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Abstract

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JEL Classification

R41, Q41, Q43

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Fuel prices and road deaths in Australia

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After years of general progress in reducing Australia's road death toll, road deaths increased in 2015 and 2016, reaching 1,293 per annum. These were also years of relatively cheap fuel following the dramatic decline in the world oil price in late 2014. This study uses monthly data to model the number of road deaths in Australia. Our estimates suggest that low fuel prices have contributed to knocking Australia off track for meeting its 2020 road safety target. The paper also provides a discussion of other factors that may have contributed to the rise in Australia's road death toll.

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1. Introduction

Land transport accidents are the leading cause of death in Australia for people aged 1–14, the second-leading cause of death for those aged 15–24, and the third-leading cause of death for those aged 25–44. They are also a key cause of premature death for adults in higher age brackets (Australian Institute of Health and Welfare, 2017). The vast majority occur on roads. Many more people are injured.[1] Road accidents impose a large burden on the Australian economy; using a willingness to pay approach, it has been estimated that this cost was around $30 billion in 2015 (Economic Connections, 2017).

Like other developed countries, Australia has made substantial progress in reducing road deaths over recent decades. As observable in Figure 1, Australia's annual road toll fell from a high of 3,798 in 1970 to 1,151 in 2014, despite large increases in the national population, car stock, and the total number of vehicle-kilometres travelled (VKT) on roads. Improvements in road design, vehicle safety, and emergency services – together with stricter rules related to seatbelts, drink driving, and speeding – have all likely contributed to lowering Australia's road death toll (Federal Office of Road Safety, 1998; Stevenson and Thompson, 2014). Peak road deaths occurred prior to the oil price rises of the 1970s.

Australia's road death toll has not declined uniformly, however. Some periods of incline are observable in Figure 1, the most recent of which was in 2015 and 2016. Australia's road death toll reached 1,293 in 2016, 12.3% higher than in 2014. The road toll rose in all states and territories other than South Australia. In proportional terms, the largest increases were in New South Wales (+24%) and Victoria (+17%). There has also been an increase in the number of road deaths per 100,000 population (Figure 2).

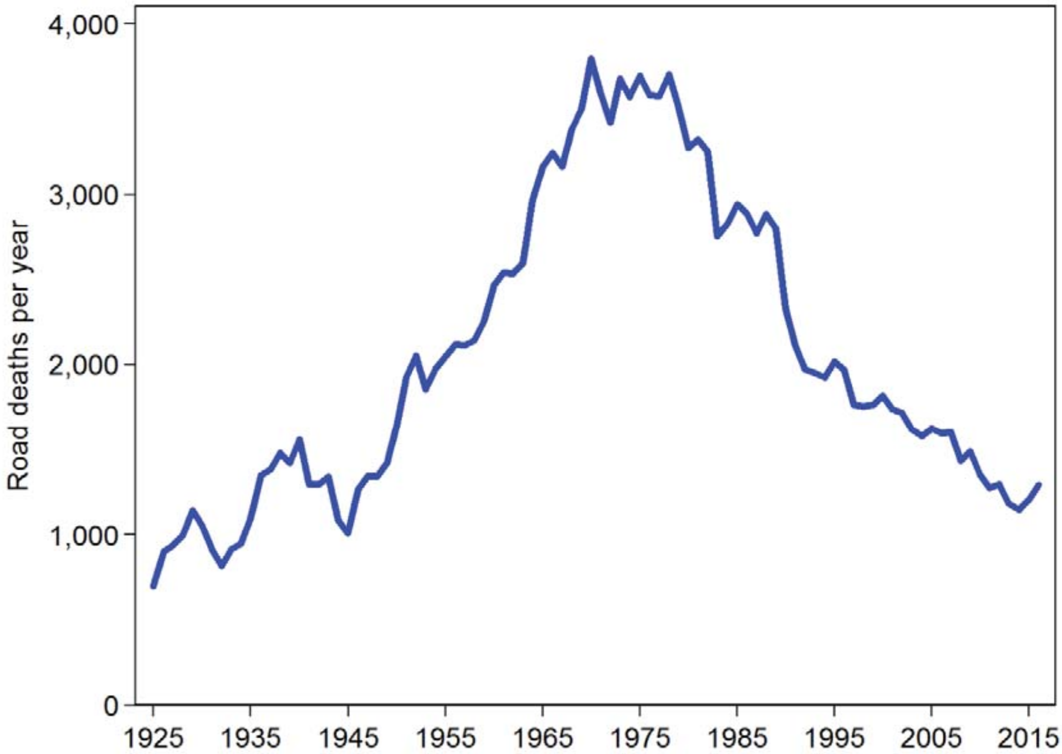
The increase in the road toll has attracted substantial concern and attention, prompting the federal government to launch an Inquiry into the National Road Safety Strategy. The first task listed in the Inquiry's Terms of Reference is to "Identify the key factors involved in the road crash death and serious injury trends including recent increases in 2015 and 2016".[2] Increases in annual road death tolls have also been observed in a number of other developed countries, including New Zealand, the United States, and Great Britain.[3] In each case the increase went against a long-term downward trend.

In this paper we present national-level analysis of the macro-level drivers of road deaths in Australia. We hypothesise that lower fuel prices result in more road deaths, all else equal, for

[1] 35,552 people were hospitalised in Australia in 2014 due to road accidents (Bureau of Infrastructure, Transport and Regional Economics [BITRE], 2017a).
[2] See http://roadsafety.gov.au/performance/files/ToR-Inquiry-into-National-Road-Safety-Strategy-2011-2020.pdf.
[3] Ministry of Transport (2017); National Traffic Safety Administration (2017); Department for Transport (2017). See Litman (2018) for a recent discussion of fuel prices and road deaths in the United States.

reasons that will be discussed. If so, the notable reduction in fuel prices in 2015 and 2016 would likely provide part of the explanation for Australia's uptick in road deaths in these years.

