INTRODUCTION

Obesity is a global public health issue that imposes significant social and economic costs on society. Often described as a public health emergency (Ayton & Ibrahim, 2019; Chan, 2013; James, 2018), worldwide over 1.9 billion adults are overweight or obese, which translates to approximately 40% of the world’s adult population (WHO, 2020). In some developed countries, up to 80% of adults and 30% of children are overweight or obese (Finucane et al., 2011; Skinner et al., 2018). The high prevalence of obesity is particularly alarming, given that obesity has been linked with increased risk of myriad health conditions, including heart disease, diabetes, hypertension and stroke, among others (Casey et al., 2008). Understanding the factors that influence obesity has, thus, been the focus of a significant body of research. While biological factors contribute to the prevalence of obesity, emphasis is increasingly being placed on understanding the role that socioeconomic factors and the built environment play in influencing people’s weight. To this point, research has mainly focused on the role of eating habits, physical activity, and expenditure on meals eaten out as channels through which petrol prices affect obesity.
activity, smoking, peer effects and personality traits, among others (see, e.g., Ding & Gebel, 2012; Durand et al., 2011; Franzini et al., 2009; Kim, 2016; Menghetti et al., 2015; Petersen et al., 2004; Poortinga, 2006; Wareham et al., 2005).

Generally, rising petrol prices have been viewed negatively. In the United States, for example, 35% of participants in a 2018 Gallup poll reported that rising gasoline prices was a cause of financial hardship (Norman, 2018). In Europe, higher petrol prices have sparked periodic protests in countries such as the United Kingdom and France (BBC, 2018). Studies have found that higher petrol prices are associated with lower levels of subjective wellbeing (Boyd-Swan & Herbst, 2012; Prakash et al., 2020). Could there be public policy benefits from higher petrol prices? In this paper, we examine whether higher petrol prices have a “silver lining” (Courtemanche, 2011) by contributing to lower rates of obesity. Very few studies have examined the relationship between petrol prices and obesity. Using pooled cross-sectional data, Courtemanche (2011) finds a negative relationship between gasoline prices and obesity in the United States. In a cross-country study that explored the impact of various environmental factors on obesity in Europe, Rabin et al. (2007) find that rising gasoline prices are associated with a decline in the proportion of a country’s population that is obese.

We examine the effect of petrol prices on obesity using 13 waves of household longitudinal data covering the period 2006–2018. To do so, in our main estimates we use monthly city-level petrol price data which we merge with 13 waves of panel data from the Household, Income and Labour Dynamics in Australia (HILDA) survey that identifies the cities in which participants live. A nice feature of HILDA for our purposes is that participants are interviewed across several months of the year. Moreover, participants are not necessarily interviewed in the same month in each wave. Thus, using petrol prices in the city in which the participant lived in the month in which they were interviewed introduces considerable variation into petrol prices over the course of the panel. We measure obesity using the body mass index (BMI) see, e.g., Finkelstein et al., 2012; James et al., 2001; Keramat et al., 2020; WHO, 2020).

Our main identification strategy instruments for petrol prices using the New York Stock Exchange (NYSE) Arca Oil Stock prices index, which is a weighted price index of global leaders in oil exploration, production and development. Overall, estimates from our preferred model, that addresses endogeneity and control for individual and time fixed effects, suggest that a standard deviation increase in petrol prices generates a 0.006 standard deviation decline in BMI, while a unit increase in petrol prices results in a 2% point decrease in the probability that a participant is obese. This general finding is robust to alternative ways of measuring obesity, different ways of measuring petrol prices, different ways of addressing endogeneity and alternative specifications. Our back of the envelope calculations suggest that a permanent $1 per liter increase in petrol prices would reduce the number of people who were obese by approximately 670,000 and save $1.4 billion dollars in medical costs every year. We also examine the channels through which petrol prices potentially influence body weight and find that frequency of participation in physical activity, as well as expenditure on meals outside the home, mediate the relationship between petrol prices and obesity.

