen its automobile ownership increase from 38.5 to 116.3 automobiles per 1,000 persons (Kenworthy *et al.*, 1999; Department of Statistics Singapore, 2001). Yet vehicle ownership, as represented in equation 7, has not been the most significant factor in the increased vkt (Figure 3) because conscious policies to restrain automobile ownership demand and use relative to increases in wealth, have been progressively implemented in Singapore since the early 1970s (Phang, 1993; Koh and Lee, 1994).

The Singapore Government has used a series of fiscal strategies to discourage demand for automobile ownership and use, combined with significant public investment in road construction and public transportation (Phang, 1993; Willoughby, 2001). The initial strategies imposed in the late 1950's included

high importation taxes, additional registration fees and road taxes, but these were mainly seen then as a revenue raising measure (Willoughby, 2001). In 1975, the Restricted Zone Area Licensing Scheme (*ALS*) was implemented (Phang, 1993; Koh and Lee, 1994; Seik, 1997; Willoughby, 2001; Goh, 2002) to restrict automobile access to Singapore's central business district during business hours on weekdays and Saturdays. The *ALS* imposed a zone entry fee on automobiles that accessed the Restricted Zone during prescribed hours, but contained exemptions for vehicles that carried at least four passengers (Phang, 1993). The impact of encouraging greater vehicle occupancy is clearly seen in Figure 3, with it contributing a significant decrease to private *vkt* during the decade 1970-1980. It also led to a reduction in traffic volume by as much as 45% (Phang and Toh, 1997).

Despite these strong fiscal strategies and improved public transit facilities, vehicle ownership has increased since 1980 as a direct consequence of Singapore's strong economic growth and consequent increased personal affluence (Figure 3). This has effectively neutralised the Government's fiscal restraints on automobile ownership (Phang, 1993; Koh and Lee, 1994; Phang *et al.*, 1996; Chin and Smith, 1996; Goh, 2002). In 1989, the license concessions for car-pooling were also scrapped (Phang, 1993; Seik, 1997) and this has contributed to the increased *vkt* in 1990 (Figure 3). Beyond 1990, Singapore has responded to this situation by introducing its Certificate of Entitlement system, whereby prospective car buyers have to bid at auction for the right to purchase a motor vehicle, which can cost tens of thousands of dollars (Kenworthy *et al.*, 1995).

3.2 Case study - Hong Kong

Hong Kong (based on the former British Crown Colony) shares a number of similarities with Singapore in having well constrained spatial dimensions, a high-density urban population (though much higher than Singapore) and strong economic growth. However, its personal affluence is not reflected in the demand for automobile ownership, with Singapore having about 2 to 3 times the number of passenger vehicles per 1,000 persons than Hong Kong in the last 4 decades. Overall, Hong Kong's average total road infrastructure length per square kilometre of land area is 1.45 km compared to Singapore's 4.4 km, and it has an average of 279 automobiles per kilometre of road compared to Singapore's 145 (Hau, 2002). Hong Kong's topography and geography and its resulting extreme high density, are significant limiting features keeping its automobile ownership at very low levels. So although in the decade 1960 to 1970, Hong Kong's private automobiles increased more than 2 times from 11.6 to 26.9 per 1,000 persons (Lam and Tan, 2002), the major drivers of increased *vkt* were population growth and decreasing vehicle occupancy (Figure 4).

In recognition of Hong Kong's inability to cope with large scale motorisation, and following a Green Paper on transport policy, the Hong Kong Government introduced a series of fiscal measures to restrain automobile and motor cycle ownership. These included a First Registration Tax (*FRT*), as well as trebling the annual vehicle license fee in 1974. In May 1982, the Government doubled the *FRT* to 70%-90% of a vehicle's value, trebled the annual license fees and doubled the petrol fuel tax. The imposition of these fiscal instruments had the desired impact, since over the decade 1980-1990 there was no significant increase in automobile and motor cycle ownership (Figure 4) (Kenworthy *et al.*, 1999; Hau, 2002; Lam and Tan, 2002).

There has been no increase in taxes or license fees since 1982 so this form of restraint on the private automobile fleet has been increasingly less effective (Hong Kong Government, 2002). The Government still expressed concern over Hong Kong's automobile ownership and implemented an experimental trial of Electronic Road Pricing (ERP) between 1983-1985. Hau (2002) reports that this trial was extremely successful, and though ERP was rejected at that time, primarily for privacy reasons and broad opposition, it has stimulated an Area Licensing Scheme similar to that operating in Singapore (Industry Commission, 1994).

4 European cities

In many parts of Europe, automobile ownership has conferred a freedom to travel anywhere at any time and enabled jobs, shops and services to relocate to peripheral urban areas. Increasing automobile ownership as a consequence of personal affluence has been the dominating influence on *vkt* growth in European cities. Thus policies to restrain urban automobile ownership and use (*ie.*, Pucher, 1997; Ahlstrand, 1998; Cervero, 1998) are essential in constraining *vkt* growth.

4.1 Case study - Munich

Within Munich (Landeshauptstadt München), vehicle ownership has been the main driver of increased *vkt* (Figure 5). This is comparable to most western European cities and has been attributed largely to the growing affluence of its citizens and the linkage of personal affluence to automobile ownership (Ingram and Lui, 1998; Dargay and Gately, 1999). Unlike Hong Kong and Singapore, the City of Munich (1990 population 1.28 million) has experienced a population decrease since 1970, yet its total *vkt* has increased through this greater accessibility to automobiles. Munich's car ownership rose from 131 cars per

1000 people in 1960 to 468 cars per 1000 people in 1990. It should be noted that the functional urban region of Munich (1990 population 2.30 million) has experienced increased population over this period. The data here refer only to the City of Munich, due to difficulties in data collection for the whole region, though the observations for this geographic area are still valid and meaningful units of analysis in the model.