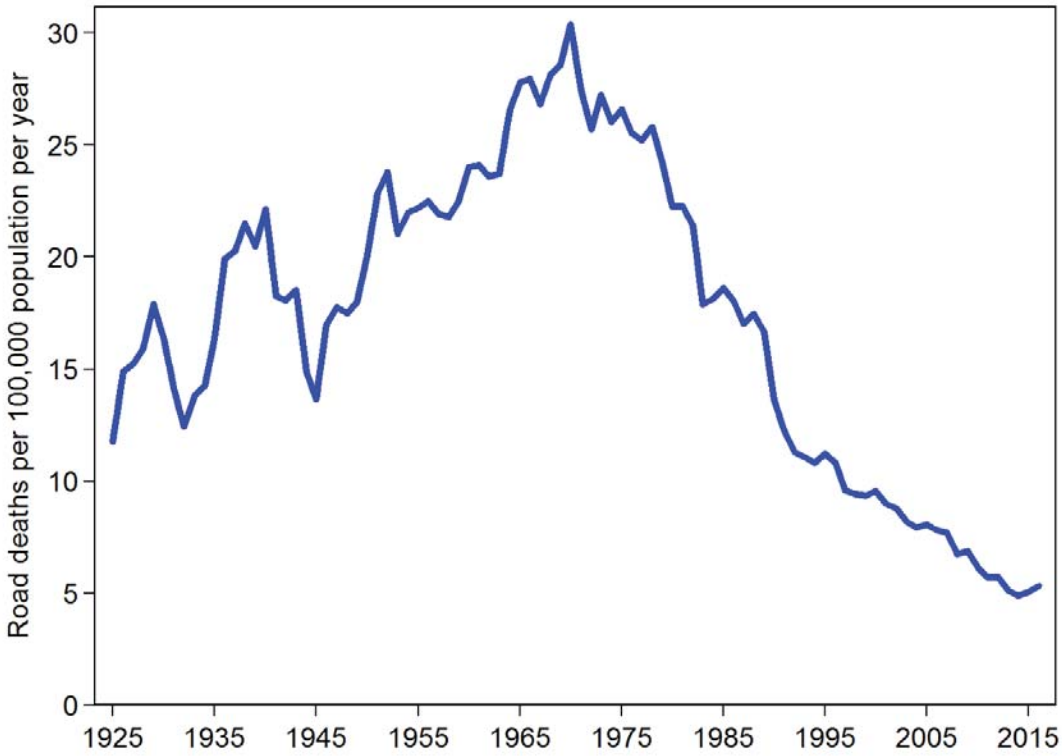
Figure 1 Australian road deaths, 1925–2016



Sources: Australian Transport Safety Bureau (2007), Bureau of Infrastructure, Transport and Regional Economics (BITRE, 2018). Prior to 1962, data exclude the Northern Territory. Around 3% of Australia's road deaths typically occur in the Northern Territory.

Our main analysis uses monthly data for the period May 1998– August 2017, using gasoline price data from Fueltrac (2017). We also present results using quarterly data. Our quarterly estimates are able to extend back to 1989 due to our use of an alternative fuel price measure from the Australian Bureau of Statistics, which is available on a quarterly basis for this longer time period (ABS, 2017b). We use an instrumental variable (IV) approach, instrumenting Australia's log real average gasoline price with the log real world oil price. The world oil price is close to being exogenous to Australian transport demand, providing a credible source of instrumental variation. We conservatively estimate a fuel price elasticity of road deaths of around –0.2. This is very inelastic, as observed overseas also (e.g. Chi *et al.*, 2012; Ahangari *et al.*, 2015). The elasticity nevertheless implies that the sizeable decline in fuel prices in Australia following the crash in the world oil price in late 2014 likely made a key contribution to the subsequent increase in Australia's road deaths.

Figure 2 Australian road deaths per 100,000 population, 1925–2016



Sources: As per Figure 1. Population data are from ABS (2014, 2017a).

Road safety is a topic of international importance. Globally, more than 1.2 million people died in road crashes in 2013, and tens of millions of people were injured (World Health Organization, 2015). The sizeable global road death toll led the United Nations to declare this to be the United Nations Decade of Action for Road Safety. Looking forward, there are ambitious visions for moving to a world of "zero road deaths" (see, for example, Welle et al. 2018). The main contribution of this paper is its conclusion, using Australian data, that macro-level variables such as the fuel price can have a material effect on progress towards meeting road safety improvement goals.

The remainder of this paper is organised as follows. Section 2 presents background information on fuel prices and road safety. Section 3 introduces our method and data. Our results are in section 4. The final section concludes.

2. Background information

2.1 Prior literature

There is a large literature on how economic variables, including fuel prices, influence the underlying frequency of road crashes. Most prior studies are for the United States [US] (e.g. Leigh and Wilkinson, 1991; Haughton and Sarkar, 1996; Grabowski and Morrisey, 2004, 2006;

Chi *et al.*, 2010, 2011, 2012, 2013a, 2013b, 2015; Montour, 2011; Morrisey and Grabowski, 2011; Ahangari *et al.*, 2017). The consensus from these US studies is that higher fuel prices tend to lead to fewer overall road deaths. The story can vary for individual road user categories, however. Hyatt *et al.* (2009) and Wilson *et al.* (2009) concluded that motorcycle deaths in the US tend to increase when fuel prices rise, as people substitute to more efficient two-wheeled travel.

Among the relatively small number of international studies, Ahangari *et al.* (2014) used four years of annual data for 16 industrialised countries (including Australia). They found a fuel price elasticity of road deaths of –0.2, similar to our estimates using monthly data for Australia. Burke (2014) and Burke and Nishitateno (2015) used annual data for up to 144 countries and found that the long-run fuel price elasticity of road deaths is around –0.3 to –0.6.

We are not aware of any prior study focusing specifically on the effect of fuel prices on road deaths in Australia. Gargett et al. (2011) provided trend analysis of Australia's road death toll. Nghiem et al. (2016) provided modelling of road deaths in Queensland, although did not examine the role of fuel prices.