Australia makes an ideal setting in which to examine the relationship between petrol prices and obesity for three reasons. First, obesity rates in Australia are representative of many high-income countries. In 2018, about two-thirds of Australian adults were overweight or obese (ABS, 2018). Australia has the fifth highest obesity rate in the Organisation for Economic Co-operation and Development (OECD) (OECD, 2017). The financial burden of obesity on the Australian economy is high. The annual estimated cost of obesity on the Australian economy is $56.6 billion (Colagouri et al., 2010), with estimates suggesting that by 2025, the financial burden could be as high as $87.7 billion (PriceWaterHouseCoopers Australia, 2015). Second, while petrol prices in Australia are relatively low among OECD countries, because Australia is primarily reliant on imported petroleum (Commonwealth of Australia, 2019) fluctuations in petrol prices in Australia over the last 2 decades have closely tracked other high-income countries (AIP, 2020). Third, from a practical perspective, Australia is home to the HILDA survey, which is one of the longest running panel data surveys in the world. By matching data from HILDA with petrol prices in the city in which the participant lives, we are able to examine the effects of petrol prices on obesity within a panel data framework while controlling for unobserved heterogeneity and time-invariant fixed effects.

Our study contributes to small bodies of literature that examine the association between gasoline prices and alternative transportation modes (see, e.g., Chao et al., 2015; Lane, 2012; Nowak & Savage, 2013; Rashad, 2009), as well as gasoline prices and physical activity (see, e.g., Hou et al., 2011; Sen, 2012). More generally, we also contribute to the growing literature that has examined the impact of petrol prices on wellbeing (Bhat et al., 2009; Boyd-Swan & Herbst, 2012; Ma et al., 2011; Marrouch & Mourad, 2019; Prakash et al., 2020), and the literature that has examined the determinants of obesity in Australia (see, e.g., Avsar et al., 2017; Byrne et al., 2011; Feng & Wilson, 2015; Hesketh et al., 2005).

We consider physical activity and eating out as potential channels through which petrol prices influence obesity. In doing so, our study also contributes to the literature that has examined the direct relationship between physical activity and obesity (see, e.g., Chin et al., 2016; Durand et al., 2011; Wareham et al., 2005; Wilks et al., 2011). We also contribute to studies that examine the direct relationship between food choices, use of specific food outlets and obesity (see, e.g., Bezerra et al., 2012;
The two studies that are closest to ours are Courtemanche (2011), who examines the association between gasoline prices and obesity in the United States using cross-sectional data, and Rabin et al. (2007), who provides aggregate cross-country evidence on the relationship between petrol prices and the proportion of people who are obese in Europe. We differ from Courtemanche (2011) in four important ways. The first is our focus. We provide evidence on the relationship between petrol prices and obesity for an important representative high-income country other than the United States. This is important because in many ways the United States is an extreme example. It has the highest obesity rates and the lowest petrol prices in the OECD (AIP, 2020; OECD, 2017). Second, from a methodological viewpoint, the use of cross-sectional data makes it more difficult to control for unobserved differences across individuals and draw causal inferences. The use of panel data helps address this problem. Third, we employ city prices, which provide more precise estimates of the relationship between petrol prices and obesity than state-wide average prices as used by Courtemanche (2011). State averages will tend to be upper bound estimates on what people in the main cities pay given that petrol costs are higher in regional areas, reflecting higher costs of transportation and less suppliers. Fourth, we explicitly seek to address endogeneity through instrumenting for petrol prices. We differ from Rabin et al. (2007) in that we present micro-level evidence. Cross-country comparisons tend to mask individual differences, and in the context of a study that examines the relationship between petrol prices and obesity, a cross-country approach is unable to control for individual behavioral differences that are likely to influence obesity or mediate the relationship.

2 WHY SHOULD PETROL PRICES INFLUENCE BODY WEIGHT?

Two potential channels through which petrol prices can influence obesity are physical activity and eating habits. While demand for petrol is relatively inelastic (Brons et al., 2008), at the margin higher petrol prices can be expected to discourage driving and encourage substitution toward alternative forms of commuting, such as biking, public transportation and walking (Hou et al., 2011). In a 2018 Gallup poll in the United States, 41% of respondents said that they would drive less in response to gasoline price rises (Norman, 2018). More active forms of commuting, such as biking and walking, entail higher levels of physical activity and burning more calories, which is associated with lower risk of obesity (see, e.g., Chin et al., 2016; Durand et al., 2011; Wareham et al., 2005; Wilks et al., 2011). Taking public transport is more physically demanding because people will often walk or cycle to the bus stop or train station near their home and then walk or cycle to their workplace at the other end. Courtemanche (2011) argues that following an increase in petrol prices, engaging in physical activity, such as walking more, makes engaging in regular physical activity more enjoyable, which consequently leads to engaging in other types of exercise as well.