Since the 1970's Munich has adopted a number of measures and policies that have shown a significant shift from accommodation to one of restriction and modification of automobile use (Pucher and Lefèvre, 1996). Munich's urban planning is based around some important land-use prerequisites of rail transit, a large dominant central core and dense residential development along radial corridors. Integral to this has been the need to restrain the demand for automobile use through reducing traffic speed limits to 30kmh^{-1} in all residential zones, narrowing many streets, as well as other traffic calming measures (Pucher and Lefèvre, 1996). In addition, Munich has been a leader in Europe since the 1970s in progressively pedestrianising its whole city centre. Munich now has 7 km of fully pedestrian streets (<http://www.carfree.com/carfreeplaces.html>). Central to Munich's urban planning and automobile restraining measures was a strong commitment to an efficient and viable public transit network (Topp, 1993; Pucher, 1997; Cervero, 1998). To this end, commencing in the early 1970s, Munich developed an extensive *U-Bahn* and *S-Bahn* system servicing the City of Munich and the whole urban region. Some central city stations, such as Karlsplatz and Marienplatz, handle in excess of 500,000 passengers per day. These measures were linked to increased automobile on-road taxes that included higher registration costs, increased petrol tax and parking fees that were always higher than comparable public transport fares (Pucher, 1997).

So while Munich's car ownership per capita increased 360% from 1960 to 1990, its car use increased only by 280%, due at least in part to these policy initiatives. For example, public transport passenger kilometres per capita increased 310% between 1970 and 1990 (Kenworthy *et al.*, 1999) due to the rapid implementation of an extensive rail system. Munich demonstrates not only the effectiveness of policies to restrain car use in the face of rising affluence and ownership, but also the need to do so. Without the policies put in place, Munich's car use in 1990 would almost certainly have been significantly higher with a range of negative environmental consequences.

4.2 Case study - Stockholm

Unlike Hong Kong and Singapore, the spatial development of Stockholm (Stockholm's Staden) has not been constrained by the lack of developable land.

Cervero (1995a) makes the point that Stockholm made conscious policy decisions to develop a *transit metropolis* in the early post-war period. This was in a country where wealth and land availability could have tended towards more sprawling auto-dependent patterns. Instead, Stockholm opted for a compact urban form led by the construction of an extensive rail system (*tunnelbana*) and satellite towns clustered around stations.

As a result, the urbanised area of the Municipality of Stockholm essentially has not changed since 1960 and vehicle ownership has been the driving force behind increased *vkt*, with only a minor contribution from population growth (Figure 6). Stockholm's urban development is built in a star configuration from a dense residential central core along and around its suburban rail and former tram networks (Cervero, 1995; 1995a; 1998). Stockholm removed all its trams, especially between 1960 and 1970, except for some tiny services to island communities in the peninsula. Tram wagon kilometres of service reduced from 14.5 million in 1960 to 0.9 million in 1970 (Kenworthy *et al.*, 1999). However, its inner city urban form is strongly linear, as it was shaped by the early tram systems. Urban development is centred in close proximity to rail stations, combining community amenities such as shopping and commercial sites with high density housing. This provides residents with very convenient access to all facilities by pedestrian paths and cycleways that are segregated from the traffic flows (Pharoah and Apel, 1995; Cervero, 1998). This continuing planning approach in Stockholm of land-use and public transport integration has been practiced to minimise individual motorised travel demand and to preserve natural areas around and between satellite communities, which allows residents and workers easy access to open space.

Despite these physical planning measures, *Trafiplan 1977* was established as a consequence of Stockholm's rapid escalation in car ownership and use during the decades between 1960 and 1980. In this twenty year period car ownership increased by 240%, while per capita car use increased even faster by 270% (Kenworthy *et al.*, 1999). The major thrust of *Trafiplan* was to discourage automobile demand and give greater emphasis to pedestrians, cyclists, bus and rail users and to keep motorised traffic away from residential areas. In 1980, the Stockholm City Council decided that motorised traffic in the inner city should be reduced initially by 20%. This reduction in traffic would be accomplished by enacting strong parking by-laws and by the end of 1989 these parking restrictions extended to a radius of 2.5 kilometres from Stockholm's central core. These strict parking by-laws were linked to a radiating scale of charges, increasing rapidly towards the central core, and offences incurred very heavy penalties (Pharoah and Apel, 1995).

Public transport use since 1970 has increased markedly in Stockholm (180% more passenger kilometres per capita in 1990 than in 1970). While it has had a programme of increasing charges for inner city parking, parking availability

has nevertheless increased 48% in the CBD, though it is still low by world standards (193 spaces per 1000 jobs compared to typical auto cities with over 500) (Kenworthy *et al.*, 1999).

Overall, Stockholm demonstrates the powerful forces of growing affluence and rising car ownership in influencing private motorised mobility and the need to respond to these forces through planning and transport policies. It demonstrates the importance of containing urban sprawl, which does not feature at all in Stockholm's growth in private motorised mobility (Figure 6). Stockholm increased its urbanised land area by only 3% between 1960 and 1990, compared to an average of 44% for all the European cities in the study by Kenworthy *et al.* (1999), the next lowest being Brussels at 26%. It also shows the importance of policies to hold vehicle occupancy steady, since this has hardly changed between 1960 (1.4 persons per car) and 1990 (1.35 persons per car). Importantly, urban density increased in all parts of Stockholm between 1980 and 1990 (metro area, CBD, inner area and outer area). At the same time car use per capita declined marginally (4867 to 4638 car kilometres per capita) while public transport use per capita rose (2124 to 2351 passenger kilometres per capita) between 1980 and 1990 (Kenworthy *et al.*, 1999). This decrease in car use per capita was unique in the sample of world cities and suggests that preventing urban sprawl has been able to negate the effect of rising car ownership and other factors that would tend towards greater car use.

Thus, despite growing auto ownership and use over the 30 years from 1960 to 1990, car use in Stockholm in 1990 remained about average for a western European city (4638 car kilometres per capita compared to 4519), while cities in the USA and Australia had grown respectively to 11155 and 6571 car kilometres per capita. Had Stockholm been unable to enact the planning policies it did, its car *vkt* change would have undoubtedly been much higher.