2.2 Potential mechanisms

A reduction in fuel prices might lead to an increase in road deaths via one of two mechanisms. The first is by encouraging people to increase their driving distances. This channel is relevant if the fuel price elasticity of vehicle kilometres travelled (VKT) is negative, which is what one would expect. While the proximate causes of any individual crash are factors such as speeding and distraction, an increase in the total distance driven should be expected to lead to an increase in the underlying exposure of the population to road crash risks. As Litman (2018, p. 1) writes, "all vehicle travel imposes risks".

A reduction in fuel prices might also lead to an increase in road deaths *per kilometre* of vehicle travel. This might occur for a number of potential reasons, including:

- People may substitute to larger, more fuel-guzzling vehicles when fuel prices are low (Burke and Nishitateno, 2013). Sheehan-Connor (2015) concluded that larger vehicles such as sports utility vehicles (SUVs) are more dangerous to the overall community than sedans.
- The share of driving undertaken by higher-risk drivers might increase if these drivers are particularly fuel-price sensitive. This might apply to young drivers, for example.
- The share of driving on open roads might increase when fuel prices are low as a result of people taking more road-based holidays.
- By relaxing consumers' budget constraints, lower fuel prices might facilitate increased consumption of alcohol and/or drugs.
- Drivers might travel at higher speeds and/or accelerate and brake more rapidly due to reduced concern about conserving fuel.

- A lower fuel price might see more freight carried by road (instead of by rail, air, or sea), and heavy vehicle travel may be particularly risky.

There are also ways via which lower fuel prices might reduce the number of road deaths. For example, there may be substitution from motorcycles to four-wheeled vehicles when fuel prices are low. Motorcycles are a particularly risky form of travel (Nishitateno and Burke, 2014), so such a switch could lead to a reduction in road deaths. Where possible, our empirical analysis will estimate effects for different types of drivers to explore some of these mechanisms.

2.3 Road safety in Australia

Australia recorded 5.1 road deaths per 100,000 people in 2015 (OECD, 2017). This is lower than the US (11.0 road deaths per 100,000 people), but higher than European countries such as Norway (2.3 road deaths per 100,000 population), Malta (2.6), and Sweden (2.6).

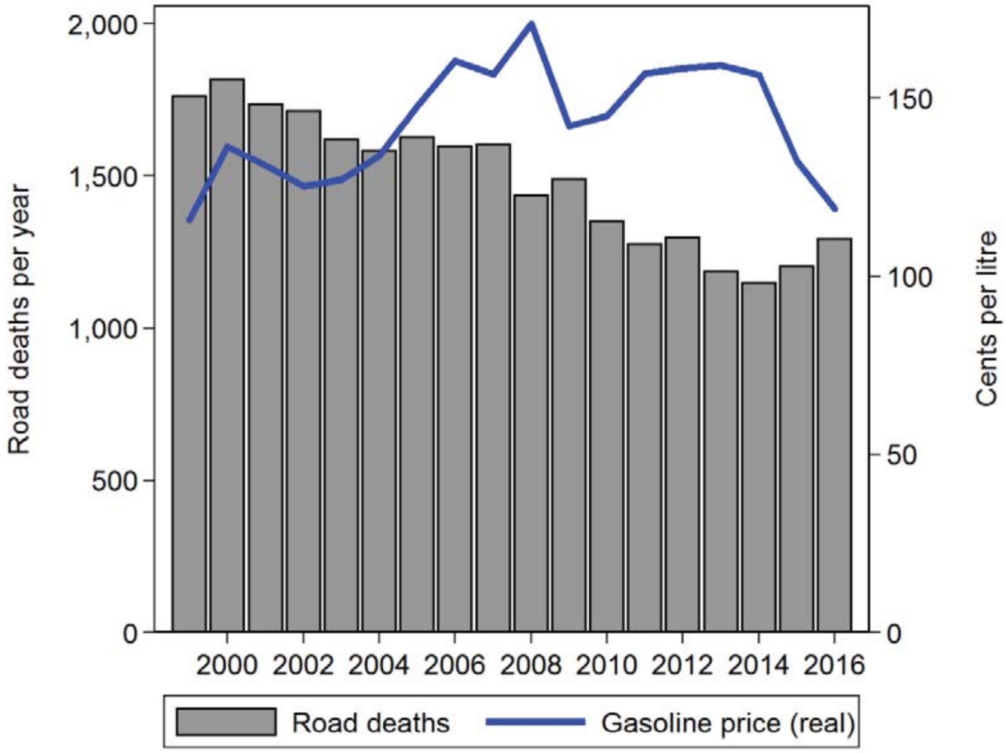
Road safety is an issue that garners considerable government and community interest in Australia. As part of the National Road Safety Strategy 2011–2020, Australia has set the target of reducing both road deaths and serious road injuries by 30% or more by 2020 relative to the average during the baseline period of 2008–2010 (Australian Transport Council, 2011). This translates to an annual road death toll of 998 or less by 2020. The increase in Australia's road death toll in 2015 and 2016 means that Australia has fallen off track to achieve this target.

Figure 3 displays annual data on average real gasoline price levels and Australia's road death toll since 1999. Road deaths fell sharply in 2008, a high-price year. They rose in 2009 after a sharp fall in real gasoline prices. They then generally fell as real gasoline prices recovered and steadied. As discussed, 2015 and 2016 saw increases in road deaths following a decline in average real gasoline prices. The national average gasoline pump price fell as low as 119¢ per litre in 2016 (Fueltrac, 2017). In nominal terms, this was the lowest level since 2005. In real terms, the lowest since 1999. Our empirical analysis will control for the effects of other macro-level variables and use an instrumental variable approach in an attempt to isolate the causal effect of fuel prices on road deaths.

