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Real-world fuel efficiency of light vehicles in New Zealand

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Abstract

A number of recent overseas studies have found that vehicles on the road generally consume significantly more fuel than would be expected from the type-approval fuel efficiency (FE) values provided by carmakers and that the divergence is growing. Similar research has not previously been undertaken in New Zealand. This paper presents the results of a study on real-world FE of New Zealand light vehicles. In particular, it looks at the divergence between actual and type-approval FE values. A large dataset of on-road fuel use in several large private corporate fleets based on fuel card transactions has been analysed. It contained data collected during 2013 and 2014 from more than 9000 light vehicles (6759 light petrol and 2511 light diesel vehicles). We have studied the effects of two of the most important factors, engine size and the year of manufacture, on vehicles' real-world FE. We have found that there is a good linear relationship between mean FE and average engine size. Moreover, for a given engine size newer vehicles are generally more fuel efficient than their older counterparts. On the other hand, the divergence between real-world and type-approval FE values is also growing for New Zealand vehicles and is normally larger for smaller vehicles. The fleet travel weighted average FE is 9.2 L/100km for the analysed light petrol vehicles and 10.1 L/100km for the light diesel vehicles. Overall, their divergence from type-approval FE is similar – about 19% on average.

1. Introduction

Road transport consumes a large amount of liquid fossil fuel and is a gross emitter of greenhouse gases (GHG). In New Zealand, road transport used about 75% of liquid fuel in 2013[2] and contributed 16% of national GHG emissions[3]. Internationally, stricter fuel efficiency (FE) regulation has driven down the fuel consumption of new light vehicles when they are tested on a type-approval (certification) driving cycle. The type-approval FE values are obtained under laboratory conditions for a specific driving cycle, for example, the New European Driving Cycle (NEDC). However, individual driving styles, geography and traffic conditions on the road can be very different from the standard test. The benefit of FE standards can be realised only if they can be translated into real fuel consumption gains in the real world. This topic has attracted attention in recent years as many countries seek to regulate to improve the FE of their vehicle fleets.

A number of studies on real-world FE of motor vehicles have been conducted in Europe, the USA, Japan and China. They have found that vehicles on the road generally consume significantly more fuel than would be expected from the type-approval FE values provided by carmakers (Mock et al., 2012, 2013, 2014; Ntziachristos et al., 2014; Kadijk and Cuelenaere, 2013; Kudoh, 2012; Huo, 2011; Mellios et al., 2011; Schipper, 2011). Furthermore, the

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[1] The opinions expressed in this paper are those of the authors, and do not necessarily represent the views of the Ministry of Transport.

[2] Based on the oil statistics from the Ministry of Business, Innovation and Employment (MBIE) (http://www.med.govt.nz/sectors-industries/energy/energy-modelling/data/oil).

[3] Based on the data in New Zealand Greenhouse Gas Inventory 1990-2013 (http://www.mfe.govt.nz/publications/climate-change/new-zealands-greenhouse-gas-inventory-1990-2013) and MBIE's Energy Greenhouse Gas Emissions – 2013 Calendar Year Edition (http://www.med.govt.nz/sectors-industries/energy/energy-modelling/publications/energy-greenhouse-gas-emissions/energy-greenhouse-gas-emissions-2014.pdf).

divergence between real-world and type-approval FE values is growing (Mock et al., 2012, 2013, 2014).

Type-approval driving cycles, particularly the NEDC, only cover a very limited set of accelerations and velocities experienced on the road, and generally focus on driving conditions with a low engine load (Lighterink et al., 2012). In principle, the efficiency of an engine is much less at higher engine loads as often experienced in the real-world driving (Lighterink et al., 2012). Unrealistic vehicle resistance (including wind and rolling resistance) used in type approval has been identified as a major reason for its low engine load (Mellios et al., 2011; Ntziachristos et al., 2014).

Similar research has not previously been carried out for the light vehicles in New Zealand. Currently we can estimate fleet average FE for our in-use light petrol vehicles based on fuel delivery data. However, we have little knowledge on the real-world FE of our diesel vehicles. The main purpose of this paper is to study real-world FE of New Zealand vehicles and the divergences between actual and type-approval FE values. Particularly, we study the effects of two of the most important factors, engine size and the year of manufacture (YOM), on vehicles' fuel consumption.