A second channel through which petrol prices can influence obesity is via food choices and eating habits (Blundell & Cool- ing, 2000; Drewnowski, 2004; Hawkes et al., 2015; Mesas et al., 2012; Morland & Evenson, 2009; Yahia et al., 2008). Eating outside the home at fast food restaurant chains, cafeterias and buffets generally involves higher intake of calories because they tend to serve relatively larger portions per person (Restrepo, 2017; Young & Nestle, 2002). Food consumed at fast food outlets also tends to have a high proportion of fat content and is calorie-dense and nutrient poor (Abdollah, 2007; Harrison, 2008; Hellmich, 2008; Hennessy-Fiske & Zahniser, 2008). Higher petrol prices increase the cost of driving to the restaurant or fast food outlet and encourage substitution towards eating at home (Anderson & Matsa, 2011). Food portions and fat content of home-cooked meals are smaller, resulting in lower calories and lower incidence of obesity (Jeitschko & Pecchenino, 2006).

Petrol prices could also influence eating habits through income effects (Courtemanche, 2011). Higher petrol prices increase the share of expenditure on fuel in the household budget, which reduces income available for other items, including food. Higher petrol prices also result in higher food production and distribution costs and, thus, food prices (Courtemanche, 2011). Less income available for expenditure on food, combined with the effect of higher food prices, could result in smaller portions being consumed and lower rates of obesity (Chou et al., 2004; Courtemanche, 2011; Rashad, 2006). Less income for expenditure on food, though, could also mean that individuals substitute good quality food with relatively cheaper, higher calorie and unhealthy foods such as tinned or packaged food. The income effect of higher petrol prices could result in the consumption of fewer lean meats, fruits and vegetables, which can be expensive compared to canned foods (Drewnowski & Darmon, 2005; Stewart et al., 2011).

Overall, we expect an increase in petrol prices to reduce the prevalence of obesity through substitution away from driving towards more physically demanding forms of transport, such as cycling, public transport and walking. We also expect petrol prices to reduce the incidence of obesity through people substituting home cooked meals for eating out. The effect of income effects on eating habits is indeterminate and depends on how higher food transportation costs influence the relative price of
healthy versus less healthy foods and whether people with less income consume more calorie dense foods. Considering these effects together, it is reasonable to expect that an increase in petrol prices will reduce obesity, unless the income effect is toward consuming calorie dense foods and is large enough to outweigh the two substitution effects.

Different categories of people are likely to respond differently to changes in petrol prices. While, at the margin, higher petrol prices can be expected to discourage driving and encourage substitution towards alternative forms of commuting, this is more likely to be the case for some socioeconomic and demographic groups than others. Given their relatively inelastic demand for petrol, high-income earners are less likely to substitute to alternative forms of commuting. This is also the case for individuals living in areas with poor public transport options, as well as people working in occupations that have heavy reliance on private transport (e.g., construction workers and delivery men that rely on punctuality). Thus, we expect that the effects of petrol prices on obesity will be more pronounced for groups that are more responsive to changes in petrol prices and will substitute driving with other forms of commuting. Similarly, some socioeconomic groups, compared to others, are less likely to change their eating habits in response to changes in petrol price. Low-income individuals can potentially feel the income effect, but are less likely to change their eating habits as they are more likely to eat cheaper unhealthy food in the population sub-groups captured by HILDA.

3 | DATA AND VARIABLES

We employ data from restricted release version 18 of HILDA, which is a nationally representative longitudinal survey of Australian households. While the survey commenced in 2001, we only employ data from wave 6 through to wave 18, covering the period 2006 to 2018 given that data on participants' height and weight, required for the calculation of BMI, were not collected for the first five waves. We merge city-level data on petrol prices with the HILDA survey using postcode/zip identifiers in HILDA and information on the month in which participants were interviewed. Thus, monthly petrol price data is matched with the interview month for each participant in each survey year. Allowing for missing observations, regressions with the largest number of observations include 13,713 individuals with 89,792 observations.

