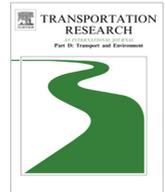




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Social and spatial effects of transforming the private vehicle fleet in Brisbane, Australia

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ABSTRACT

Transformation of the motor vehicle fleet has been an important feature of the world's peak car phenomenon. Very few urban transport studies have explored such important changes in large urban cities. Using an innovative green vehicle datasets constructed for 2009 and 2014, this paper investigates the ongoing change in urban private vehicle fleet efficiency (VFE) in Brisbane. The spatial patterns of VFE change were examined with social-spatial characteristics of the urban area. The results showed that the social and spatial effect of VFE changes remain uneven over urban space. The inner urban areas have experienced higher level of VFE change, whilst people in the outer and oil vulnerable areas showed a low tendency in shifting to more efficient vehicles. The implication of VFE change for future household vehicle adoption was also evaluated based on a cost-benefit analysis of new vehicle technology costs and expected fuel savings for households that choose a fuel efficient vehicle. The results show that imposing a stronger national fuel economy target in the long term would accelerate evolution of vehicle fleets and oil vulnerability reduction in Brisbane.

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1. Introduction

1.1. Peak car and vehicle fuel efficiency

Growth in car travel has been a continuing trend in many industrialised countries since the 1970s. Recent international investigations have shown that these trends have recently reached their nature 'peak' or begun to decline through the late 2000s. People tend to leave their cars or drive less because of the growing culture of urbanism, carbon and sustainability concerns, rising fuel costs and growth of public transport and other transportation modes (Newman and Kenworthy, 2011; Banister, 2013; Dennis and Urry, 2013; Goodwin, 2013; Lipschutz, 2012; Metz, 2013; Rigal and Rudler, 2014). Cities in highly car dependent nations like Australia, the USA and Canada are beginning to spurn the automobile; this will have diverse consequences for the future of transportation in cities. Governments and scholars anticipate that these new trends in car use will lead to significant opportunities to meet the global goal of carbon mitigation, improve energy security and provide wider social and economic benefits (Newman and Kenworthy, 1999; Dodson et al., 2010; Gilbert and Perl, 2008).

The automotive transportation sector faces considerable transformation in response to the car peak and challenges of petroleum depletion and climate mitigation. One important feature of the peak car debate is change in vehicle fuel efficiency

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(VFE) of motor vehicles. This changes in VFE reflect energy cost pressures towards reducing the carbon intensity of travel overall. Fuel efficiency improvements may also substitute for reduced travel in response to higher fuel costs (Newman and Kenworthy, 2011). Recent international comparisons have shown that the fuel economy improvements have accelerated over the car peak in many countries (Millard-Ball and Schipper, 2011; Kuhnimhof et al., 2013a, 2013b; Van Dender and Clever, 2013). The United States alone showed an annual decline of 4.6% in fuel consumption per vehicle kilometres travelled (VKT) over the period, reflecting the contribution of the improved vehicle fuel economy (Puentes and Tomer, 2008).

1.2. Efficiency of Australian vehicle fleet

Australia has committed to improve fuel efficiency for motor vehicles. However, the VFE improvement in Australia lags behind most other developed countries (ClimateWorks, 2014). Current Australian strategies for managing vehicle energy consumption focus on voluntary targets, incentives programmes and awareness campaigns in promoting energy efficient vehicles (Li et al., 2015). In 2002, the motor vehicle industry in Australia adopted a voluntary target to reduce average vehicle fuel consumption, with a goal of reducing average VFE from 11.1 L/100 km to 8.2 L/100 km by 2010. Although the industry did not achieve the targets, there was still a noticeable improvement in fuel economy (Australian Bureau of Statistics, 2010). In 2011, the Australian Government announced a plan to adopt stronger emission standards for the light motor fleets (Commonwealth of Australia, 2011). Although the best practice standards are still in assessment, the implementation of these standards will present a significant opportunity to reduce carbon emissions whilst providing broader benefits.

Although Australian motor vehicles are becoming more efficient (Australian Bureau of Statistics, 2013), compared with the vehicle efficiency standards adopted in Europe and the US, there are still opportunities for further efficiency improvements. Research has shown that, over a longer term, significant improvement of the fuel efficiency of vehicle fleets can offer the large and cost-effective emission reduction opportunities in the Australian transport sector (CSIRO, 2012). The potential financial benefits of this change for private vehicle users are also significant. Recent research has shown that if the European standards were implemented in Australia in 2020, the efficiency improvement could provide fuel savings of an average AU \$500 per year for a private vehicle user (ClimateWorks, 2014).

1.3. Urban oil vulnerability

Oil expenditure has been an important concern for motor vehicle users in Australia. Because of their high car dependency, Australian cities face increasing energy security and climate mitigation challenges. The globally rising oil prices in the last decades have placed Australian cities at greater risk. A series of studies has shown that many low-income households tend to live in the outer suburbs of a city where are highly car-dependent, owing to the increase in housing costs and agglomeration of productive economies in the central urban areas (Burnley et al., 1997; Stimson and Taylor, 1998). These households who travel on long distance and lack of alternative transport will experience high levels of financial stresses if fuel prices increase substantially beyond their current levels. There is high risk that the rising vehicle fuel price and travel costs may aggravate household economic burdens and compound other forms of socio-economic disadvantages in the highly socially vulnerable areas (Dodson and Sipe, 2008).