2. Data sources and data analysis

2.1 Data sources

A large dataset of real-world fuel use based on fuel card transactions was sourced from several New Zealand companies. It included 6759 light petrol and 2511 light diesel vehicles. No hybrid and petrol turbo charged vehicles were included. Light vehicles are those with a gross vehicle mass (GVM) less than 3500kg as defined in the technical standards for vehicles (http://www.nzta.govt.nz/vehicle/classes-standards/standards/). This classification follows international general practice (Ntziachristos and Samaras, 2014). The sample includes both light passenger and commercial vehicles (mainly for the carriage of goods). All vehicles were corporate vehicles and their fuel use was monitored during 2013 and 2014. The vast majority of the vehicles were made in 2010 or later. We have no specific knowledge of the tasks performed by the vehicles and have assumed that all vehicles were operated under the same conditions. The technical specifications of the vehicles, including type-approval FE values, were taken anonymously from the New Zealand Motor Vehicle Register (MVR)[4].

2.2 Data analysis

All vehicles have multiple records of fuel transaction (some have more than 100 records). The data were cleaned up before further analysis was carried out and those records with an extreme FE value were deleted. This was to ensure that bad data points did not 'contaminate' the calculation of FE value for individual vehicles. To further reduce the impact of the uncertainty of individual transactions, the FE value for each vehicle was calculated as total fuel use divided by total kilometres travelled for the vehicle over the entire time period.

3. Results and discussion

Many factors can affect real-world fuel efficiency of a vehicle. In this work, we study the effects of two of the most important factors, engine size (engine displacement) and the year of manufacture. These factors are key variables in most vehicle emission models, for example, the European COPERT 4 (http://emisia.com/copert). The YOM is a key factor for

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[4] The New Zealand Motor Vehicle Register (http://www.nzta.govt.nz/vehicle/registration-licensing/information.html) contains extensive technical information of registered vehicles, including make, model, weight, usage category, cc rating, fuel type, wheelbase, odometer reading, country of origin, whether imported second hand or new, and so on.

FE because it is closely related to technology used. The actual engine power outputs could be a better measure of FE than engine size. However, the engine power outputs are highly variable in terms of how and where a vehicle is operated. It is impractical to obtain quality data on them. What we are studying is FE of a vehicle rather than that of its engine only. In this sense, GVM may be more relevant than engine size. As shown in section 3.1, GVM strongly correlates with engine size for the studied vehicles. Furthermore, most vehicle emission models use engine size when estimating fuel consumption for light vehicles.

3.1 The effects of engine size

Table 1 shows FE values (L/100km) of the light petrol vehicles for different engine size bands (cubic centimetres, cc). The engine size ranges are the same as those used in the Ministry of Transport's in-house Vehicle Fleet Emission Model (VFEM; in contrast, there are only three engine size bands used in the COPERT 4 model). Note that in the dataset only ten petrol vehicles have an engine size larger than 4000cc. Their statistics are therefore not included in this table.

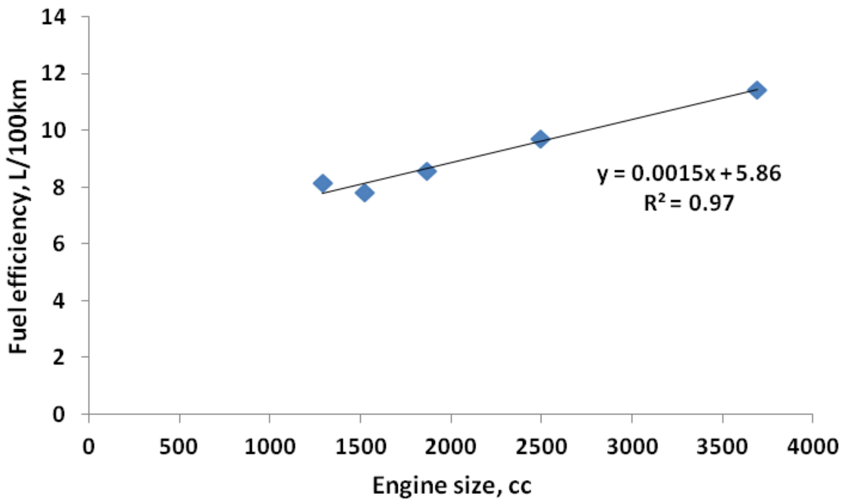
It is interesting to note that vehicles with a very small engine (<1350cc) are somewhat less fuel efficient than those with a slightly larger engine (1350cc – <1600cc). The most likely reason for this is that vehicles with a very small engine need to be driven harder than larger ones to keep up with the traffic in the real world. This will keep the engine of a small vehicle running in a less efficient way. In general, there is a good linear relationship between mean FE and average engine size of these light petrol vehicles for different engine size bands (Figure 1). The correlation between mean engine size and average GVM is also found to be very strong (R^2 = 0.97). This follows a basic logic – when the engine size of a vehicle (along with its GVM) increases, the power generated and engine load will also increase, leading to the consumption of a larger amount of fuel.