That there is a relationship between fuel prices and road deaths is not unknown in Australia. Assistant Commissioner John Hartley of the New South Wales Police Force, for instance, referred to low fuel prices in explaining the spike in road crashes in 2015 (Olding, 2015). Our estimates will be of use for government agencies, insurance companies, the police, and other parties seeking to understand and predict road safety outcomes.

Before proceeding to our data description and method, we make a broader point about fuel prices. Fuel price reductions increase the ability of consumers to purchase fuel, to purchase other goods and services, and to save. Low fuel prices therefore provide numerous benefits, perhaps including health benefits if people are able to devote additional resources to healthcare (for example). Our focus is on identifying whether fuel price reductions also lead to the adverse outcome of increased road deaths.

Figure 3 Road death toll versus average gasoline price (real), 1999–2016



Note: Uses annual data. Our empirical analysis uses monthly and quarterly data.
Sources: BITRE (2018), Fueltrac (2017), ABS (2017b).

3. Data and method

3.1 Data

Our source of data on road deaths is the Australian Road Deaths Database (BITRE, 2018), which provides information on every Australian road death since 1989. Road deaths are those resulting from unintentional crashes on public roads in which death occurred within 30 days. We focus exclusively on deaths because up-to-date, high-frequency national data on road injuries are not available (BITRE, 2017a).

Our main fuel price measure is the monthly real average pump price for gasoline (unleaded petrol). The nominal series is from Fueltrac (2017). We use the capital city averages for our state-based analysis, and the average of the capital city averages for our national analysis. These data are available from May 1998. In additional specifications we use quarterly data on the price index for automotive fuel from the ABS (2017b), which cover diesel as well as gasoline. The series allows us to extend the analysis back to 1989.

Data sources for explanatory variables include the ABS (2017c, 2017d), ANZ-Roy Morgan (2017), and IndexMundi (2018). Variable definitions and data sources are in an Appendix.

3.2 Unit root testing

Before proceeding to select a functional form, we carefully checked the time-series properties of the key monthly data series. We used the following procedure:

1. Regress variable on month-of-year dummies, and obtain residual.
2. Carry out an augmented Dickey and Fuller (1979) regression on the residual, choosing the lag length based on the Bayesian information criterion (with a maximum lag length of 4).

For three of our key variables (log road deaths; unemployment rate; consumer confidence index), we were able to reject the null of a unit root at the 8% significance level or higher. For our log real gasoline price measure, we were only able to reject this null at the 14% significance level. While this test result is outside the standard significance level, we nevertheless pursue estimates in levels (rather than first differences) throughout, as is the common approach in prior studies (e.g. Ahangari *et al.*, 2014). We also present a specification that includes a lagged dependent variable. Note that the cross-country estimation approach of Burke and Nishitateno (2015) employed a method that avoids the unit root issue altogether.

3.3 Estimation method

We adopt a base estimation model of the form:

$$\ln D_m = \alpha + \beta \ln G_m + \gamma t_m + \eta_{m:y} + \delta E_m + \theta L_m + \vartheta S_m + \mu U_m + \pi C_m + \varepsilon_m \qquad (1)$$

where D is road deaths in month m; G is the average real gasoline price; t is a linear time trend; η is a set of 11 month-of-year (m:y) dummies; E is an Easter dummy; L is a dummy for leap-year Februaries; S is the number of Saturdays; U is the unemployment rate; C is a consumer confidence index; and ε an error. $\hat{\beta}$ will provide an estimate of the gasoline price elasticity of road deaths.

The motivations for including the above explanatory variables are as follows. The time trend is included to account for the net effect of gradual ongoing changes, such as population growth, urbanisation, road improvements, vehicle improvements, hospital improvements, and the like. The month dummies are included to account for seasonal effects. The Easter dummy is included because there may be a spike in road deaths at Easter, and because Easter is not always in the same month of a year. The leap-year February dummy is included to take into account the additional exposure time relative to non-leap-year Februaries. S is included because Saturdays are the most dangerous day on Australia's roads (Decent, 2015). The effect of unemployment on road deaths is expected to be negative, as higher unemployment means fewer people commuting to work (International Transport Forum, 2015). The consumer confidence index is included as a monthly measure of the state of Australia's economy, noting that monthly national account data are not available. Our quarterly specifications control for log real gross national income.

Estimation of Eq. 1 faces a potential endogeneity challenge: high fuel demand might at times induce higher fuel prices, and also be directly associated with greater road safety risks. This may potentially introduce a positive bias to estimates of the fuel price elasticity of road deaths. We consequently employ an IV strategy, instrumenting $\ln G_m$ with the log real world oil price (measured in real US dollars).[4] This variable provides an exogenous source of variation in local pump prices. Our approach is similar to studies that use a supply-side instrument to estimate the price elasticity of demand for a commodity (e.g. Burke and Yang, 2016; Burke and Abayasekara, 2018), with the link to road deaths being that road death risks are themselves associated with the demand for gasoline.[5] Burke and Nishitateno (2013, 2015) and Gillingham (2014) have used a similar strategy in estimating the effects of fuel prices on various road-sector outcomes.

Eq. (1) is a contemporaneous specification, and will not capture the full long-run effect. Over a long time horizon, people are able to respond to fuel price changes by altering their place of work, place of residence, and travel habits. Chi and Boydstun (2017), for example, conclude that higher fuel prices encourage people to move closer to their workplace, while Creutzig (2014) concludes that higher fuel prices encourage less urban sprawl. The long-run fuel price elasticity of road deaths is thus likely to exceed the short-run elasticity.

We are not able to control for all variables that might affect road toll outcomes. For example, it is not possible to accurately control for use of electronic devices such as smartphones and navigation devices. Such distractions are unlikely to be highly correlated with fuel prices, however. We do not control for the log population, primarily because this variable is highly correlated with the time trend control.[6] We also do not attempt to control for VKT, as doing so would shut down one potential channel via which fuel prices may influence road deaths (see above discussion). The VKT data are also only available on an annual basis (BITRE, 2017b), and

[4] Wholesale gasoline and diesel prices in Australia closely track Singapore export prices. Singapore export prices are in turn closely linked to the world oil price. There are lags between changes in export prices in Singapore and changes in Australian wholesale prices, but these often occur within an intra-month period (AIP, 2017). The world oil price might be correlated with other variables that affect road deaths, thus breaking the IV exclusion restriction. Controlling for the unemployment rate and the consumer confidence index helps to reduce but not eliminate any such potential channels. The instrument is measured in US dollar terms to ensure it is exogenous to Australia.