It is recognized that improved vehicle fuel technologies (e.g. vehicles using more energy efficient engine and transmission systems and new energy) can offer an opportunity to save vehicle fuel consumption and reduce social economic risks from rising fuel costs. However, incorporating the new technology into new motor vehicles often entail additional costs of new efficient vehicles. The International Energy Agency estimates that within the Europe Union, achieving a 50% improvement in fuel efficiency will cost in the range of \$2500 per vehicle by 2020, with costs decreasing further over time (International Energy Agency, 2012). If current low efficient vehicle holders on low income and are already under heavy economic burdens, they typically have less of a capacity to afford vehicle upgrades or rapidly alter their vehicle technology. This socioeconomic stress would impede the oil vulnerability reduction through the implementation of new vehicle technologies. To this end, Dodson et al. (2010) argued that policies that focus on vehicle technology need to account for not only the technology-led benefits but also the costs of new vehicle technology and the adaptability of households in altering their vehicle ownership patterns.

1.4. Research questions

Transformation of the motor vehicle fleet has been an important feature of the car peak phenomenon. This transformation provides an opportunity for private car users to achieve fuel saving, reduce the costs, and overcome transport fuel security problem through technologies. No urban transport studies have explored such important changes in a large vehicle fleet and the effects of changing vehicle technology on household fuel energy and affordability in urban areas. Understanding the social spatial effects of changing vehicle fleet is an important dimension of the peak car phenomenon. First, the improved VFE will change households' transport energy patterns and stresses from rising oil costs and that must be considered in a transport policy. Next, the VFE change and the opportunity of fuel savings would influence future household vehicle choice and urban vehicle fleet patterns. Current studies have offered limited insights into these issues. Research that can help manage the policy and social implications of this transforming vehicle fleet in Australian cities, and thus inform wider international debates about the future of the car is needed. In addition, most peak car discussions to date have focused

on the national aggregate scale (Goodwin, 2013; Kuhnimhof et al., 2013b; Metz, 2010; Millard-Ball and Schipper, 2011; Newman and Kenworthy, 2011), there has been almost no investigation of the spatial dimensions of peak car impacts at the metropolitan level. The social and spatial effect of increasing fuel economy may remain uneven, due to social spatial conditions and the prices of new efficient vehicles and fuel energy costs. These distributional effects will also have a spatial component given the differentiation in household socio-economic profiles. Research thus needs to attain a clear understanding of how car fleets are changing over space and the distributional consequences across urban areas in order to better inform transport policy to respond effectively to the peak car phenomenon.

This paper investigates this problem using Brisbane's private vehicle registration and efficiency data over five years (2009–2014). The investigation of the social and spatial effects of VFE change will answer four major research questions: (1) What are spatial patterns of VFE change across urban space? (2) How do the changes in VFE intersect with oil vulnerability patterns in the city? (3) To what level would the improved VFE achieve household fuel savings? (4) How a stronger fuel economy policy would influence future household vehicle ownership choices?

2. Data construction

This paper draws on major datasets we have constructed to investigate changes in the VFE of the overall car fleet at the metropolitan scale. We have assembled unit-record private passenger vehicle data (i.e. every registered vehicle) for year 2009 and 2014. The datasets were obtained from the motor vehicle registration agency in Queensland, Australia. Each dataset provides comprehensive detail on motor vehicle make, model and engine size, including suburb-level spatial information on place of registration. These motor vehicle registration datasets were matched with the Australian Government's Green Vehicle Guide (GVG) data on VFE and emissions by vehicle make and models. GVG is an online consumer information resource that rates motor vehicles based on their energy efficiency, greenhouse emissions and air pollution. This information updates annually to include new vehicle make and models available in the Australian market. Because motor vehicle registration data includes the address of the owner we are able to link the vehicle characteristics to the location of registration. In this study, each unit record contains details that can be used to understand VFE at the suburb level. Linking the spatially referenced motor vehicle registration with standard vehicle efficiency measures at the unit-record level is rare in international transport study. In this paper, the motor vehicle and efficiency datasets were constructed for 2009 and 2014 to permit a comparative study of changes within the urban vehicle fleet.

3. Analytical methods and results

3.1. Spatial change in VFE

We undertake an analysis of changes in VFE and distribution between 2009 and 2014. This analysis of motor vehicle fleet changes focussed on VFE and other major vehicle attributes such as vehicle age, body shape, engine size and fuel type. Analysing spatial patterns of motor vehicle efficiency at the metropolitan scale will identify the location characteristics of VFE change in relation to the social and spatial structure of urban areas.

The change in average VFE of Brisbane's private vehicle fleet is shown in Fig. 1. Overall, the average fuel economy of Brisbane's private vehicle fleet improved from 9.2 to 8.3 (l/100 km) between 2009 and 2014. Geographically, the change in VFE presents an interesting spatial pattern. The level of VFE improvement tends to be higher in the inner urban areas. These areas are typically of high density, served by good public transport systems and are residences of many high income people. In contrast, the VFE improvements in the outer areas in the far north and far south were relatively lower. People living in these outer areas typically have lower incomes and are highly car-dependent and own larger and low efficient vehicles (Li et al., 2013). Compared with the areas in the far north and far south, some suburbs in the Brisbane's far west (e.g. Ipswich) exhibited a high level of improvement in the fleet efficiency. This is possibly a consequence of the migration of mid-income households who moved from middle suburbs, attracted by housing upgrade and large housing stocks in those areas. In addition, the economic development in this area formed higher land use density and less transport activities that require large and low efficient vehicles. A Local Indicators of Spatial Association (LISA) (Anselin, 1995) analysis was conducted to further identify spatial patterns of VFE change. LISA analysis captures the spatial similarities (or local autocorrelation) between the values of VFE change in a suburb and its nearby suburbs.¹ The spatial patterns of VFE change are highlighted in the inset map. The high level of VFE change was concentrated across inner north and inner west suburbs. Areas having low levels of VFE change tended to cluster in the far north and far south of Brisbane. The high level of VFE change in some suburbs tended to spill over and cluster with the VFE change in the nearby suburbs. On the other hand, the VFE change in some outer areas in combination lagged behind the regional average.