5 New World Auto Cities

The automobile has shaped the suburban landscape of both the United States of America and Australia and is a central feature in the lifestyle of urban residents in these countries (Pucher and Lefèvre, 1996; Newman and Kenworthy, 1999). This has led to decentralised, low-density suburban landscapes that have developed during the era of the automobile and are made possible and practicable by very high automobile ownership and use - the auto city (Newman and Kenworthy, 1999).

5.1 Case study - New York

Although a central part of American culture, New York (Tri-State Metropolitan Planning Region) has a history that predates the automobile and hence the changes in its *vkt* are more representative of Europe than America. Its car use per capita in 1990 of 8317 kilometres per annum is also by far the lowest of the USA cities (average 11155) and its public transport use of 1334 passenger kilometres per capita was, in 1990, 280% of the USA city average (Kenworthy *et al.*, 1999). Like many European cities, growth in *vkt* has occurred as a direct consequence of increased vehicle ownership (Figure 7), while urban sprawl and other factors do not feature strongly in the changes in car *vkt*. The New York region's urban area increased 57% between 1960 and 1990, compared to an average 118% in the other 12 USA cities in the study by Kenworthy *et al.* (1999). This compares to an average increase of 44% in urbanised land area of European cities.

More recently, New York has experienced a strong renaissance in public transport during the decade of the 1990's (Pucher, 2002). Rather than major automobile demand restraint measures, New York's boom in public transport was partly due to the city's positive economic climate and rapid employment growth. In the 1990's decade New York's public transport system has also been partly revitalised with new buses and trains, renovated rail stations and strict graffiti control, thus improving passenger facilities and amenity (Pucher, 2002).

5.2 Case study - Perth and Phoenix

Typical examples of urban sprawl cities of the Auto City era are Phoenix (Maricopa County) and Perth (Perth Statistical Division), where little restraint has been placed on residents' automobile demand. In both cases, the increase in *vkt* is a combination of population, urban sprawl, greater vehicle ownership and decreasing vehicle occupancy. Without any clear policies or restraints, all factors have contributed to the increased *vkt* (Figures 8, 9). This is very different to the situation in the Asian and European cities where a range of policies have strongly influenced some of the key factors outlined by equation 7.

Phoenix in 1990 had the equal lowest use of public transport of all cities in the study (15 trips per capita per annum, together with Sacramento) and the lowest public transport service provision of any city in the study (10 vehicle kilometres per person, the next lowest being Houston with 17) (Kenworthy *et al.*, 1999). Between 1960 and 1990 it also led the USA cities in the factors that

promote greater private motorised mobility, according to the model. Phoenix's urban area increased by 198%, while the other 12 USA urban areas increased by an average of 106%. Phoenix's car occupancy declined by 13.3% (average for other USA cities, -5.7%), its population increased 220% (average for other USA cities 62%) and the number of cars increased by a massive 460%, while the other USA cities increased by 158%. In summary, there was no resistance on any policy dimension over this thirty year period, to increasing private motorised mobility in Phoenix (Figure 8).

There are remarkable similarities with Perth. In 1990, Perth had the equal lowest public transport service provision in the Australian cities and the lowest public transport use within this group of cities. Between 1961 and 1991 Perth's population grew 140%, its urban area increased 252%, its cars increased 426% and its car occupancy declined 13.2% (Figure 9). Whilst Perth has been doing more for public transport development than Phoenix, especially with the development and extension of an electric suburban rail system, by 1990 this had been insufficient to prevent what is continued steady growth in per capita car use (about an extra 2000 car kilometres per person between 1961 and 1971 and an extra 1000 in each of the two decades between 1971 and 1991). Perth's electrified rail system only opened in 1988 and a new 30 km line was initiated in 1993, so that possible changes in car use arising from these improvements will not become fully evident until the 2001 decadal analysis.

6 Regional Trends

Figure 10 highlights the regional changes that have occurred in *vkt*. In particular, increasing car ownership has been a major driver of changes in *vkt* since the 1960's. This is especially true in the established cities of Europe. Urban sprawl has contributed to the growth in vehicle use, particularly in Australia, Canada and the USA where cities have developed through the automobile era. Such cities have a clear urban sprawl signature (Table 3), with average urban densities far lower than the European and Asian cities, and average car use much higher. However, even for these cities, sprawl by itself has not been the main driver in increasing *vkt*. It is increased vehicle ownership that has been the driving force behind much of the increase in *vkt* since 1960, combined with population growth. Although higher vehicle ownership is a consequence of increasing affluence (Ingram and Liu, 1998; Dargay and Gately, 1999), it is also driven by urban sprawl and the need for private motorised mobility in the absence of good quality public transport infrastructure.

7 Policy Implications

Lave (1992) describes automobile dependence as an "irresistible force" that is essentially unstoppable anywhere in the world where affluence is increasing. One of the arguments here is that as incomes rise the value placed on time increases and this shifts transport demand from slower, cheaper modes of transportation to speedier more expensive modes, which means, in most urban transport situations, the automobile.

In a similar vein, other authors imply that the growing ownership and use of cars essentially reflect the idea that cars are a superior consumer good, while public transport is an inferior consumer good and as affluence grows and car affordability improves, cities will inevitably become more automobile dependent (Gordon and Richardson, 1989; Gomez-Ibañez, 1991; Kirwan, 1992).

Lave (1985) captures the essence of these arguments in the following statement: *The villain responsible for the long-term decline in transit patronage is easy to identify: the increase in per capita income. Higher incomes gave people more freedom of choice and greater ability to do the things they wanted to do. Unfortunately, the things they chose were inimical to mass transit. Higher incomes permitted people to implement their strong desire to get out of cities and live in single-family, detached homes, resulting in the suburbanisation of America. Higher incomes permitted people to implement their taste for higher quality transportation and buy automobiles (Lave, 1985:3).*

The evidence in this paper suggests that such arguments about the inevitable growth in urban sprawl and motorisation are overly deterministic and that urban systems are responsive to land use and transport policies and other strategies that can reduce the growth in automobile dependence. Singapore's economic constraints on car ownership and use in parallel with significant investments in public transport, especially a mass rapid transit system, and the strong integration of urban development around stations on the MRT system, have shown how motorisation can be curbed in the context of rapidly rising incomes (Kenworthy *et al.*, 1995).