3.1 | Main outcome variable

Our main outcome variable, BMI, is a measure of individual body weight based on survey participants' self-reported weight and height. We employ the conventional definition of BMI, whereby BMI is calculated as the participant's weight in kilograms divided by the square of their height in meters. By way of construction, a higher BMI indicates an increased risk of life-style diseases. The World Health Organization divides BMI scores into several broad categories that are linked to the nutritional status of individuals. A BMI between 25 and 29.9 identifies someone as overweight, while a BMI above 30 implies that a person is obese. In our sample, the average BMI score is 26.376, indicating that the average participant is in the overweight category (see Table A1 in the online appendix). Figure 1 plots the proportion of our sample who are in different weight categories. While about 43% of the sample are in the healthy weight category (BMI between 18.5 and 24.9), approximately 54% of the total...
sample are in the overweight or obese categories. The proportion of those in the overweight and obese categories has increased from approximately 54% in 2006% to 66% in 2018. The HILDA data is highly representative of the national population in terms of overweight and obese categories. The figure for 2018 reflects the national average. According to the National Health Survey, about two-thirds of Australian adults were either overweight or obese in 2017-2018 (The Department of Health, 2019). 3

3.2 Petrol prices

In the last 2 decades, petrol prices in Australian cities, on average, have fluctuated between $0.73 per liter and $1.74 per liter with petrol prices in regional Australia being higher on average. In our main analysis we employ unpublished real monthly city-level unleaded petrol price data provided by the Department of Infrastructure, Regional Development and Cities (DIRDC). Figure 2 graphs the nominal and real city-level unleaded petrol price between 2006 and 2018. Real city-level unleaded petrol prices peaked in 2008, were falling between 2014 and 2016 and rising between 2016 and 2018. Despite them rising over the last couple of years of the period we study, real prices at the end of the period were lower than at the beginning.

In a first sensitivity check, we employ real petrol price data at other frequencies and levels of aggregation. Specifically, we employ annual average city-level petrol prices, sourced from the DIRDC and annual data for petrol prices in each of the Australian states and territories sourced from the Australian Institute of Petroleum. 4 In a second robustness check, we use data on monthly city-level diesel prices from the DIRDC and supplement this analysis by using annual average city-level diesel prices and annual state-level diesel prices sourced from the Australian Institute of Petroleum. 5 Finally, we use disaggregated regional fuel price data for one state - Western Australia - obtained from Fuel Watch - for the period 2006-2018. 6

3.3 Covariates

We control for individual demographic and socioeconomic characteristics, that have been shown to influence BMI (see for e.g. Avsar et al., 2017; Courtemanche, 2011; Lancaster, 2009). Specifically, we control for age, gender, employment status, marital status, education status and income. In robustness checks, we also include controls for state-level variables, such as per capita income, population density and city-level prices for takeaway food, restaurant meals and transportation using data obtained from the Australian Bureau of Statistics. The inclusion of these additional variables controls for heterogeneity across cities that can be attributed to economic conditions and trends in population in different states. In further checks, following studies in the health literature (see for e.g. Neymotin & Nemzer, 2014; Popova, 2012; Wardle & Steptoe, 2003), we also include measures of Locus of Control (LoC) and personality, that capture the effects of these non-cognitive traits on body weight.

Figure 2 Real and nominal petrol prices over time, 2006-2018. Annual city—level petrol prices are used to obtain yearly average [Colour figure can be viewed at wileyonlinelibrary.com]
3.4 | Mechanisms

We examine the role of physical activity and eating habits as possible channels through which changes in petrol prices can affect obesity rates. To examine the role of consumption choices as a channel we use household expenditure on meals eaten outside the home. To measure active modes of commuting, Courtemanche (2011) “calculate[s] the number of times an individual walks, bicycles (excluding stationary bikes), and obtains other types of exercise per week”. HILDA does not provide explicit information on direct measures of active transport. In all waves, however, participants were asked: “How often do you participate in physical activity?” Individual responses were coded on a six-point scale where 1 represents “not at all” and 6 represents “everyday”. We use responses to this question as an indirect indicator of the extent to which participants engage in active modes of transport. We think that the question: “How often do you participate in physical activity?” is a reasonably good proxy for active transport, given that surveys suggest that walking and bicycling are among the most popular forms of physical activity in Australia. For example, AusPlay, which is a large-scale national population tracking survey administered by Sport Australia, found that among the top 20 sports and physical activities in which Australians engage, found that among the top 20 sports and physical activities in which Australians engage, walking was ranked number one and cycling number six (Sport Australia, 2019). This said, the “physical activity” variable is a noisy measure of active transport that includes other forms of physical activity that are not related to active modes of commuting or transport. This means that it is likely to represent an upper bound of the indirect effect of petrol prices through the use of alternative transportation modes.