[5] Angrist and Krueger (2001) provide an overview of the history of the IV technique, which was initially developed to aid the identification of individual supply and demand curves.

[6] Using quarterly data for our sample period, the R^2 of a regression of log population on a time trend is 0.99. Population data are not available on a monthly basis.

are neither directly measured nor measured to a high degree of accuracy. For this reason we do not attempt to decompose the effect of fuel prices on (a) VKT, and (b) road deaths per VKT.

Finally, we note that our estimation approach does not seek to identify if there was an enhanced effect of fuel prices on road deaths near the end of our sample period. Instead, we estimate the average fuel price elasticity of road deaths over the full sample period. We subsequently assume that this elasticity has remained constant, and apply our estimate to understand the likely contribution of lower fuel prices in 2015 and 2016 to the observed reduction in road deaths. Our data and estimation commands will be available online.

4. Results

4.1 Main specifications

Table 1 presents our main estimates. Column 1 uses ordinary least squares, and obtains a gasoline price elasticity of road deaths of –0.2, differing from zero at the 1% level. A negative coefficient is observed for the time trend, suggesting an underlying decline in national road deaths of around 0.2% per month for reasons other than the other variables included in the model. We obtain a negative coefficient for the unemployment rate: on average, an additional percentage point of unemployment is associated with around 4% fewer road deaths. This is similar to what has been found for other developed countries (e.g. International Transport Forum, 2015; He, 2016). The variables in the model explain 74% of the monthly variation in log annual road deaths. This is a reasonably high degree of explanatory power.

Column 2 of Table 1 uses a negative binomial model, an approach suited to count data. We obtain a similar estimate of the gasoline price elasticity. Column 3 includes a lagged dependent variable. The same-month gasoline price elasticity again remains similar (–0.2). This is true also when the one-year lag of the gasoline price term is included in column 4.

Column 5 of Table 1 employs our IV approach, instrumenting the log real gasoline price with the log real world oil price. As expected, the coefficient on the instrument in the first stage is positive. Its value suggests that a 1% increase in the real world oil price (in US dollars) is on average associated with a 0.24% increase in the local average real gasoline price in the same month, holding the other variables fixed. It makes sense that this is less than unit elastic, as Australian pump prices include a specific excise and other components. The F statistic on our instrument is large, easily passing the Stock and Yogo (2005) test for weak instruments. The IV estimate of the gasoline price elasticity of road deaths is –0.33, larger in point estimate terms than the other estimates.

Table 1 Main estimates

Dependent variable: Ln Road deaths$_m$. Estimation period: May 1998–August 2017

	(1)	(2)	(3)	(4)	(5)
	OLS	Negative binomial	Lagged dependent variable	Year lag of gasoline price term	IV
Ln Gasoline price (real)$_m$	-0.22***	-0.18***	-0.20***	-0.24***	-0.33***
	(0.07)	(0.07)	(0.07)	(0.09)	(0.08)
Time trend$_m$	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***
	(0.0001)	(0.000)	(0.0002)	(0.0001)	(0.0001)
Unemployment rate$_m$	-0.04***	-0.04***	-0.04***	-0.04***	-0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Consumer confidence index$_m$	-0.001	-0.001	-0.001	-0.001	-0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Ln Road deaths$_{m-1}$			0.11		
			(0.07)		
Ln Gasoline price (real)$_{m-12}$				0.02	
				(0.07)	
Month-of-year dummies	Yes	Yes	Yes	Yes	Yes
R^2	0.74	0.15	0.75	0.73	0.74
Observations	232	232	232	220	232
Instrumented variable: Ln Gasoline price (real)$_m$. Instrument: Ln World oil price (real)$_m$					
Coefficient on instrument					0.24***
F statistic on instrument					632.46

Notes: ***, **, and * indicate statistical significance at 1, 5, and 10%. Robust standard errors are in parentheses. Coefficients on constants, month-of-year dummies, an Easter dummy, a leap-year February dummy, and the number of Saturdays are not reported. OLS = ordinary least squares. IV = instrumental variable. Column 2: The dependent variable is not logged; the gasoline price coefficient retains an elasticity interpretation; the R^2 is the pseudo-R^2; the Easter and leap-year February dummies are excluded to achieve convergence. Column 5: The Stock-Yogo test statistic for 10% maximal IV size is 16.38; if the *F* statistic on the instrument exceeds this value, the null of a weak instrument can be rejected.

Table 2 presents quarterly estimates. Columns 1–2 use the Fueltrac (2017) pump price data for gasoline. We obtain slightly smaller point estimates, although they remain equal to –0.2 when rounded to one decimal place. Columns 3–4 use the ABS (2017b) automotive fuel price index over a longer estimation period. Quite similar estimates are obtained.

As a check on the robustness of our results, we re-ran the OLS and IV monthly specifications twenty times each, each time excluding one year from the sample. The results are in Table 3. Interestingly, we obtain similar results in each of the specifications except the one excluding 2016. When 2016 is excluded, the estimated effect of fuel prices reduces, although it remains significantly different from zero in the IV estimation.