As shown in Table 2, Singapore, with a GDP per capita of \$US 29,000 in 1995 had only 116 cars per 1000 people and car use of 3,600 passenger kilometres per capita. Perth, with 658 cars per 1000 people and 13,500 car passenger kilometres per capita had a GDP per capita of \$US 22,000. Hong Kong too has benefited from similar economic restraints on car ownership and use and highly effective integration of urban development around an expanding mass transit railway, contributing to very low car ownership and use (46 cars per 1000 people and 930 car passenger kilometres per capita in 1995, with a GDP per capita of some \$US 23,000).

Of course, the much higher density urban form of Singapore and Hong Kong assists significantly in explaining the absolute magnitude of differences in car ownership and use compared to a low density city like Perth (Table 2). However, this does not detract from the effectiveness of policies in keeping car ownership and use in check within these Asian cities. Bangkok's traffic chaos is an object lesson for Asian cities in the consequences of failing to implement policies to restrain motorisation (Kenworthy, 1995; Poboan and Kenworthy, 1995). Likewise, the cases of Perth and Phoenix, that have had limited if any significant physical planning, transport or economic policy interventions to manage growth in demand for private transport, show the extent to which automobile dependence can grow largely unabated.

In physical planning terms, Munich and Stockholm both demonstrate how integrated land use and transport planning, especially transit-orientated nodal development around rail stations, traffic calming measures, parking restrictions and widespread urban redevelopment to restrict the growth in urban land area, can reduce the growth in private motorised mobility (see Lyons *et al.*, 2003 for a discussion of the significance of restricting the growth in urban land area). Stockholm, in particular, suggests the positive transport benefits of restraining the growth in urbanised land area.

Finally, the perspectives on the effectiveness of urban policy interventions to moderate motorisation are not limited to the cities discussed here. They are repeated in many cities around the world. For example, Pucher and Clorer (1992) describe for Freiburg, Germany, the combined and coordinated effects of constraints on urban sprawl through high density mixed use development around an LRT system, investments in upgrading the public transport system and strong pro-pedestrian and pro-bicycle policies that have created excellent environments for walking and cycling. Between 1976 and 1991 total daily trips rose by 30.4%, but automobile trips rose by only 1.3% and the automobile's modal share dropped from 60% of non-pedestrian trips to 47%. This occurred in the context of quite rapidly rising automobile ownership (422 cars per 1000 in 1990). Further case studies demonstrating how motorisation can be reduced through a variety of urban policies can be found in Newman and Kenworthy (1999) for cities such as Curitiba (Brazil), Zurich, Copenhagen, Toronto and Vancouver.

8 Conclusion

The increase in urban mobility between 1960 and 1990 has been the direct result of increased affluence and the consequent greater ownership of private motor vehicles. Such increased vehicle ownership does not automatically flow to increased private *vkt* and a number of cities in Europe and Asia have

shown that clear policy initiatives can contain the growth of urban private motorised mobility. Despite the urban sprawl apparent in USA, Canadian and Australian cities, this has not been as significant a contributor to growth in *vkt* as population increase and greater affluence, although there is a more even contribution between the various factors in these cities.

However, in other cities such as Stockholm, the control of urban sprawl such that densities have increased, appears to have been pivotal in reducing the growth in car use, despite strong growth in affluence and car ownership. Overall this highlights the fact that if cities are to minimise growth in car use, then they cannot afford to overlook any of the key underlying drivers of private motorised mobility in their policy approaches. The evidence in this study suggests that whilst forces of growing affluence are strong, there is nothing *inevitable* or *irresistible* about growing automobile dependence in cities.

Although the Cameron *et al.* (2003) model predicts private motorised mobility, a full description of urban mobility requires an understanding of mobility by public transport as well. Some of the case studies (Munich, Singapore, Stockholm and Hong Kong) have suggested the importance of developments in public transport working hand-in-hand with other urban policies to minimise private motorised mobility. Likewise, the absence of better public transport in other case studies is seen to be associated with less abated growth in car use (Perth, Phoenix). The application of this model illustrates the consequences on private motorised mobility of a number of key policy initiatives, yet the full story clearly also requires the modelling of urban mobility incorporating both public and private motorised mobility, as well as non-motorised mobility.

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Table 3 Urban sprawl and its attendant characteristics in 1995 (based on Kenworthy and Laube, 2001).

	1960-1990	1995
<i>mad</i>	0.063	0.072
<i>rmsd</i>	0.087	0.096
<i>a</i>	0.0098	-0.0357
<i>b</i>	0.982	1.049
<i>r</i>	0.937	0.899

Table 1
 Statistical comparison between actual and predicted private motorised mobility for initial cities (1960-1990) and an independent set (1995) (after Cameron *et al.*, 2003).

Factor	Hong Kong	Singapore	Munich	Stockholm	New York	Phoenix	Perth
Population	6,311,000	2,986,500	1,324,208	1,725,756	19,227,361	2,526,113	1,244,320
Number of jobs	2,980,151	1,700,900	768,700	838,800	10,108,808	1,035,214	521,810
Metropolitan GDP per capita (\$US, 1995)	\$22,969	\$28,578	\$54,692	\$33,438	\$34,935	\$26,920	\$21,995
Urban density (persons per sq km)	32035	9353	5566	2902	1804	1039	1089
Cars per 1000 people	46	116	469	386	444	531	658
Length of freeway per capita (metres per 1000 persons)	13.0	44.2	45.3	130.4	112.8	178.9	42.6
Passenger car passenger kilometres per person	930	3,570	5,913	8,460	12,845	15,082	13,546
Public transport passenger kilometres per capita	3,675	3,143	2,622	2,317	1,266	100	642
Percentage of daily trips by walking and cycling (%)	34.1	16.3	32.3	28.0	16.1	4.9	9.1

Table 2. Some key land use and transport characteristics of the seven case study cities (1995) (based on Kenworthy and Laube, 2001).