We present the descriptive statistics of all these variables in appendix Table A1.

4 | METHODOLOGY

We estimate the following reduced form regression model for BMI and obesity, respectively:

\[
BMI_{i,\text{mc}} = \alpha_0 + \beta P_{mc} + \gamma X'_{ict} + \theta_i + \phi_c + \rho_m + \tau_t + \epsilon_{i,\text{mc}} \tag{1}
\]

\[
Obesity_{i,\text{mc}} = \alpha_0 + \beta P_{mc} + \gamma X'_{ict} + \theta_i + \phi_c + \rho_m + \tau_t + \epsilon_{i,\text{mc}} \tag{2}
\]

where \(BMI\) is a measure of individual \(i\)'s BMI in city \(c\) in month \(m\) and year \(t\). The month and year correspond to the month and year in which participants were interviewed, which varies for each participant both within waves and across waves as interviews were conducted across several months and the same participant was not necessarily interviewed in the same month in each wave. \(Obesity\) is a dummy variable set equal to 1 if the individual’s BMI is above 30, indicating the person is suffering from obesity. \(P\) denotes the real petrol price. The vector \(X\) consists of demographic and individual socioeconomic factors correlated with a person's weight. To account for time-invariant differences across cities that may simultaneously influence petrol prices and body weight, we include controls for individual fixed effects captured by \(\theta\) and city level fixed effects captured by \(\phi\). To account for seasonal variations such as changing weather patterns, we include monthly fixed effects captured by \(\rho\) in our model, and year fixed effects \(\tau\) to control for time-varying yearly aggregate trends. \(\alpha\) and \(\epsilon\) are the constant and idiosyncratic error term, respectively. We begin our analyses by estimating Equations (1) and (2) using pooled ordinary least squares (OLS) and panel fixed effects method in our baseline model.

Petrol prices is likely to be endogenous for various reasons. One potential source of endogeneity, in the context of our study, is omitted variable bias. There are several unobservable factors that are likely to be correlated with both petrol prices and obesity and, thus, in a multivariate regression framework, it is difficult to rule out more than one omitted variable, making it impossible to clearly predict the direction of bias. One source of omitted variable bias, for example, is time spent driving. Time spent driving influences the petrol price that people pay because the length of time that one spends on the road determines the level, or frequency, of exposure to different petrol stations with different petrol prices. At the same time, time spent driving also influences weight as it affects the frequency of using alternative active means of transport. The exclusion of this variable in a model examining the relationship between petrol prices and obesity could potentially result in either underestimation (downward bias) or overestimation (upward bias) of the coefficient on petrol prices, depending on whether the average person drives more or less. Other omitted variables, for which we are unable to control, include the availability of alternative means of transport, the quality of road infrastructure, vehicle type and fuel efficiency, among others.

While the panel fixed effect model is generally known to be effective in addressing omitted variable bias, endogeneity may also emerge from potential measurement error and simultaneity bias. Measurement error arises because average prices are imperfect proxies for the underlying prices that people pay. This could also result in the panel fixed effect estimates being upward or downward biased, depending on whether people pay above or below the average price. Depending on where they
live and where, and for how long, they drive, participants are likely to face petrol prices that are either higher or lower than the average petrol price. We expect that on average if more people face lower (higher) petrol prices than the average petrol price, endogeneity arising from measurement error will result in upward (downward) bias.

Simultaneity bias is a third source of endogeneity, which arises because people who are overweight may engage in fewer activities outside of their homes, such as visiting family or friends, playing sport or other recreation pursuits that require travel in the car. If people who are overweight, or obese, travel in their car less, they are less likely to benefit from variations in the price of petrol and therefore end up paying higher prices on average. This could result in an upward bias in the panel fixed effect estimates. Given the interaction of the different sources of endogeneity, it is difficult to unambiguously predict the direction of the overall bias. However, because measurement error and omitted variable bias could go either way, if simultaneity bias is prominent, the panel fixed effect estimates may be upward biased.