Table 1 highlights the top 20 suburbs in Brisbane that experienced the highest level of VFE improvement between 2009 and 2014. Their respective changes in vehicle age, engine size, body shape and energy type in the local fleet are also reported.² The aim of analysing these car attribute variables is to gain an understanding of types of vehicle characteristics that

¹ Nearby suburbs are all surrounding suburbs that attach the boundary of the target suburb.

² The change in other vehicle attributes were measured by the change in number of vehicle within each attribute category in relative to the total vehicles in each suburb.

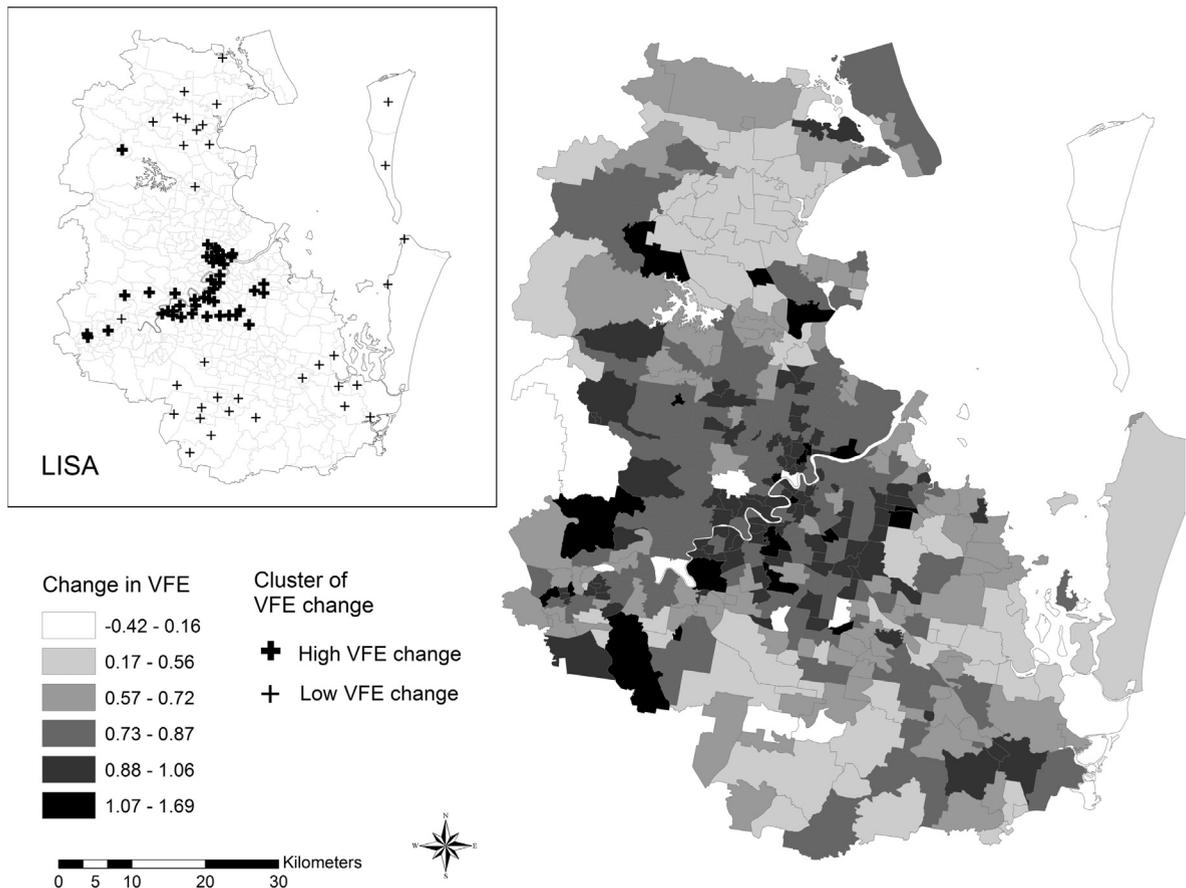


Fig. 1. Changes in average VFE between 2009 and 2014 across Brisbane suburbs.

are associated with the improvements in local VFE. The result shows that among multiple vehicle attributes, vehicle engine size appeared to be an important factor corresponding to the VFE change. The number of large engine vehicles (greater than four engine cylinders) decreased by 8% in these 20 suburbs, which was higher than the average reduction in the entire fleet in Brisbane (6%). Change in vehicle body shape also corresponded to the increase in the local VFE. There were 16 out of 20 suburbs showed an increase in the compact vehicles (e.g. hatchbacks) in the local fleet. The fleet turnover (change in car age) was also a contributing factor to the VFE change, even though the fleet turnover in the top 20 suburbs was not as strong as the average in total suburbs. The last column shows the increases in the new energy vehicles in the top 20 suburbs, indicating a close association with local motor vehicle fuel transitions. Table 1 also reports the correlation between change in VFE and changes in other vehicle attributes for total suburbs, showing that the decrease in large engine vehicle in the local fleet was strongly associated with improvement in VFE ($r = 0.31$).