Region	Urban area sq km	Population density Persons/sq km	Automobile ownership Cars/1,000 persons	Automobile use Annual car <i>vkt</i> /capita
USA	3,836	1,451	587	12,847
Australia	1,741	1,327	590	7,652
Canada	877	2,619	530	6,386
Europe	397	5,533	401	4,492
Asia	788	16,781	172	2,179

Table 3

Urban sprawl and its attendant characteristics in 1995 (based on Kenworthy and Laube, 2001).

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Figure 5 Relative changes in factors influencing annual vkt for Munich. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

Figure 6 Relative changes in factors influencing annual vkt for Stockholm. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

Figure 7 Relative changes in factors influencing annual vkt for New York. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

Figure 8 Relative changes in factors influencing annual vkt for Phoenix. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

Figure 9 Relative changes in factors influencing annual vkt for Perth. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

Figure 10 Relative importance of factors influencing changes in annual vkt for (a) USA, (b) Australia, (c) Canada, (d) Europe and (e) Asia. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

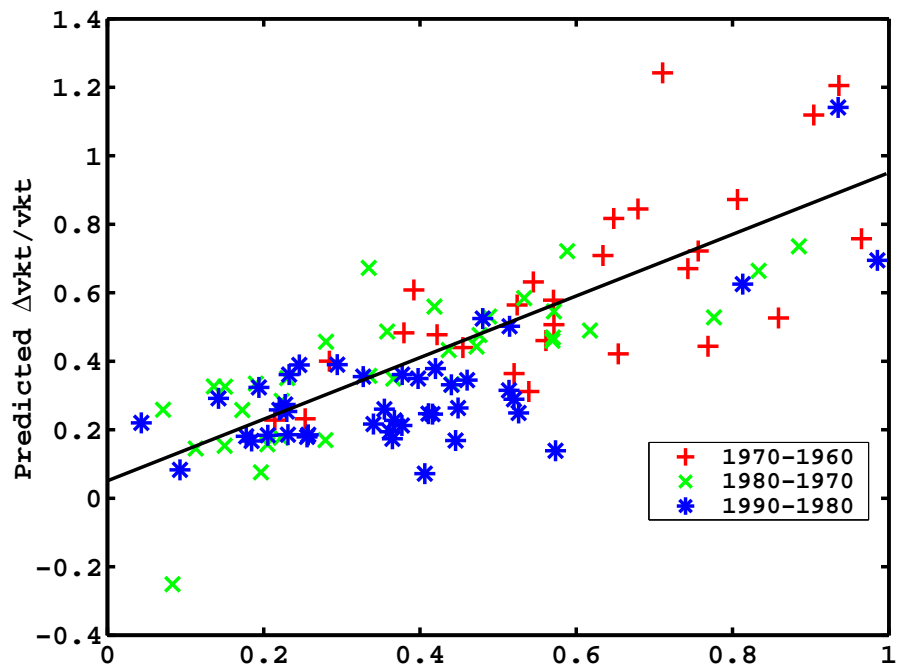


Fig. 1. Comparison between predicted and observed decadal change in annual vkt

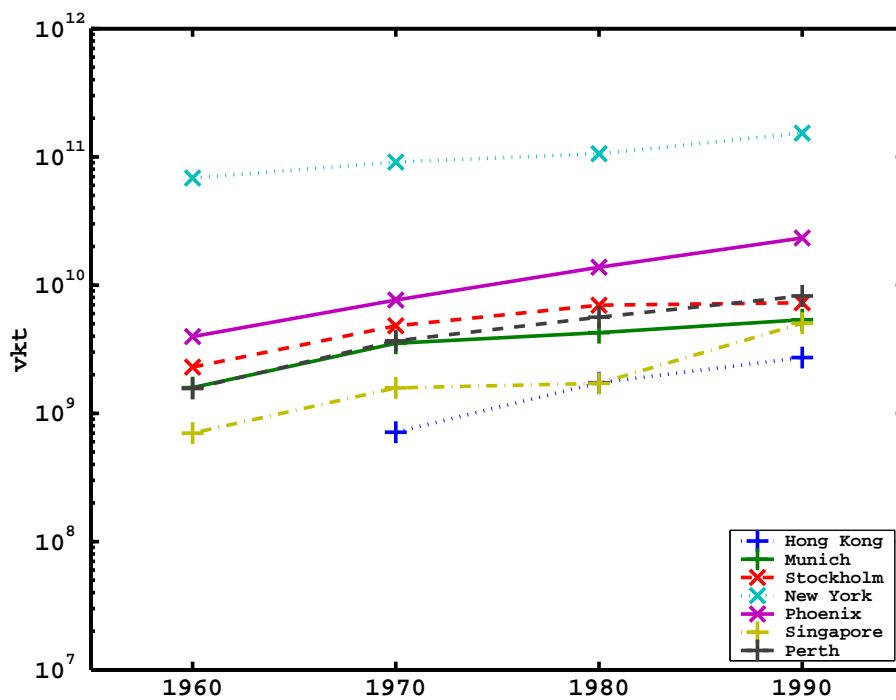


Fig. 2. Annual vkt for selected cities.