Table 1: Fuel efficiency (L/100km) of the light petrol vehicles

Engine size band (cc)	Number of vehicles	Mean FE	Median FE	Confidence interval*	Mean GVM (kg)
<1350	857	8.15	7.98	8.15 ± 0.074	1545
1350 – <1600	1228	7.81	7.67	7.81 ± 0.076	1686
1600 – <2000	2093	8.58	8.42	8.58 ± 0.049	1857
2000 – <3000	2126	9.72	9.67	9.72 ± 0.062	2116
3000 – <4000	445	11.4	11.2	11.4 ± 0.14	2410

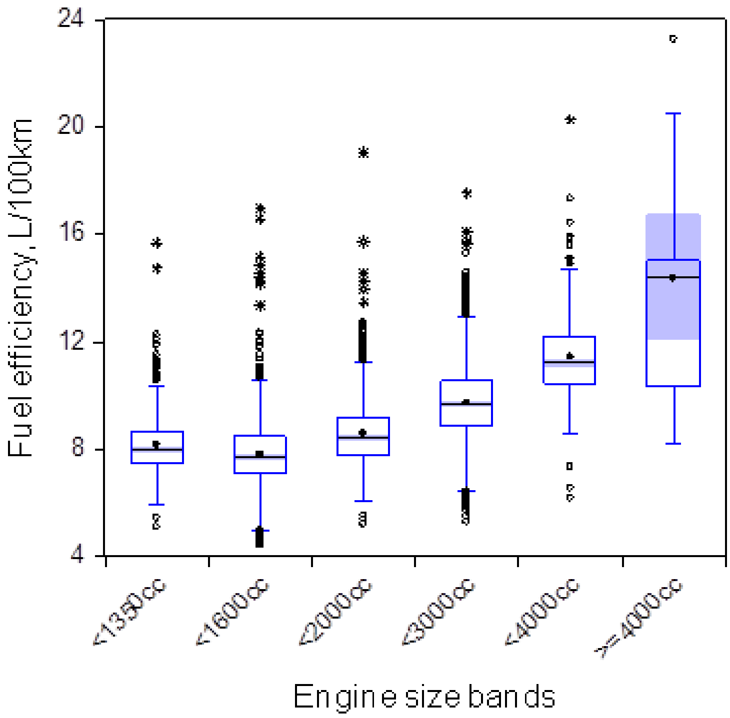
*Note: confidence interval for FE is at the 95% level.

Figure 1: Relationship between mean FE and average engine size of the light petrol vehicles for different engine size bands



As seen in the box plots in Figure 2, FE values of individual light petrol vehicles are widely distributed. This is normal, as the FE of a vehicle is affected by many factors, such as vehicle technology, driving style (frequency of acceleration and deceleration, and speed), road conditions, geography, weather conditions, and the use of air conditioning. On the other hand, the trend for increasing fuel use with increasing engine size can be still seen clearly in Figure 2.

Figure 2: Box plots of FE of the light petrol vehicles for different engine size bands



Note: in box plots, the bar inside a box indicates the median and the dot inside the box indicates the mean.

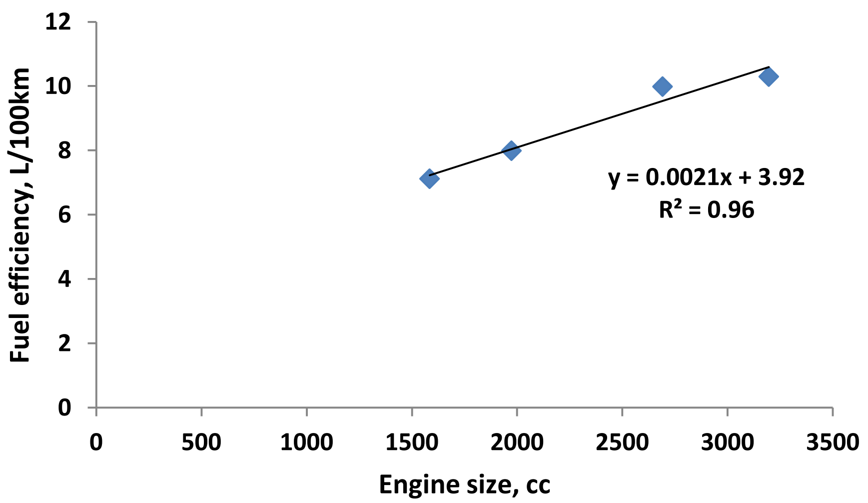
Fuel efficiency values of the light diesel vehicles for different engine size bands are given in Table 2. Note that in this dataset none of the light diesel vehicles have an engine size less than 1350cc and that only 13 of them have an engine size over 4000cc (so their statistics are not shown here). There is also a very good linear relationship between mean FE and average engine size of the light diesel vehicles for different engine size bands (Figure 3). The correlation between mean engine size and average GVM is also found to be very strong (R^2 = 0.98). Similar to light petrol vehicles (Figure 2), the FE values of individual light diesel vehicles are also widely distributed (not shown here).