3.2. VFE change in oil vulnerable suburbs

In this section, we compare the change in VFE of private vehicle fleets with generalised household oil vulnerability in Brisbane to explore the socio-spatial consequences of motor fleet change. The index for 'vulnerability assessment for mortgage, petrol and inflation risks and expenses' (VAMPIRE) was used to measure household oil vulnerability in Brisbane. The VAMPIRE index was originally created by Dodson and Sipe (2007) through an analysis of the Australian Bureau of Statistics (ABS) Census data to examine oil and mortgage vulnerability in Australian cities. The VAMPIRE index was constructed from four major socio-economic variables including household income, car ownership, level of car usage and economic burdens from home mortgage to measure relative household vulnerability to fuel cost in an area.³ Households in a highly oil vulnerable suburb, as indicated by high VAMPIRE scores, are more exposed to potential adverse impacts from rising fuel costs than households in a suburb with a lower VAMPIRE score.

³ VAMPIRE index = (proportion of households own two or more vehicles) + (proportion of people travel to work by car) + (household weekly income) * 2 + (proportion of homes are being purchased with a mortgage) * 2. The values of each variable were standardized using rated points between 0 and 5.

Table 1
Top 20 VFE improvement suburbs in Brisbane and change in other vehicle attributes (2009–2014).

Rank	Top 20 VFE improvement suburbs	Change in average VFE (total cars)	Change in average car age (years)	Change in share of large engine vehicles	Change in share of hatchback vehicles	Change in share of diesel and electric vehicles
1	Berrinba	-1.68	-5	-0.13	0.09	0.04
2	Albion	-1.32	-5	-0.06	0.11	0.03
3	Kholo	-1.31	-5	-0.14	0.2	0.06
4	Augustine Heights	-1.23	-3	-0.08	0.07	0.07
5	Samford Village	-1.22	-16	-0.08	0.12	0.04
6	Wacol	-1.21	-4	-0.09	0.12	0.01
7	Bowen Hills	-1.21	-8	-0.07	0.13	0.04
8	Mount Gravatt	-1.2	-5	-0.06	0.12	0.05
9	Woodend	-1.17	-6	-0.07	0.13	0.01
10	Griffin	-1.16	-5	-0.08	0.15	0.02
11	Rocklea	-1.15	-9	-0.11	0.13	0.01
12	Dakabin	-1.15	-5	-0.03	0.15	0.03
13	Milton	-1.12	-5	-0.04	0.14	0.06
14	Dutton Park	-1.11	-5	-0.12	0.08	0.03
15	Chandler	-1.1	-5	-0.12	0.15	0.04
16	Wulkuraka	-1.09	-10	-0.04	0.11	0.02
17	Kelvin Grove	-1.06	-8	-0.05	0.11	0.03
18	Nathan	-1.05	-4	-0.03	0.12	0.12
19	Yeerongpilly	-1.05	-5	-0.06	0.11	0.05
20	South Brisbane	-1.03	-4	-0.04	0.09	0.04
Average change	Top 20 suburbs	-1.18	-6.1	-0.08	0.12	0.04
Average change	Total Brisbane suburbs	-0.91	-6.9	-0.06	0.11	0.03
Correlation to VFE change	Total Brisbane suburbs		0.16	0.31	0.03	0.09

Next, we overlaid the VAMPIRE measures with the VFE change (2009–2014) at suburb level to identify the suburbs that are the most oil vulnerable and have the high level of VFE improvement in the local fleet. The suburbs with the highest VFE improvement were those suburbs with VFE increases greater than one standard deviation from the mean of total suburbs. The most oil vulnerable suburbs were those with VAMPIRE scores in the highest decile class. We use different methods to determine the thresholds of VAMPIRE score and VFE improvement because of different data distribution and the need to identify distinct high value areas within each datasets.

Fig. 2 shows the distribution of the suburbs that are the most oil vulnerable and have the highest level of VFE improvement in the local fleet. Overall, the level of spatial intersection between the areas of high VFE improvement and the most oil vulnerable suburbs is very low- only six out of the 55 most oil vulnerable suburbs have experienced high levels of VFE improvement of the local fleet. Other than that, most highly oil vulnerable suburbs in Brisbane remained at relatively lower levels of VFE improvement. Households in these oil vulnerable areas showed a lower tendency to shift motor vehicles towards more efficient ones. The implication of this is that the lower socio-economic status households that already face relatively high economic burden and vehicle energy costs would have higher financial difficulties in shifting to a newer and efficient vehicle. Therefore, the potential reduction of oil vulnerability through implementing fuel efficient vehicle is deemed challenging. People living in the highly oil vulnerable areas would need a higher level of financial programs or significant fuel savings returns before it would become cost-effective to change their vehicle ownership patterns.

3.3. Fuel saving from improved VFE

This section evaluates the economic benefits of VFE change for households in terms of total fuel savings. The value of fuel savings for households is calculated using three influential factors: improvement in VFE, vehicle kilometres travelled (VKT) and fuel price.

In order to estimate the fuel saving benefit exclusively from improved vehicle fleet efficiency, the analysis was conducted based on assumption that no major changes took place in the household VKT between 2009 and 2014.