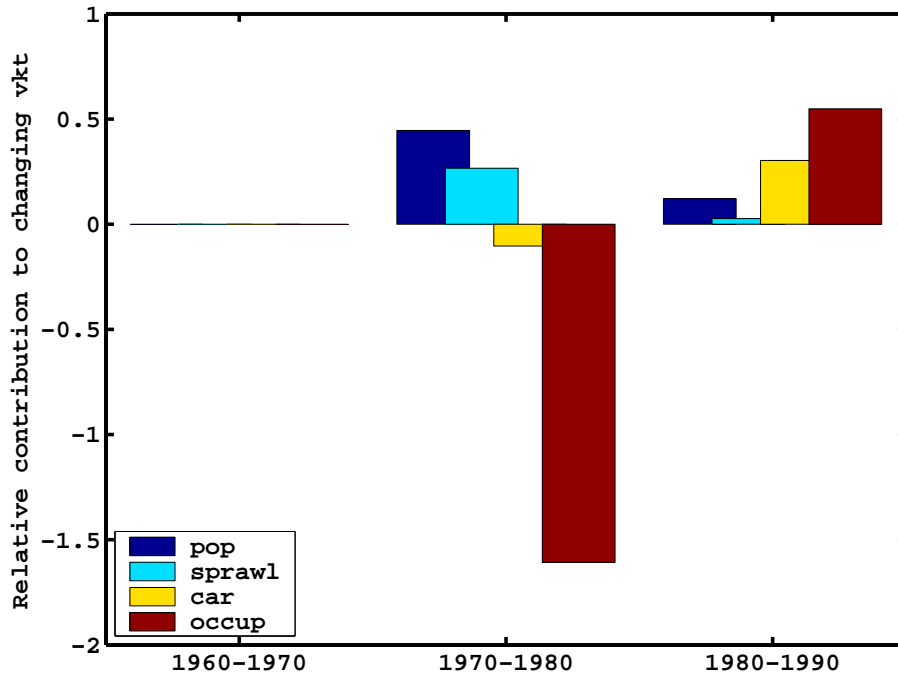


Fig. 3. Relative changes in factors influencing annual vkt for Singapore. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

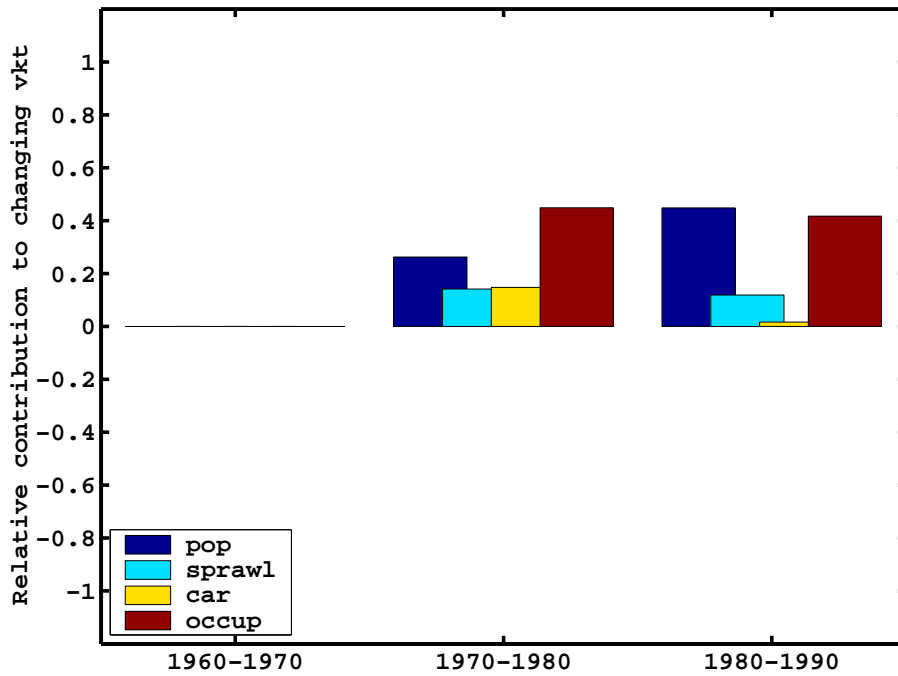


Fig. 4. Relative changes in factors influencing annual vkt for Hong Kong. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

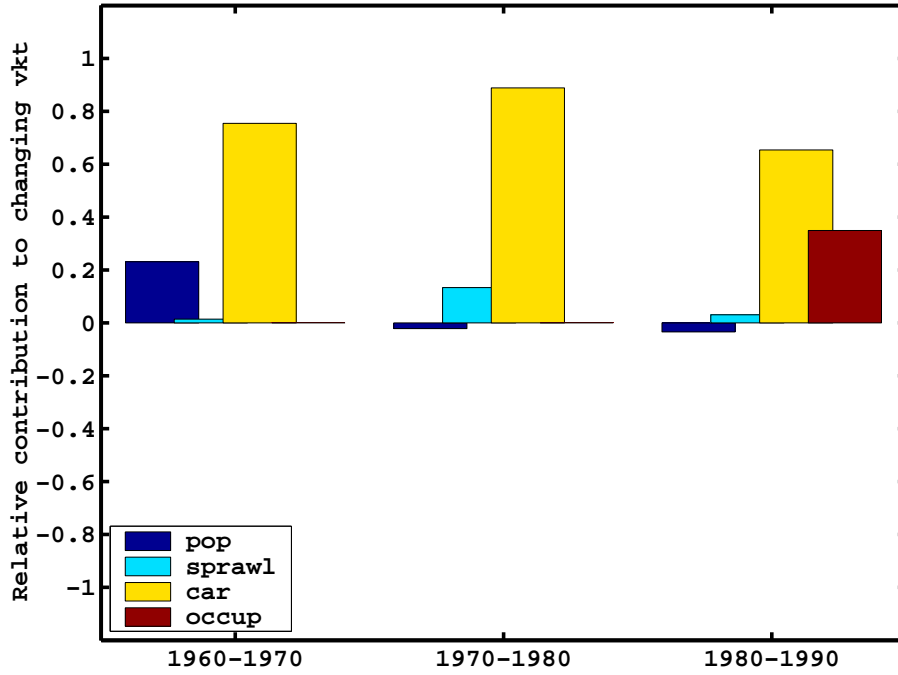


Fig. 5. Relative changes in factors influencing annual vkt for Munich. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