Table 2: Fuel efficiency (L/100km) of the light diesel vehicles

Engine size band (cc)	Number of vehicles	Mean FE	Median FE	Confidence interval*	Mean GVM (kg)
1350 – <1600	106	7.12	7.07	7.12 ± 0.15	1919
1600 – <2000	516	7.99	7.81	7.99 ± 0.12	2387
2000 – <3000	1513	9.99	9.87	9.99 ± 0.068	2855
3000 – <4000	363	10.3	10.1	10.3 ± 0.11	3195

*Note: confidence interval for FE is at the 95% level.

Figure 3: Relationship between mean FE and average engine size of the light diesel vehicles for different engine size bands



3.2 Divergence between type-approval and real-world fuel efficiency

As noted above, previous overseas studies have shown a consistent gap between the real-world and type-approval FE values. We have found the same result. The divergence between real-world and type-approval (NEDC) FE values is larger for the vehicles with smaller engines. This holds true for both light petrol (Figure 4) and light diesel (Figure 5) vehicles. A similar trend has been found overseas (Ntziachristos et al., 2014). Several reasons have been suggested to explain this. First, low power vehicles may need to be driven harder than larger ones to keep up with the traffic. Second, the impact of factors demanding higher fuel consumption, such as loading from the use of air conditioning, are relatively more important for lower power vehicles. (Ntziachristos et al., 2014).

Figure 4: The divergence (vertical axis) between real-world and type-approval (NEDC) FE values of the light petrol vehicles (all analysed vehicles included)

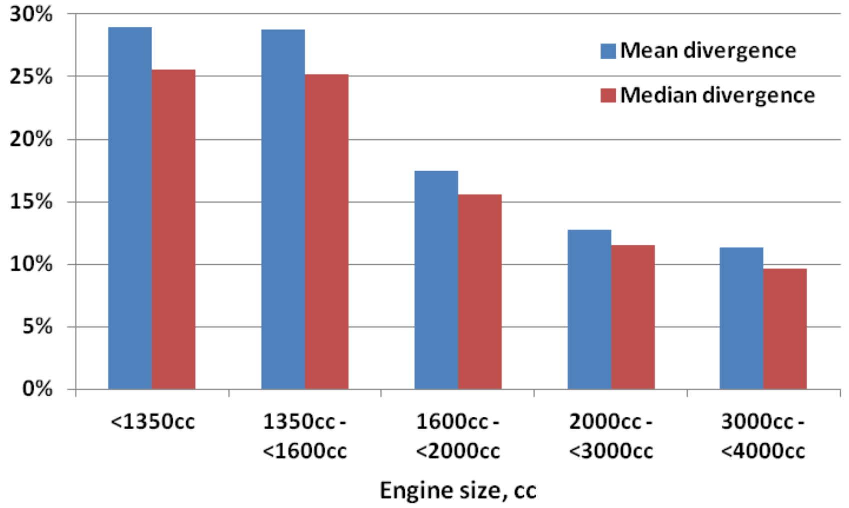
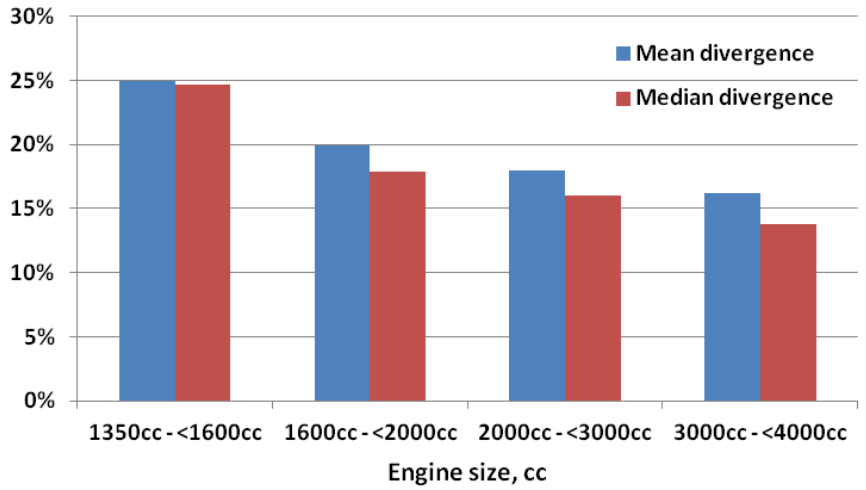


Figure 5: The divergence (vertical axis) between real-world and type-approval (NEDC) FE values of the light diesel vehicles (all analysed vehicles included)



The average divergence between real-world and type-approval FE values for the light petrol vehicles ranges from 10% to more than 25%, and 15% to 25% for the light diesel vehicles. To confirm that there is a significant difference in the divergence among the engine size bands, we have run a Kruskal-Wallis test (a nonparametric one-way ANOVA). This is because these variables do not have a normal distribution. These tests did find a significant difference for both light petrol and diesel vehicles ($p < 0.0001$ in both cases).