First, a linear model is applied city wide to estimate annual VFE change for every suburb between 2009 and 2014. Because there was no motor vehicle data for each individual year between 2009 and 2014, we assume an even increment in VFE change across the 5-year period. Because the VFE measures provided by the Green Vehicle Guide tend to be 20 percent higher than the actual on-road fuel consumption (BITRE, 2014), the VFE values each year were adjusted to account for additional fuel consumption in an on-road traffic environment.

The second factor influencing vehicle fuel consumption is household VKT. Because households living in the different suburbs may present different vehicle travel behaviour (e.g., people living in the outer suburbs may drive longer distances than

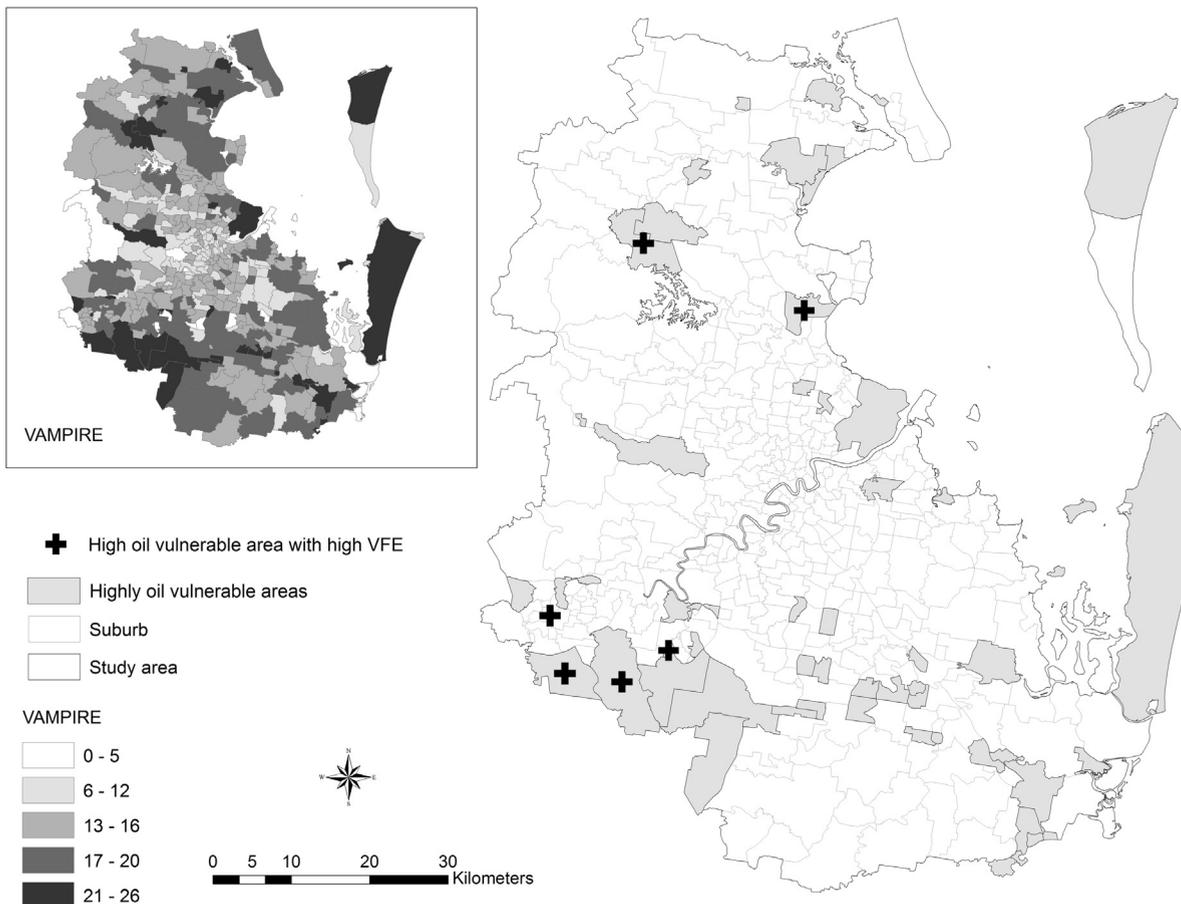


Fig. 2. VFE change in Brisbane's most oil vulnerable suburbs (oil vulnerability is measured using the VAMPIRE index).

people in the inner suburbs to conduct major urban activities), we diversify these variations in household VKT using measures of travel distance mainly from journey to work (JTW). The JTW dataset was obtained from the 2011 Australian census which contains detailed trip origin zones and destination zones over Brisbane's urban area and total number of trips (in this study, by car) between each origin and destination pair. Combined with road network data, the average VKT of JTW for each suburb was calculated using a spatial analysis of the distance of the shortest path between trip origin and destination.

In order to account for household vehicle travels for other purposes (e.g. travel to shop), the average VKT from JTW in each suburb was adjusted to estimate a total household VKT. The level of adjustment for each suburb was derived from the South East Queensland Household Travel Survey provided by the Queensland Department of Transport and Main Road. The travel survey data contains sampled household travel information for all types of activities including travel to work, shop, education, recreational activities. A ratio between household VKT from JTW and total household VKT was calculated for each suburb using the sampled survey data. The ratio was then applied to the calculated household JTW distance to estimate the household total VKT in a suburb. The formulas used to calculate total household VKT and total fuel saving are provided below:

$$\text{Total Household VKT} = \text{VKT}_{\text{JTW}}^* (\text{Total VKT}_{\text{Travel survey}} / \text{Work VKT}_{\text{Travel survey}}) \quad (1)$$

$$\text{Total fuel saving} = (\text{VFE}_{2009} - \text{VFE}_{2014})_{\text{Adjust}} * \text{Total Household VKT} \quad (2)$$