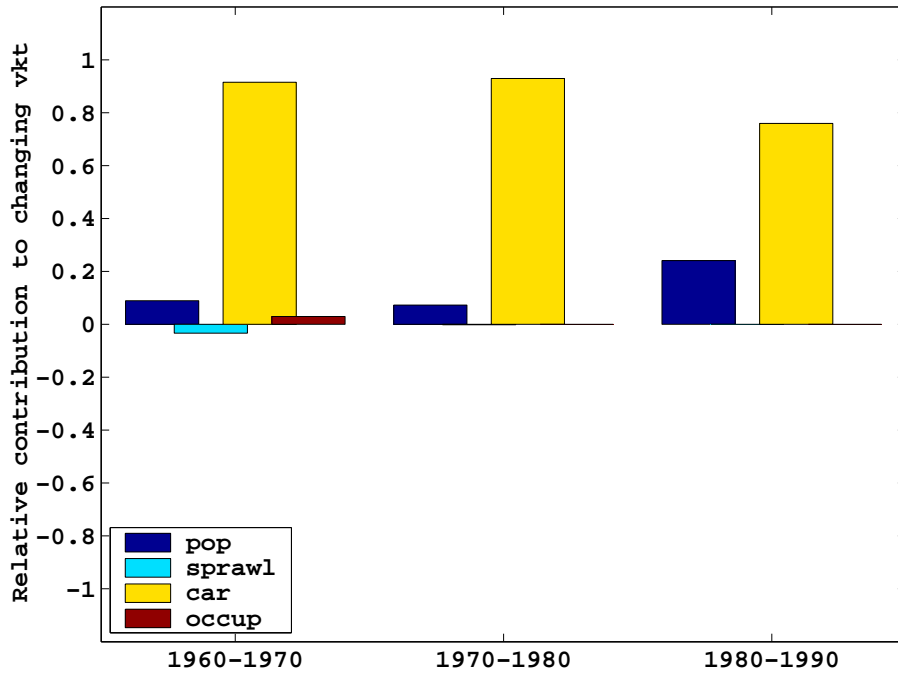


Fig. 6. Relative changes in factors influencing annual vkt for Stockholm. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

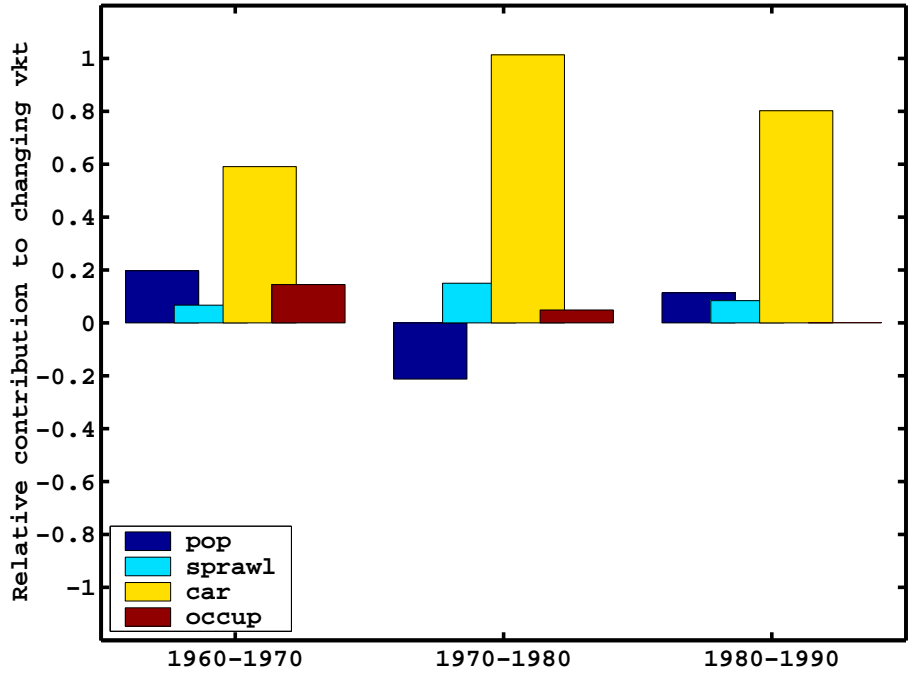


Fig. 7. Relative changes in factors influencing annual vkt for New York. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

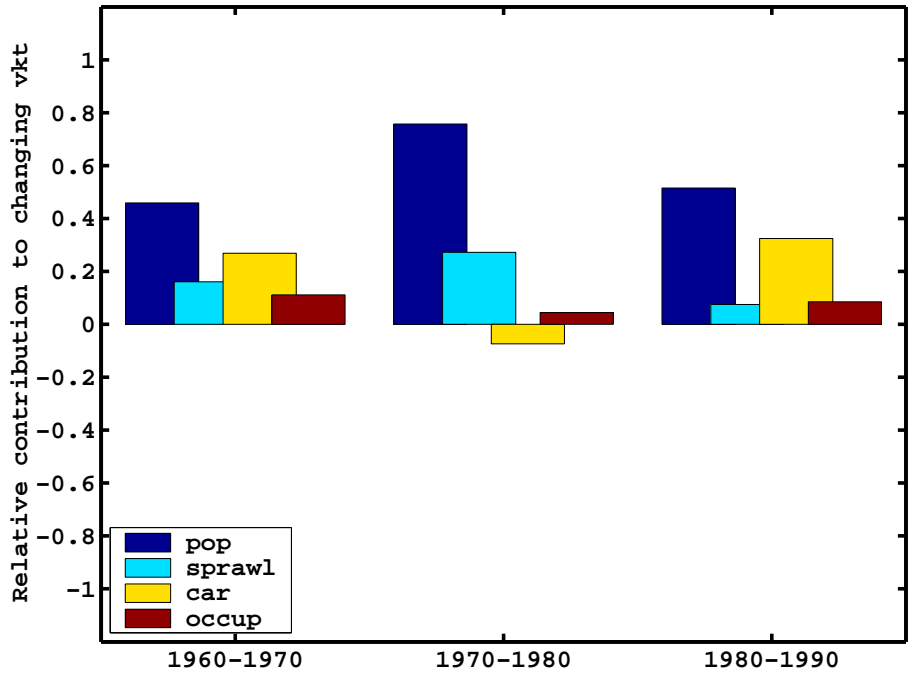


Fig. 8. Relative changes in factors influencing annual vkt for Phoenix. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