3.3 The effects of the year of manufacture

When studying the effects of YOM on FE, we have only included those vehicles made in 2010 or later because in this dataset the number of vehicles made before 2010 was limited.

As shown in Figure 6, the FE of newer light petrol vehicles in recent years is steadily improving. The difference in FE is not a function of changes in engine size since the average engine size is similar for different YOM (although the mean engine size is slightly higher for the 2010 vehicles). On average, the real-world FE has improved by 1.6% per year since 2011. In contrast, we have found that the type-approval FE for the same vehicles improved by 3.4% per year. This demonstrates that although the real-world FE of new vehicles is improving over time, the improvement is far less than would be expected from the type-approval FE values. Nevertheless, we could reasonably argue that as newer vehicles enter our fleet and older vehicles are scrapped, the overall FE of the fleet will gradually improve (although it would improve more quickly if average engine size was also reduced).

The trend for newer vehicles to be more fuel efficient is consistent with the actual FE trend of the entire light petrol fleet in New Zealand estimated based on fuel delivery data (Figure 7). This shows a small, but steady increase in FE of on-road vehicles since 2009. The fleet average FE values of New Zealand's in-use light petrol vehicles shown in Figure 7 were estimated using fuel delivery data and the distance travelled recorded at regular vehicle inspections. Unfortunately, the same methodology cannot be applied to our diesel vehicles. This is because the fuel delivery data for on-road transport diesel are insufficient for us to accurately separate the diesel used by light vehicles from that by heavy vehicles (Field, 2010; Outcome Management Services, 2008).

Figure 6: Fuel efficiency *vs.* the year of manufacture for the light petrol vehicles

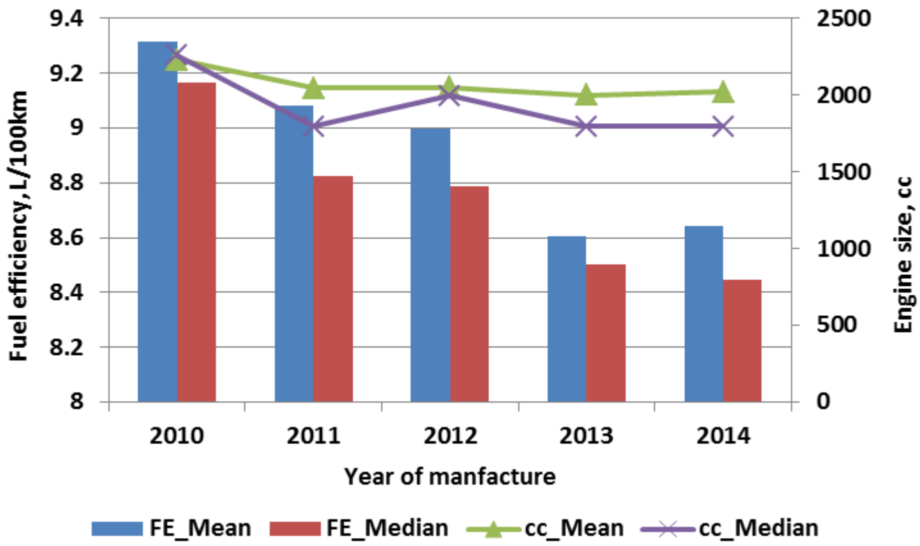
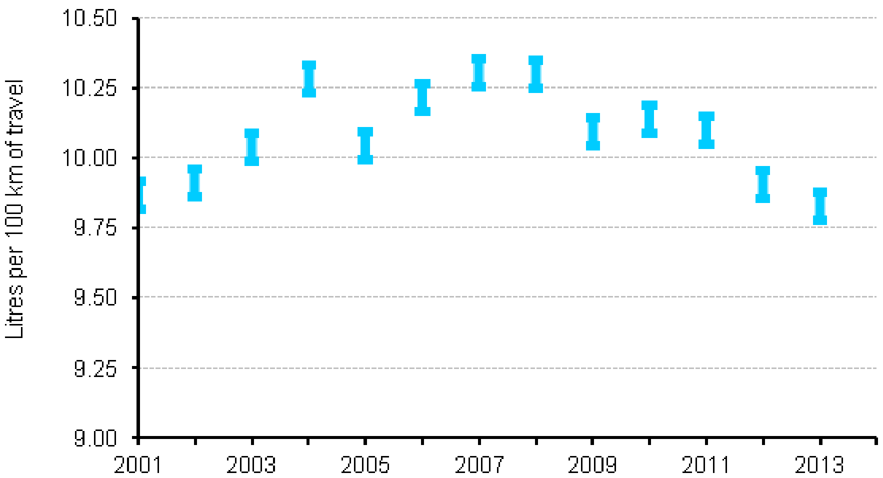
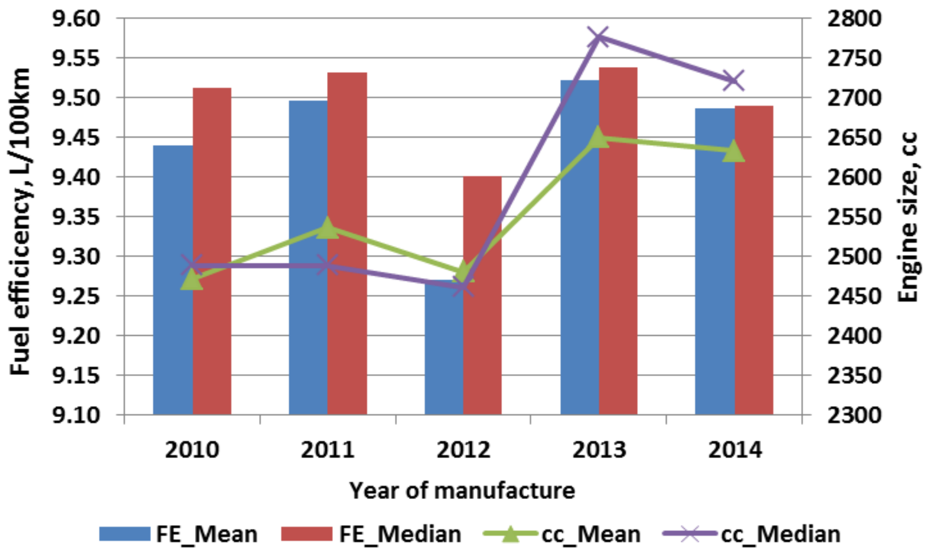