To ensure that our results are robust to endogeneity, we instrument for petrol prices using the NYSE Arca Oil Stock prices index, which is a weighted price index of global leaders in oil exploration, production and development. This follows the identification strategy initially proposed by Prakash et al. (2020) in their study of petrol prices and subjective wellbeing. It is also in the spirit of studies examining the relationship between energy poverty and health that have instrumented for energy poverty using energy prices (Awaworyi Churchill et al., 2020; Kahouli, 2020), as well as studies examining the relationship between income and health that have used commodity prices to instrument for income (Brukner & Antonio, 2007; Thomas & Strauss, 1997). Our identification strategy relies on two assumptions. The first is that stock prices of the world’s major oil suppliers are correlated with petrol prices. The other is that movements in NYSE Arca Oil Stock prices have no direct effect (other than through petrol prices) on the body weight of participants in the survey.

Intuitively, the first assumption is likely to be satisfied. It is very likely that the stock prices of major oil companies are directly correlated with global oil prices, which, in turn, largely determine petrol prices, given that Australia is heavily reliant on imported petroleum (Commonwealth of Australia, 2019). A potential threat to the second assumption—the exclusion restriction—is if participants hold oil shares, or shares more generally, and an adverse movement in oil stocks generates a negative income effect. This might result in less money for activities associated with good weight management, such as gym memberships, or result in substitution towards work, leaving less time for exercise. Another possibility is that adverse movements in oil stocks might generate stress, for which the participant either compensates by overeating or leads them to feel that they lack the energy to exercise.

We submit that these threats to identification are not very likely in practice. The income effects are likely to be very small. Very few Australians hold shares directly in companies that form the NYSE Arca Oil Stock Index. A survey by Deloitte Access Economics (2017) found that less than 10% of Australians held shares listed on overseas stock markets and the number would be even smaller for the NYSE. It is possible that movements in the NYSE Arca Oil Stock Index might influence movements in oil stocks on the Australian Stock Exchange, but again the effects on expenditure patterns are likely to be small. Evidence on the extent to which the Dow Jones moves the ASX 200 is, at best, mixed (Allen & Macdonald, 1995; Narayan & Smyth, 2004; Roca, 1999; Valadkhani & Chen, 2014). Even if movements in the Dow Jones does cause the ASX 200 to move, only a relatively small proportion of Australians own shares listed on the ASX 200 and even less hold oil shares. The Deloitte Access Economics (2017) survey found that about one-third of Australians hold shares on the Australian Stock Market, but importantly most of these held small pockets of shares that formed a tiny portion of their overall wealth. Thus, movements in the Australian stock market are unlikely to have any significant effect on household expenditure patterns for most households.7

More generally, it is conceivable that movements in the NYSE Arca Oil Stock Index could be a proxy for the state of the global and Australian economies and that this might cause stress resulting in people overeating or not exercising, irrespective of whether they own shares. But again, the evidence for this is tenuous. Employing HILDA, Frijters et al. (2015) find, at best, weak evidence that movement in the Dow Jones influence the subjective wellbeing of Australians, which is correlated with health. The NYSE Arca Oil Index is much more specific in its coverage and, unlike the Dow Jones, is very rarely ever reported in the Australian media, except in the financial pages. Hence, any link between the NYSE Arca Oil Index and the health of Australians is likely to be weaker than that with the Dow Jones.

As a robustness check on the NYSE Arca Oil Stock Index, we use Dated Brent crude oil prices as an alternate instrument, which is one of the most widely employed benchmarks for oil prices in Australia (Australian Institute of Petroleum, 2020).

As a final check, we use the Lewbel (2012) approach, which does not rely on the exclusion restriction for validity but on the presence of heteroskedasticity, which is a precondition for identification. The Lewbel (2012) approach allows for the identification of structural parameters in models with endogenous regressions if the regressors are not correlated with the product of the heteroscedastic errors. To demonstrate this, consider the following model:

\[
BM or Obesity = X' \beta + P + \varepsilon_1 \quad \varepsilon_1 = \alpha U + V_1
\]  

(3)
\[ P = X' \beta_2 + \varepsilon_2 \quad \varepsilon_2 = \alpha_2 U + V_2 \]  

(4)

where \( BMI \) and \( Obesity \) and \( P \) remain as previously defined. \( U \) denotes unobserved characteristics, which affect both BMI and petrol prices and \( V_1 \) and \( V_2 \) are idiosyncratic errors. The Lewbel (2012) method relies on heteroskedasticity in the data to estimate a 2SLS regression by taking a vector \( Z \) of observed variables and utilizing \( [Z - E(Z)]\varepsilon_2 \) as an instrument if the conditions hold:

\[ E(X \varepsilon_1) = 0 \quad E(X \varepsilon_2) \quad \text{cov}(Z, \varepsilon_1, \varepsilon_2) = 0 \]  