Table 2 Quarterly estimates

Dependent variable: Ln Road deaths$_q$

	(1)	(2)	(3)	(4)
	Gasoline price (Fueltrac) Q3 1998–Q2 2017		Automotive fuel price index (ABS) Q1 1989–Q2 2017	
	OLS	IV	OLS	IV
Ln Gasoline price (real)$_q$	-0.15*	-0.19**		
	(0.09)	(0.09)		
Ln Automotive fuel price index (real)$_q$			-0.19**	-0.14*
			(0.08)	(0.08)
Time trend$_q$	0.000	0.000	-0.003	-0.002
	(0.003)	(0.002)	(0.003)	(0.003)
Ln Gross national income (real)$_q$	-0.84***	-0.77***	-0.42	-0.54
	(0.31)	(0.28)	(0.32)	(0.33)
Unemployment rate$_q$	-0.06***	-0.06***	-0.04***	-0.04***
	(0.01)	(0.01)	(0.01)	(0.01)
Consumer confidence index$_q$	-0.001	-0.001	-0.001**	-0.001**
	(0.001)	(0.001)	(0.001)	(0.001)
Quarter-of-year dummies	Yes	Yes	Yes	Yes
R^2	0.90	0.90	0.94	0.93
Observations	76	76	114	114
Instrumented variable: Ln Gasoline price$_q$. Instrument: Ln World oil price (real)$_q$				
Coefficient on instrument		0.30***		0.25***
F statistic on instrument		362.17		183.79

Notes: ***, **, and * indicate statistical significance at 1, 5, and 10%. Robust standard errors are in parentheses. Coefficients on constants, quarter-of-year dummies, an Easter dummy, a leap-year February dummy, and the number of Saturdays are not reported. OLS = ordinary least squares. IV = instrumental variable. q = quarter. The Stock-Yogo test statistic for 10% maximal IV size is 16.38. If the F statistic on the instrument exceeds this value, the null of weak instruments can be rejected.

Table 3 Excluding individual years

Excluded year	OLS	IV	Excluded year	OLS	IV
1998	-0.23***	-0.34***	2008	-0.24***	-0.35***
1999	-0.24***	-0.34***	2009	-0.21***	-0.34***
2000	-0.23***	-0.34***	2010	-0.23***	-0.33***
2001	-0.23***	-0.34***	2011	-0.21***	-0.29***
2002	-0.22***	-0.33***	2012	-0.23***	-0.34***
2003	-0.24***	-0.35***	2013	-0.17**	-0.30***
2004	-0.23***	-0.35***	2014	-0.19**	-0.32***
2005	-0.24***	-0.34***	2015	-0.25***	-0.34***
2006	-0.25***	-0.34***	2016	-0.09	-0.21*
2007	-0.23***	-0.31***	2017	-0.20**	-0.31***

Notes: Estimations use the specifications in columns 1 and 5 of Table 1, but excluding each individual year (one-by-one). Coefficients for controls not shown. OLS = ordinary least squares. IV = instrumental variable.

4.2 Heterogeneity analysis

Table 4 presents gasoline price elasticities of road deaths for different types of road deaths, and for the total number of fatal crashes (noting that some crashes result in multiple deaths). We take the conservative approach of showing OLS estimates, as these generally provide smaller gasoline price elasticities. Our estimates are statistically strongest for driver deaths, male driver deaths, off-peak deaths, the number of fatal crashes, and the total number of road deaths. In point estimate terms, the gasoline price has the largest effect on deaths of young drivers, although this estimate is not tightly bound. A large positive coefficient is obtained for cyclist deaths, although one that is also not statistically different from zero. This divergent estimate may be because some people switch to bicycle travel when fuel is dear, thus heightening their accident risks. It is of interest that we do not obtain a large or significant effect of fuel prices on peak-hour deaths.

Table 4 Gasoline price elasticity by type of road death

Type of road death/crash	Gasoline price elasticity
Young driver deaths	-0.40
Male driver deaths	-0.37***
Sunday deaths	-0.38*
Driver deaths	-0.33***
Pedestrian deaths	-0.32
Female driver deaths	-0.28
Off-peak deaths	-0.25***
Fatal crashes (number)	-0.25***
Total road deaths	**-0.22*** **
Motorcyclist deaths	-0.18
Peak hour deaths	-0.08
Cyclist deaths	0.63

Notes: Estimations use the specification in column 1 of Table 1, but with specialised dependent variables. Motorcyclists and cyclists include passengers. “Drivers” refers to drivers of vehicles with > 3 wheels. “Young” refers to those aged under 25. Peak hour is defined as 7am–9am and 5pm–7pm, weekdays. There are some months with zero cyclist deaths. We included a value of 0.1 in place of 0 to avoid observations being dropped in the cyclist specification. The Sunday deaths specification controls for the number of Sundays. The timing of deaths is based on the time of the crash. Elasticities are ordered from most negative to most positive, in point estimate terms. Coefficients for controls not shown.

Table 5 presents estimates using state-level data. We focus on the five most populous states, where 93% of Australia’s road deaths occurred in 2016. Effects for individual states are estimated less precisely, as seen in the larger standard errors relative to column 1 of Table 1. We obtain negative and significant effects of the gasoline price on road deaths for Western Australia and New South Wales. The estimate for Victoria is similar to the national result in column 1 of Table 1, although is not significantly different from zero. Interestingly, a small, insignificant effect of fuel prices on road deaths is obtained for Queensland. Column 6 presents a panel estimate that controls for state fixed effects and separate time trends for each state. The estimate produces an average gasoline price elasticity of road deaths of –0.28, significantly different from zero at the 1% level.