Figure 7: Fleet average FE of light petrol vehicles in New Zealand over time (fleet years) – minimum and maximum estimates based on fuel delivery data



For the light diesel vehicles, newer vehicles seem to be also more fuel efficient, but the trend is not as pronounced (Figure 8). The lack of a clear trend is mainly because those light diesel vehicles made in 2013 and 2014 in this dataset have a larger engine size on average than those made in earlier years. If their average engine size was the same as those made in 2012 or earlier, their fuel consumption for 100 km travelled would have been lower than what was observed.

Figure 8: Fuel efficiency *vs.* the year of manufacture for the light diesel vehicles



3.4 The growing divergence between real-world and type-approval FE values

As discussed in Section 3.2, there is a clear divergence between real-world and type-approval FE values and the divergence is larger for vehicles with smaller engines. In addition to the divergence trend based on engine size, we also see a clear trend of increasing divergence based on the year of manufacture for both light petrol and light diesel vehicles (Figures 9 and 10). This finding is consistent with overseas studies (Mock et al., 2014, 2013, 2012). Kruskal-Wallis tests confirm that there is a significant difference in the divergence among different years of manufacture for both petrol and diesel vehicles ($p < 0.0001$ in both cases).

Figure 9: The divergence between real-world and type-approval (NEDC) FE values *vs.* the year of manufacture for light petrol vehicles