(5)

Thus, identification can be achieved provided there is some heteroscedasticity in \( \varepsilon_1 \). The vector \( Z \) could be a subset of, or equal to, \( X \). Given that \( \varepsilon_2 \) is a population parameter, which cannot be observed, we use the sample estimate obtained from the first stage regressions (denoted as \( \hat{\varepsilon}_2 \)), and, thus, in the Lewbel estimates our instrument is given as the vector \( [Z - E(Z)]\hat{\varepsilon}_2 \).

The Lewbel (2012) method is typically used in the literature as a robustness check on 2SLS findings based on external instruments (see, e.g., Awaworyi Churchill & Smyth, 2017, 2020; Buch et al., 2014; Emran & Shilpi, 2012; Mishra & Smyth, 2015).

In our potential channel analysis, we examine an individual's participation in physical activity and eating habits as channels through which petrol prices influence obesity. For these factors (i.e., engaging in physical activity and eating outside the home) to qualify as potential channels in our analysis, in addition to being associated with petrol prices and body weight, their inclusion as additional variables in the main empirical specification should decrease the size of the coefficient of petrol prices on body weight or result in it being statistically insignificant (Alesina & Zhuravskaya, 2011; Awaworyi Churchill et al., 2019).

5 | RESULTS

5.1 | Main results

Table 1 presents the baseline estimates from Equations (1) and (2), in which we examine the association between petrol prices and BMI using both pooled OLS and panel fixed effects methods. In panels A and B, we examine the effect of petrol prices on BMI and obesity, respectively. In each of the columns we present estimates with robust standard errors (in parentheses) along with standardized coefficients (in square brackets). In both panels, we show the relationship between petrol prices and our outcome variable as we progressively include additional controls. In panel A, columns (1) and (2) show the association between petrol prices and BMI without any controls using pooled OLS and panel fixed effects, respectively. In columns (3) and (4), we include demographic controls, while city-level fixed effects are included in columns (5) and (6). In columns (7) and (8), we also include month and year fixed effects. The relationship between petrol prices and BMI is negative in all cases. In our preferred estimates in Columns (7) and (8), which are based on the most complete specification, the coefficient on petrol prices is negative with an effect size of 0.517 using pooled OLS and 0.561 using the panel fixed effects model. These estimates at the sample mean height correspond to 1.505 and 1.633 kg of body weight. The magnitude of these point estimates, while appearing to be small, are comparable to Courtemanche’s (2011) study, whose estimates, at the sample mean height, correspond to a significant reduction in body weight of around 2.28 pounds, which is equivalent to around 1.034 kg. These estimates, in terms of the standardized coefficients, suggest that a standard deviation increase in petrol prices is associated with declines in BMI of 0.014 and 0.015 standard deviations in our preferred baseline pooled OLS and panel fixed effects models, respectively.

In panel B, we employ the same set of specifications as in panel A, but the outcome variable is a dummy variable set equal to 1 if the individual's BMI is above 30 indicating that the person is obese. The results from column (1) to column (8) show a significant negative association between petrol prices and the likelihood of being obese. The standardized coefficients from our preferred panel fixed effects model in column (8) suggest that there is a stronger association between petrol prices and the likelihood of being obese than petrol prices and BMI.

In Table 2, we present 2SLS results from the specification in which we instrument for petrol prices using the Arca Oil Stock price index. The first stage tests show that the oil stock price is positively correlated with city-level petrol prices and the F-statistics are larger than 10, indicating that our instrument is not weak (Stock & Yogo, 2005). The panel IV fixed effect estimates are smaller than baseline panel fixed effect. This suggests that the panel fixed effect estimates are upward biased, which
is consistent with a strong role for simultaneity bias and/or measurement error if several participants actually face relatively lower petrol prices than the average.

Our preferred estimates in Column 8 suggest that a standard deviation increase in petrol prices causes a decline in BMI of 0.006 standard deviations. Similarly, in panel B, higher petrol prices result in a lower probability of being obese. In Column 8, a unit increase in petrol prices results in a 2% point decrease in the probability that a participant is obese. 