Next, the total litre of vehicle fuel saved in each year was calculated by multiplying the average household VKT and VFE improvement within each suburb, accounting for the number of days of the travel. Finally, the total household vehicle fuel savings were accumulated over five years for each suburb. The average annual fuel prices in Brisbane (from 2009 to 2014, in Australian dollars) were used to transform total fuel savings to the monetary cost

Fig. 3 shows the distribution of total household fuel savings estimated from improved VFE between 2009 and 2014. It illustrates a contrasting pattern to the VFE change over time. Although the VFE improvement was not strong in Brisbane's outer suburbs (showed in Fig. 1), the net vehicle fuel saving per household gained from the VFE change was higher than in the inner suburbs. We calculated that the total fuel saving of fleet in the outer suburbs (greater than 20 km from the CBD) was 46% higher than that in the inner and middle urban areas (less than 20 km from the CBD). The high level of vehicle

fuel savings estimated in the outer suburbs is primarily driven by higher household car ownership and more dispersed vehicle travel patterns (e.g. longer VKT) in those areas. Although the level of VFE improvement is relatively low in the outer suburbs, a small improvement in VFE would offer greater fuel saving opportunity, especially for the suburban areas where people travel longer distances, use older and less efficient vehicles.

3.4. Fuel saving opportunities vs. new technology costs

Although improved VFE can offer economic benefits for households it also means higher upfront cost of vehicles which is considered as a major impediment to social uptake of highly efficient vehicles (as illustrated in Figs. 1 and 2). Household's tendency of shifting to a fuel efficient vehicle could be strongly motivated by financial incentives. For example, household's willingness of investing the fuel efficient technologies (e.g. paying higher price for a new and more efficient vehicle) is often influenced by the level of fuel saving from the new vehicle and how long it will take to recover these additional costs through fuel saving. To raise household awareness and strengthen understanding of the value of VFE change, there is a need to assess and compare the household costs and potential benefits of adopting a fuel efficient vehicle, and how this would potentially assist current transport and fuel economy strategies to achieve a stronger transformation of urban vehicle fleet.

This section compares the future fuel savings from improvement in VFE in the future years and upfront costs of fuel efficient technologies incorporated by new vehicles that generate fuel savings for households. The implications of VFE change for future household vehicle choice is evaluated based on a benefit-cost analysis of upfront cost associated with fuel efficiency technologies and the expected value of fuel saving for households that choose a fuel efficient vehicle. It evaluates whether the improvement in VFE would in the long term generate high level of fuel savings that can impact household vehicle choices.

The expected annual fuel savings for the future years in Brisbane were estimated under two scenarios. The first scenario assumes that the current trend of VFE change will continue in the future. The second scenario assumes that all car users in Brisbane will choose a more efficient vehicle to meet a strict national fuel economy target in Australia (6.5 L/100 km by 2030).⁴ The annual VFE change and fuel savings under each scenario were calculated using the formulas (3)–(5) listed below. In order to estimate the potential fuel saving exclusively from future VFE, both scenarios assumes that there will be no major change in the household VKT in the future years.

$$\text{Annual fuel saving} = \text{Annual VFE change} * \text{average household VKT per year} \quad (3)$$

Scenario I (current trend):

$$\text{Annual VFE change} = (\text{VFE}_{2009} - \text{VFE}_{2014}) / 5 \text{ years} \quad (4)$$

Scenario II (imposing a national target):

$$\text{Annual VFE change} = (\text{VFE}_{2014} - 6.5) / (2030 - 2015) \text{ years} \quad (5)$$

To account for the rising fuel prices that are likely to occur, the values of fuel saving over the period of vehicle ownership were calculated using the projected fuel price for the future years (International Energy Agency, 2016). It assumes the future fuel price will increase incrementally and reach an average AU\$1.9 per litre by 2030.⁵ The level of incentives for households to choose an efficient vehicle was estimated based on the number of years of vehicle ownership required to generate fuel saving to match the upfront cost of new efficient vehicles.

The information on the costs associated with fuel efficiency technologies for new efficient vehicles in Australia was not available. Therefore, we adopted an approach previously used by ClimateWorks (2014) to estimate the costs using the most relevant information from the US that is targeting a similar level of fuel economy improvement. The estimate suggests that the additional vehicle technology required to achieve the fuel economy target would increase the retail price of approximately AU\$1500 per vehicle. Estimates of incremental vehicle cost include the costs of a number of additional fuel saving technologies that can be used in different combinations to determine the overall effect on cost and VFE.

Fig. 4 illustrates the number of years required to generate fuel savings that match the upfront cost of new efficient vehicles. The number of suburbs that are able to generate enough fuel savings within each year class is also reported for the two scenarios. The results show that if current VFE change continues, this change will result in only 34 out of 440 suburbs in Brisbane are able to generate enough fuel savings to recover the new technology cost within 10 years. Most of these capable suburbs are located in the far north-west of Brisbane. Fig. 4 further illustrates that if the VFE change accelerates, then that will meet the fuel economy target of 6.5 L/100 km by 2030, there 107 suburbs in Brisbane will be able to generate total fuel savings to match the new vehicle technology costs within 10 years. These areas are mainly distributed in Brisbane's far north, far south, and far west. This result clearly indicates that although current trend in VFE can make certain level of fuel savings, implementing a stronger national fuel economy mandate effectively will offer good potential for car drivers to generate significant financial return that can recover the upfront cost of new efficient technology within a relatively short period of vehicle ownership.