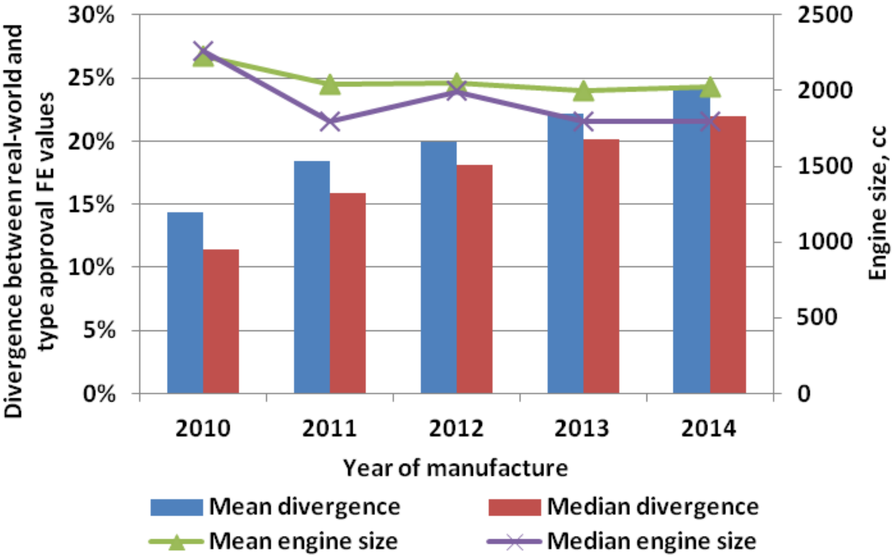
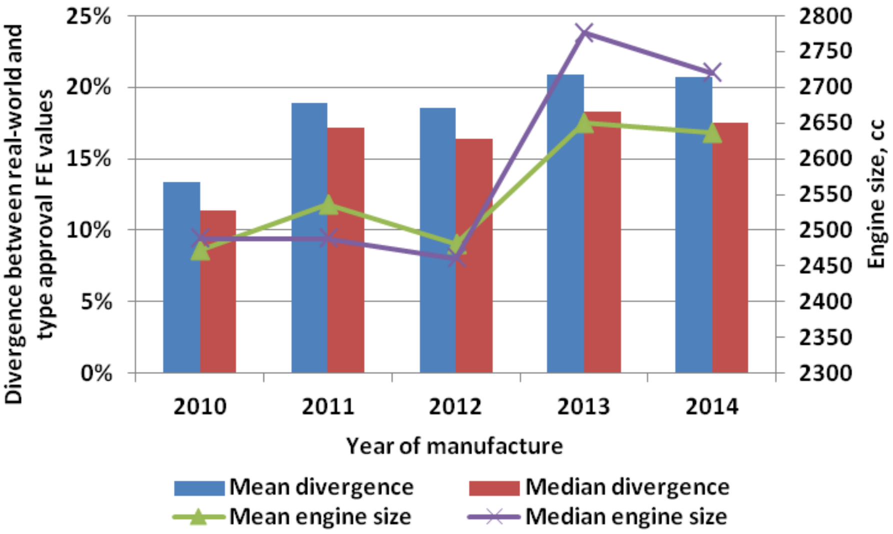


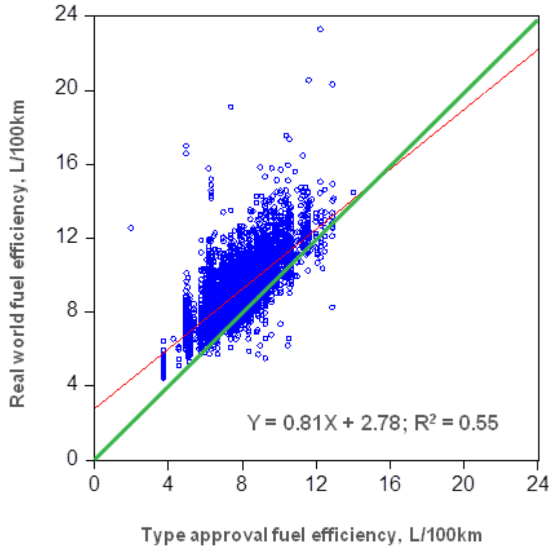
Figure 10: The divergence between real-world and type-approval (NEDC) FE values *vs.* the year of manufacture for light diesel vehicles



As noted above, those light diesel vehicles made in 2013 and 2014 have a larger engine size on average than those made in earlier years. Our research (Section 3.2) shows that the divergence between real-world and type-approval FE values is smaller for vehicles with larger engines. Therefore, the apparent increasing divergence trend with the YOM for diesel vehicles is less pronounced than that for petrol vehicles, where mean engine size is similar for different years of manufacture.

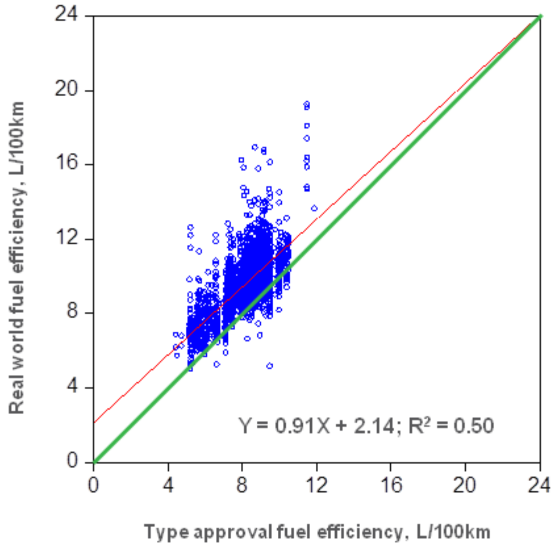
Despite the growing divergence, there is still a reasonably good correlation between the real-world and type-approval FE values for both light petrol (Figure 11) and diesel vehicles (Figure 12). This suggests that the NEDC used in type approval may have captured the main trend of real-world fuel efficiency, which could form a basis for establishing a quantitative relationship between the two variables. A robust relationship between real-world and type-approval FE values will help forecast future fuel use and GHG emissions from road transport. Further research is required in this area. In addition to engine size and the YOM, other factors need to be considered include power, vehicle mass, and fuel injection and transmission techniques (Ntziachristos et al., 2014; Kudoh, 2012).