Table 5 Analysis by state

Dependent variable: Ln Road deaths$_{s,m}$. Estimation period: May 1998–August 2017

	(1)	(2)	(3)	(4)	(5)	(6)
State:	NSW	Victoria	Queensland	Western Australia	South Australia	Panel: 5 states
Ln Gasoline price (real)$_{s,m}$	-0.34**	-0.23	0.03	-0.55**	-0.19	-0.28***
	(0.13)	(0.16)	(0.14)	(0.24)	(0.29)	(0.08)
Time trend$_m$	-0.003***	-0.002***	-0.002***	-0.001***	-0.003***	
	(0.0002)	(0.0002)	(0.0003)	(0.0003)	(0.0004)	
Unemployment rate$_{s,m}$	-0.02	-0.03	-0.06***	-0.08***	-0.01	-0.05***
	(0.03)	(0.03)	(0.01)	(0.03)	(0.03)	(0.01)
Consumer confidence index (national)$_m$	0.002	-0.001	-0.003*	-0.003	0.000	-0.001
	(0.002)	(0.002)	(0.002)	(0.003)	(0.004)	(0.001)
Month-of-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
State time trends						Yes
State fixed effects						Yes
R^2	0.55	0.46	0.36	0.16	0.27	0.77
Observations	232	232	232	232	232	1,160

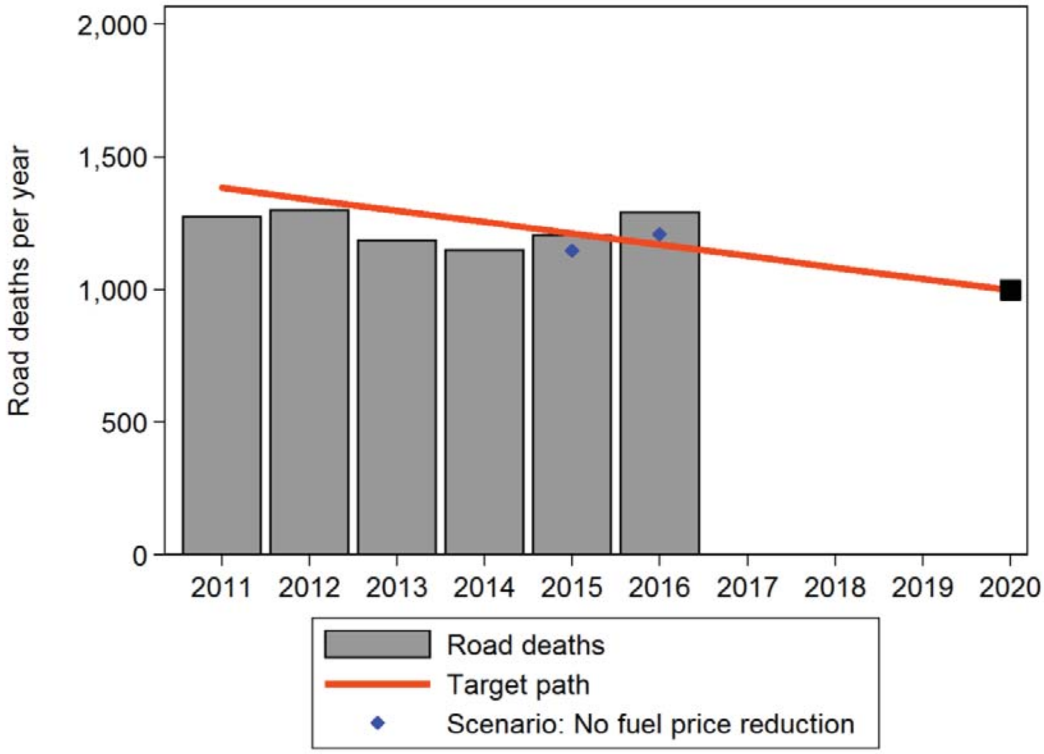
Notes: ***, **, and * indicate statistical significance at 1, 5, and 10%. Coefficients on constants, month-of-year dummies, an Easter dummy, a leap-year February dummy, the number of Saturdays, state time trends, and state fixed effects not reported. Robust standard errors are in parentheses. Estimates use ordinary least squares. Column 6: standard errors clustered by state; R^2 includes explanatory power of state fixed effects.

4.3 Calculating the effect of lower fuel prices in 2015 and 2016

What do our estimates suggest Australia's road death toll would have been if gasoline prices had not fallen from their early-2014 levels? To answer this question we simulate Australian road deaths using our OLS estimate from column 1 of Table 1, but assuming a constant gasoline price of A163.99¢ per liter (2016 prices) throughout 2015 and 2016. This was the real gasoline price recorded in January 2014. The simulated counterfactual road death tolls for 2015 and 2016 are shown as dots in Figure 4. Figure 4 also shows the linear trajectory towards Australia's 2020 target road death toll.

The estimates in Figure 4 suggest that around 83 fewer people would have lost their lives on Australian roads in 2016 if real fuel prices had not fallen. The estimate suggests that Australia's road deaths would still have increased, but by less than half of the realised increase. We therefore conclude that the fall in fuel prices made a material contribution to knocking Australia off-track for meeting its 2020 road safety target.

Figure 4 Australian road deaths and progress toward 2020 target



Notes: The dots show our model's point-estimate predictions of road deaths if the average gasoline pump price in 2015 and 2016 remained equal to A163.99¢ (2016 prices). The estimates are the sum of monthly predictions from the regression in column 1 of Table 1, and are subject to confidence intervals. The 2020 target is the black square. The target path is a linear interpolation from the baseline period. Road death data are from BITRE (2018).

4.4 Other factors potentially contributing to the increase in Australia's road death toll

As seen in Figure 4, our estimates suggest that the reduction in fuel prices was likely not the only factor contributing to Australia's 12.3% increase in road deaths from 2014 to 2016. From our modelling results, we can identify the following other apparent contributors:

- ***Unemployment rate:*** Australia's unemployment rate fell from an average of 6.1% in 2014 to an average of 5.7% in 2016. Based on our estimates, this may be expected to have contributed to an increased in road deaths of approximately 1.7% (*ceteris paribus*).
- ***Consumer confidence:*** The average consumer confidence index increased from 111.3 in 2014 to 115.5 in 2016. Based on our estimates (which for this variable are only sometimes statistically significant), this may be expected to have led to around 0.5% more road deaths (*ceteris paribus*). This is consistent with international evidence that road deaths tend to spike when economic conditions are favourable (International Transport Forum, 2015).
- ***Saturdays:*** 2016 had 53 Saturdays rather than the usual 52. The (unreported) estimates for our Saturday variable indicate that an additional Saturday in a month typically results in

3.8% more road deaths in that month. An additional Saturday in a year should thus be expected to lead to around 0.3% more road deaths in that year (*ceteris paribus*).