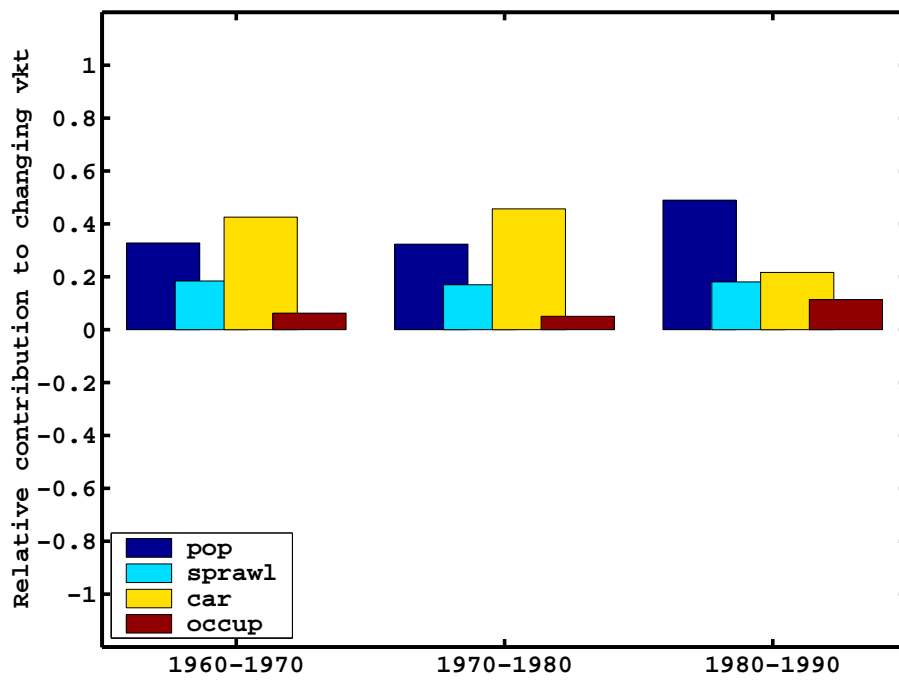


Fig. 9. Relative changes in factors influencing annual vkt for Perth. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)

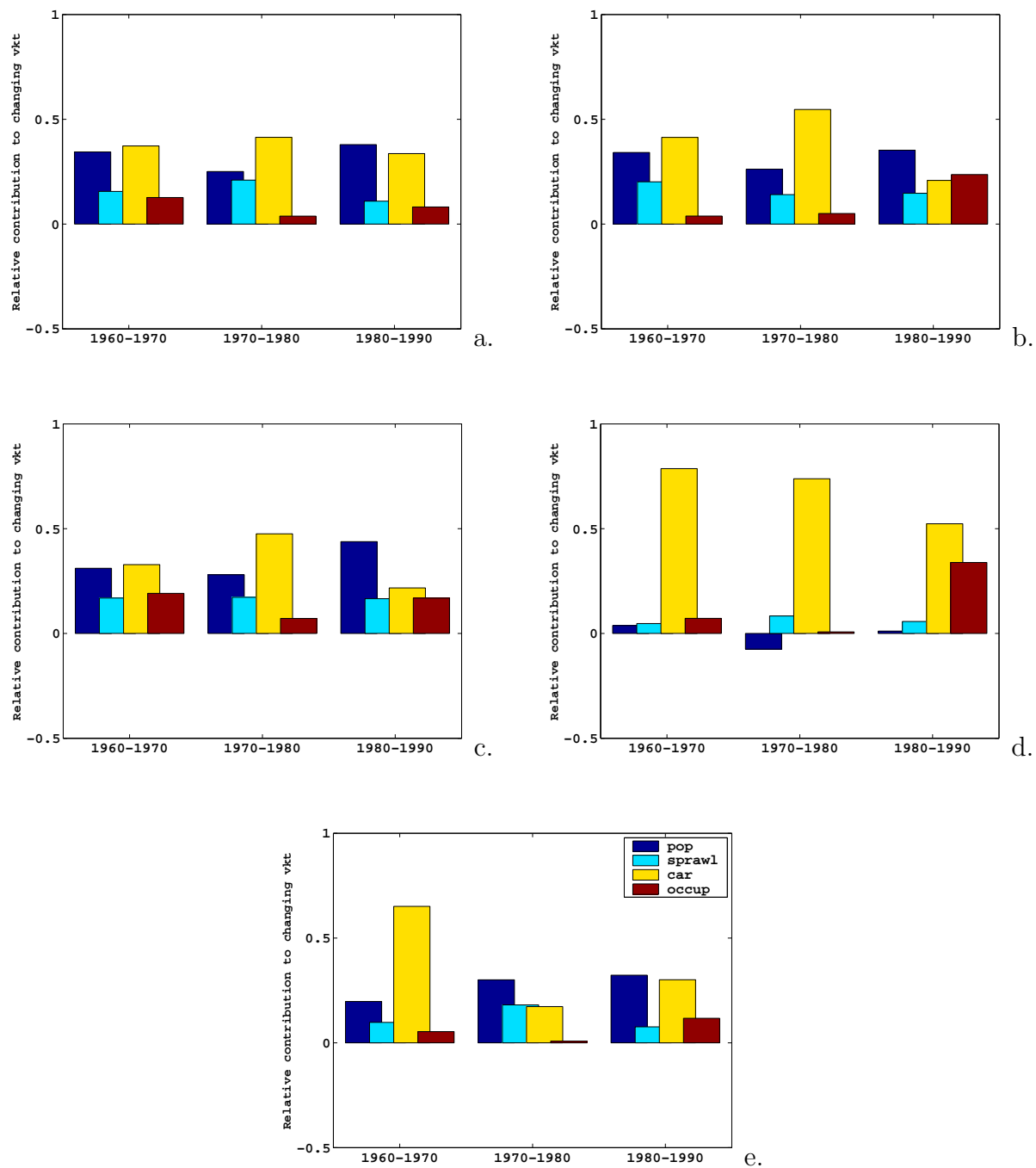


Fig. 10. Relative importance of factors influencing changes in annual vkt for (a) USA, (b) Australia, (c) Canada, (d) Europe and (e) Asia. (pop - population growth, sprawl - urban sprawl, car - car ownership and occup - vehicle occupancy)