Figure 11: A scatter plot of real-world and type-approval FE values of the light petrol vehicles



Note: the green line is the 1:1 line and the red line is the linear regression line.

Figure 12: A scatter plot of real-world and type-approval FE values of the light diesel vehicles



Note: the green line is the 1:1 line and the red line is the linear regression line.

3.5 Fleet travel weighted average fuel efficiency

The proportion of travel by vehicles in each engine size band in this sample is different from that of the entire light petrol or diesel vehicle fleet in New Zealand. We have therefore calculated fleet travel weighted average FE values[5] for these vehicles (Table 3). On average, a light diesel vehicle uses more fuel for every 100km travelled than a light petrol vehicle (10.1

[5] When working out fleet travel weighted average FE values, we weight the travel by the proportion of actual travel done by light vehicles in each engine size band in the entire light petrol or light diesel fleet.

L/100km *vs.* 9.17 L/100km). This is largely attributable to the fact that the average engine size of the diesel vehicles (2579cc) is significantly larger than that of the petrol vehicles (2054cc). It may also reflect a different usage pattern, with at least some diesel vehicles being used to carry freight or heavy equipment.

Table 3: Fleet travel weighted average FE values of the light vehicles and the divergence from type-approval FE values

	Fleet travel weighted FE (L/100km)		Divergence from type-approval FE (%)	
	Mean	Median	Mean	Median
Light petrol	9.17	9.04	19.1	17.0
Light diesel	10.1	9.92	18.6	16.4

Comparing the results in Table 3 with Figure 7, we can find that the fleet average fuel consumption of the light petrol vehicles analysed is lower than that of the entire light petrol fleet (9.83 L/100km in 2013). One factor for this could be that the vehicles in this dataset are, on average, much younger than the entire light petrol fleet in New Zealand (the average age was more than 13 years in 2013). For the same reason, we expect that the fleet average fuel consumption of the light diesel vehicles analysed here is also lower than that of the entire light diesel fleet, which is currently unknown.

Overall, the divergence between real-world and type-approval FE values of all the light petrol and diesel vehicles analysed in this dataset is similar, with a mean of 19% and a median of 17% (Table 3). This is on a similar magnitude to those found in overseas studies (e.g. Huo 2011, Ntziachristos et al., 2014).

4. Conclusions and further research

4.1 Key findings

Key findings from our analyses are summarised below.

- On average, fuel efficiency has a good linear relationship with engine size for both light petrol and light diesel vehicles
- Newer light vehicles in recent years, for a give engine size, are generally more fuel efficient
- Light petrol vehicles with a very small engine (<1350cc) are less fuel efficient than those with a slightly larger engine (1350 cc – 1600cc)
- Vehicles on the road consume more fuel for the same distance travelled than would be expected from the type-approval FE values
- The divergence between real-world and type-approval FE values is larger for smaller vehicles and also larger for newer vehicles (for a given engine size)
- The fleet travel weighted average FE for the light petrol vehicles analysed is 9.2 L/100km and 10.1 L/100km for the light diesel vehicles.
- The average divergence between real-world and type-approval FE values of the light petrol and diesel vehicles analysed in this dataset is similar - about 19%.

4.2 Limitations and further work

As indicated earlier, the vehicles analysed in this work are all corporate vehicles. Research has found that corporate vehicles generally consume more fuel than their private counterparts (Mock et al., 2014). At present, we are not aware of any good data on real-world fuel use of private vehicles in New Zealand. In Europe (Mock et al., 2014), the USA (Greene, et al., 2007) and China (Huo, 2011), websites or similar platforms have been set up to allow private vehicle users to voluntarily report their real-world fuel use. We need to think about how we can effectively collect fuel data for in-use private vehicles in New Zealand. The re-designed New Zealand Household Travel Survey[6] could be one channel for this purpose. Note also that the vast majority of the vehicles analysed were made in 2010 or later, which, on average, are much younger than the light vehicle fleet in New Zealand. More work is also required to collect real-world fuel use data for older vehicles.

To forecast future fuel use and GHG emissions from road transport, we not only need sound forecasts on fleet composition and vehicle travel, but also require a good knowledge on real-world FE of the vehicles entering the fleet. Further research is required to establish a robust quantitative relationship between real-world and type-approval FE values for light vehicles.

Acknowledgements

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[6] For more information about the New Zealand Household Travel Survey, follow the link: http://www.transport.govt.nz/research/travelsurvey/

and "real-world" fuel consumption and CO_2 values for passenger cars in Europe, International Council on Clean Transportation, Beijing

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