2016 was a leap year, which one might expect would also result in 0.3% more road deaths (=1/365). Our regressions do not find a significant and positive effect for our leap-year February variable, however.

Additional factors that we have not included in our model may well also have contributed to the increase in Australia's road death increase in 2015 and 2016. These include:

- ***Driver distraction:*** We have not modelled the effect of increased use of electronic devices (e.g. smartphones). Distractions from such devices have long been known to increase crash risks (see, for example, Mccartt *et al.*, 2006). Use of smartphones and other devices is often cited as an increasing risk factor on Australia's roads (e.g. Patten and Uribe, 2017).
- ***Drug use:*** We have not modelled use of drugs (either legal or illicit). The Australian Automobile Association (2017) mentions drugs as a potential candidate for contributing to Australia's increase in road deaths.
- ***Population growth:*** Australia's population continued to grow in 2015 and 2016, although at a similar rate to prior years (ABS, 2017a). Relatively rapid population growth in Victoria may partly explain that state's above-average increase in road deaths.

The above is not an exhaustive list. We also acknowledge a potential random element, although the fact that road deaths have increased in a similar way in some other countries such as New Zealand suggests that underlying structural causes are at play. Further research on factors affecting road safety in Australia, particularly using micro-level data, may be of high value.

5. Conclusion

This study has presented macro-level estimates of the factors affecting road deaths in Australia. We obtained estimates of the fuel price elasticity of road deaths of around –0.2 to –0.3. This range is likely to underrepresent the long-run effect, as many responses to fuel prices take time to be realised. Our estimates are quite similar to estimates from the United States (e.g. Chi *et al.*, 2012). Based on our estimates we conclude that lower real fuel prices in 2015 and 2016 (relative to 2014) likely made a material contribution to the increase in the national road death toll. A reduction in the unemployment rate is among other macro-level variables that appear to have also made a contribution to Australia's increased road death toll.

While as of 2016 Australia had fallen off track to meet its 2020 road safety target, the target is not totally out of reach. Our results imply that any large reduction in fuel prices would be likely to make the task more challenging, however. Fortunately, Australia recorded a 5% reduction in road deaths in 2017 relative to 2016 (BITRE, 2018). Australia still recorded around 7% more road deaths than in 2014, however. Average nominal gasoline pump prices rose by more than

10% during the first ten months of 2017 relative to the same period in 2016 on the back of the recovery in the world oil price (Fueltrac, 2017).

The effects of low fuel prices on road deaths form part of the economic rationale for fuel taxes, although from an economic point of view it is possible for fuel taxes to be set too high as well as too low (Parry *et al.*, 2014). Australia has a fuel excise equal to A40.3¢ per litre as of August 2017. A 10% goods and services tax (GST) is also applied (including to the excise component), taking the total tax on gasoline and diesel to over A50¢ per litre. This is low relative to developed countries outside North America (OECD, 2015). As a demonstration of the magnitude of the effect on road safety, our estimates suggest that Australia's current fuel tax arrangements reduce the national road toll by more than 150 deaths per year.[7] Consistent with this finding, Burke and Nishitateno (2015) concluded that countries that subsidise rather than tax fuel sales tend to have higher road death tolls (all else equal).

Improving road safety is a multi-faceted challenge. One implication of our findings is that times of low fuel prices are potentially important moments for ramping up road safety campaigns. Another is that there may be opportunities for increasing the use of price-based measures for improving road safety (Litman, 2013).

Large changes in the road transport sector are underway, with electric and autonomous vehicles likely to become increasingly popular. For people with access to rooftop solar power, electricity costs are often low. Electrification of the vehicle fleet might thus be expected to lead to an increase in driving and place upward pressure on road deaths. At the same time, autonomous vehicles have the potential to deliver a substantial reduction in road deaths. Electrification and autonomisation of the vehicle fleet will likely mean that the link between oil prices and road safety will diminish.

[7] This is an underestimate given that our analysis does not capture long-run responses.

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Appendix. Variable definitions and sources.

Road deaths: Number of deaths due to road crashes. Deaths are counted if they occurred on a public road, were unintentional, and the death occurred within 30 days from injuries sustained in the crash. Source: BITRE (2018). Measured at the state level in Table 5.

Gasoline price (real): Gasoline pump price in Australian cents. Calculated as the simple average across the eight state/territory capitals for unleaded (not premium unleaded) gasoline. Source: Fueltrac (2017). We deflated using the consumer price index so that the series is in 2016 prices. This was done using a monthly consumer price index generated by interpolating the monthly series. Source of consumer price index: ABS (2017a). Measured at the state level in Table 5.

Time trend: In the monthly analysis, this is equal to 0 in May 1998 and increases by 1 in each subsequent month. In the quarterly analysis, this is equal to 0 in the third quarter of 1998 and increases by 1 in each subsequent quarter.

Easter dummy: Equals 1 if the month/quarter includes Easter Sunday; 0 otherwise.

Leap-year February: Equals 1 for February of a leap year; 0 otherwise.

Number of Saturdays: Number of Saturdays in the month/quarter.

Unemployment rate: Unemployment rate (original; %). In our quarterly estimates we use the average over each month. Source: ABS (2017b). Measured at the state level in Table 5.

Consumer confidence index: ANZ-Roy Morgan (2017) Australian consumer confidence index. In our quarterly estimates we use the average over each month.

World oil price (real): Dubai Fateh average price, in US dollars per barrel. Source: IndexMundi (2018). We deflated using the monthly US urban consumer price index from the St Louis Fed (2017).

Automotive fuel price index (real): Automotive fuel price index, deflated using the consumer price index. Base reset to equal 100 in 2016. Source: ABS (2017a).

Gross national income (real): Real gross national income (chain volume, dollars). Measured quarterly. Source: ABS (2017c).