⁴ 6.5 L/100 km in 2030 matches the Australian Government's target to reduce carbon emissions by 25% by 2030.

⁵ This is calculated by translating the IEA high GDP potential oil supply projections into Australian retail petrol prices.

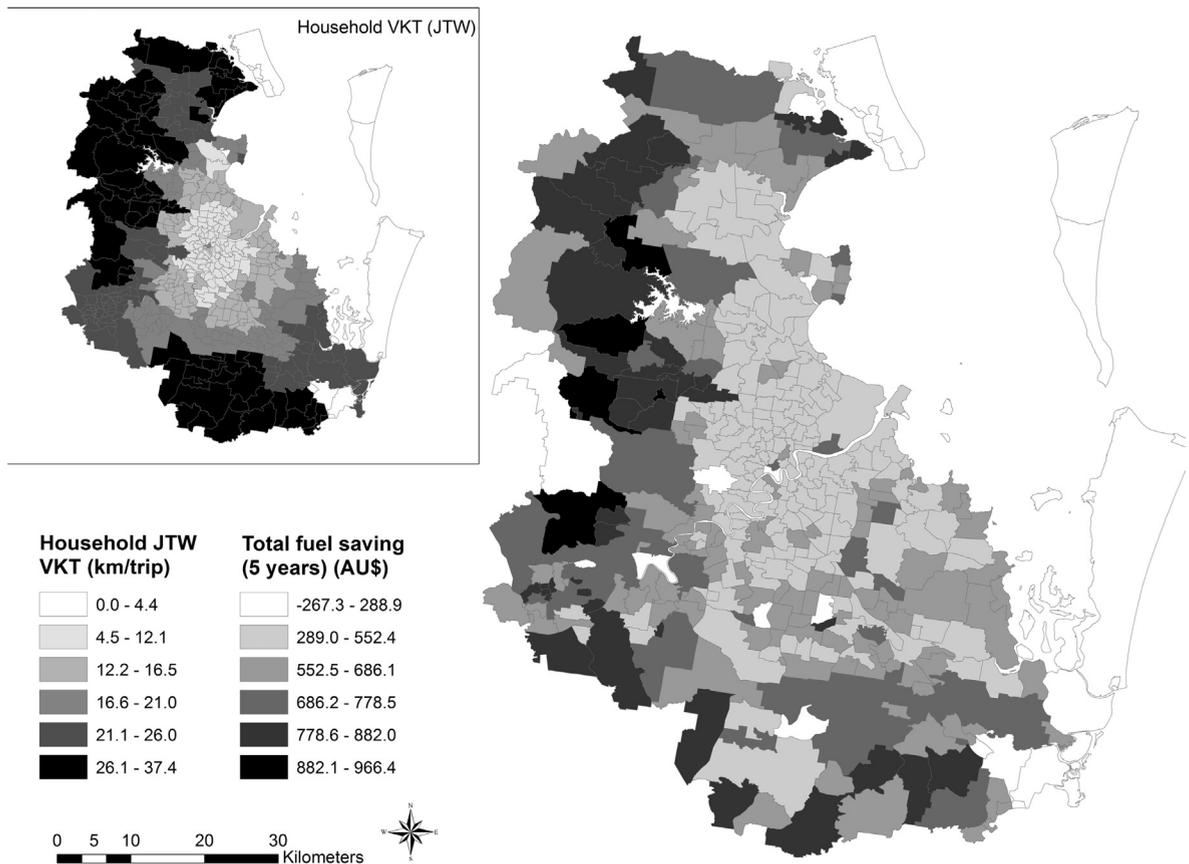


Fig. 3. Accumulated household fuel savings from improved VFE (2009–2014) (the average household JTW VKT is displayed in the inset).

4. Discussion and conclusion

The automotive transport sector faces a considerable transformation in response to the car peak and challenges of petroleum depletion and climate change. A significant area of research within the peak car debate is investigating the technical, social and economic consequences of peak cars for cities (Schipper et al., 2010; Cohen, 2012; Li et al., 2015b, 2016). This paper offers a deep insight of this issue of peak cars by conducting a major spatial analysis to exploit the metropolitan pattern of VFE change in Brisbane's private vehicle fleet. Through a comparison of motor vehicle registration and efficiency datasets between 2009 and 2014, this paper shows a strong pattern of VFE change in Brisbane's private vehicle fleets. The VFE improvement tended to be higher in the inner urban areas. These areas have typically high densities, served by good public transport systems, and have residences of many high income people. In contrast, the level of VFE improvements in the outer and less wealthy suburbs was relatively low, implying some social and spatial impediments to a rapid transition. This paper further evaluates how changes in VFE intersect with social economic variables across urban area, including the VAMPIRE index, which measures relative household oil vulnerability. The results show that households in the highly oil vulnerable areas of Brisbane showed a low tendency in shifting to efficient vehicles. This result reflects a strong differential social economic capacity in transforming vehicle efficiency on urban area. Some low income groups under heavy economic burdens and living highly car dependent are trapped with old and low efficient vehicles and whilst more affluent households in the inner urban zones take advantage of new technology. The finding suggests that a smooth and uniform fuel transition in the suburban vehicles would need strong financial strategies (e.g. either through managing the vehicle market price or effective incentive programs) to make new and fuel efficient vehicles become affordable for outer suburban households.

Combining the VFE change with household travel patterns, our analysis further illustrates that although the VFE change in the outer suburbs was relatively low, the potential fuel savings generated in those areas were significant. This is because the longer household VKT and the higher level of fuel consumption in those areas. Given their dispersed mobility patterns, a marginal change in VFE would have a strong effect on household fuel savings on large suburban areas. The estimation shows that the average fuel savings in the outer suburban areas was greater than inner and middle urban areas by 46% over a 5 years period. This result suggests that greater policy supports that aim to improve fuel economy of existing fleets can be a rapid and cost-effective strategy to change vehicle transport outcome in the Australia's large and dispersed suburban areas. Often the alternative transport infrastructure such as new public transport, walking and cycling facilities in the

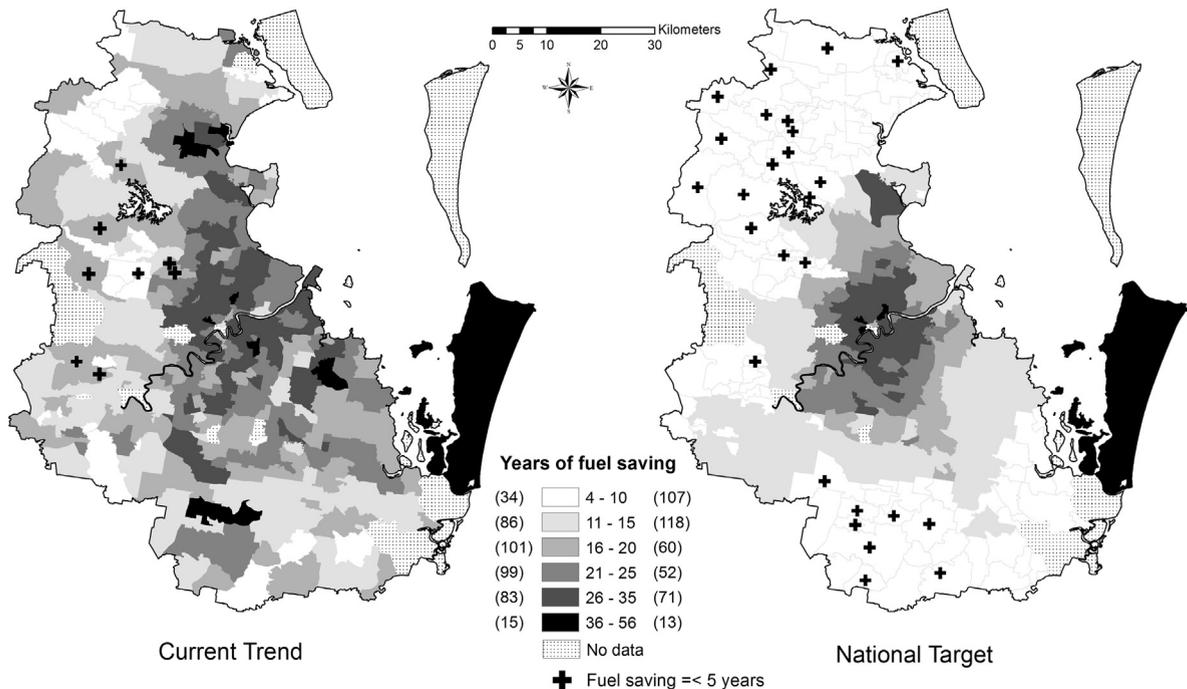


Fig. 4. Number of years required to generate fuel savings that match the upfront cost of new efficient vehicles (the number of the suburb is reported in each class). Left: Current VFE trend. Right: National VFE mandate.

dispersed suburban areas can entail expensive investments and need longer period to recover the costs of development. However, to make the vehicle fleet transformation socially achievable, people living in the highly oil vulnerable areas would need a higher level of financial programs and fuel saving opportunities before it would become cost-effective to shift to new and efficient vehicles.

The final part of this paper compares the expected fuel savings for households and the cost of fuel saving technologies to evaluate how VFE improvement would in a long term affect household vehicle adoption and affordability. The expected fuel savings in the future years were estimated and compared with the upfront cost of new technology for a new and efficient vehicle. The results show that although current change in VFE can manage rising fuel costs, policies that rely on market-led improvement in fleet fuel economy are unlikely to quickly shift away from low efficient vehicle. Comparably, imposing a stronger national fuel economy target to the entire vehicle fleet would offer greater fuel saving opportunity for households and financial return to adopt a more fuel efficient vehicle. Such fuel saving benefits is even greater for a number of suburban areas where people use low efficient vehicle and drive longer distances annually. The results show that in a great number of suburbs, the economic wide upfront investments could be paid off from fuel savings if they were to adopt new and more efficient vehicles under a stronger VFE improvement program. Therefore, a stronger transition policy that offers more than market-led fuel adjustment to the existing vehicle fleets would generate quicker benefits to make vehicle upgrades cost-effective for suburban households. The analysis has strengthened our understanding of the value of VFE change, and economic benefits of implementing a stronger national fuel economy strategy in Australian cities.

In general this paper contributes to wider international debates about the future of the car. The findings of this paper are particularly important for policy makers, those charged with identifying highly oil vulnerable communities and designing VFE improvement strategies. Although our methods bear several assumptions and limitations, they provide a suburb-level of policy analysis by identify areas where high rate of disadvantage coincide with low rates of high VFE uptake, and appraises the long-term VFE target and policy consequences of these differential social and vehicle patterns in Australia. The results of analysis provide useful indications to assist policy and governance adjustments necessary to respond to the changing patterns of car use and social-spatial vulnerability in Australian cities.

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