5.2 Channel analysis

Next, we examine the role of physical activity and expenditure on meals outside the home as possible channels through which petrol prices could potentially influence body weight. As a first step, we show that physical activity and expenditure on meals eaten out of the home are correlated with petrol prices. These results are presented in Table 3 using data on all those who have reported their level of engagement in physical activity and meals eaten out. Consistent with expectations, in column 1 of Table 3, our estimates suggest that an increase in petrol prices are associated with greater levels of physical activity, while in Column 2 of Table 3, higher petrol prices are associated with decreased expenditure on meals outside the home.

Table 4 reports estimates for regressions in which we include our measures of physical activity and expenditure on meals eaten outside the home as additional covariates. Since our channel analysis in Table 3 is based on a sub-sample of those individuals who reported on their level of physical activity and meals eaten out, we also re-run regressions for BMI and obesity on the same sub-sample to ensure consistency. The results are presented in column 1 and column 3 of Table 4 for BMI and obesity, respectively. The coefficients on petrol prices are negative and significant, consistent with our estimates in Tables 1 and 2.
In panel A of Table 4, the coefficient on physical activity is negatively correlated with BMI and the likelihood of being obese and its inclusion as an additional covariate in the model specification reduces the magnitude of the coefficient on petrol prices. This result suggests that increased engagement in physical activity mediates the effect of petrol price on body weight, consistent with findings that physical activity is important for fostering healthier body weight.

In panel B of Table 4, we do the same analysis for expenditure on meals outside the home. The results in column 2 and column 4 show that eating out more is positively associated with BMI and obesity, respectively. The coefficient on eating out is significant when the dependent variable is BMI, but insignificant when the dependent variable is being obese; hence, the results for being obese should be viewed with caution. This said, the inclusion of meals eaten out as an additional variable in the model specification marginally decreases the effect of petrol price on both BMI and obesity. Taken together, this suggests that eating out less due to an increase in petrol prices, reduces the direct impact of petrol prices on body weight.
To explore the sensitivity of our results for different categories of people we conduct a series of checks focused on people with different income levels and occupation categories. First, we consider a sub-sample of participants in the top and bottom 20% of earners. We also consider a sub-sample consisting of socioeconomically disadvantaged individuals, based on the Australian Socio-Economic Indexes for Areas (SEIFA) 2001 Index of relative socio-economic advantage/disadvantage. Finally, we interact petrol prices with different income quintiles. The results, which are reported in Table 5, show that the impact of petrol prices is relatively stronger for people in the bottom 20% compared to those in the top 20%. We also observe a relatively strong effect for the socio-economically disadvantaged. Similar results are observed across the interaction terms, which show that the

### TABLE 3

| Variables          | (1) Physical activity | (2) Meals eaten out |
|--------------------|-----------------------|---------------------|
| Petrol prices      | 0.149***              | −0.036***           |
|                    | (0.053)               | (0.009)             |
|                    | [0.012]               | [−0.020]            |
| Observations       | 89,511                | 60,216              |
| R-squared          | 0.006                 | 0.157               |

*Note:* All models include controls variables and FE at individual, city, month and year levels. The Arca oil prices index is used as the instrument in all specifications. Meals eaten out is measured by the log of real household expenditure on meals eaten out. Physical activity is measured by the number of times that an individual engages in physical activity on a scale of (1) Not at all to (6) every day. The channel analysis is based on those individuals in our sample who have reported values on the variables included in this analysis. For other details, see notes to Table 1.

### TABLE 4

| Variables          | (1) DV is BMI | (2) DV is BMI | (3) DV is being obese | (4) DV is being obese |
|--------------------|---------------|---------------|-----------------------|-----------------------|
| **Panel A: Inclusion of physical activity as potential channel** |               |               |                       |                       |
| Petrol price       | −0.253***     | −0.181***     | −0.020**              | −0.016**              |
|                    | (0.075)       | (0.069)       | (0.009)               | (0.008)               |
|                    | [−0.006]      | [−0.004]      | [−0.006]              | [−0.005]              |
| Physical activity  | −0.139***     | −0.010***     |                       |                       |
|                    | (0.009)       | (0.001)       |                       |                       |
|                    | [−0.009]      | [−0.036]      |                       |                       |
| Observations       | 89,511        | 89,511        | 89,511                | 89,511                |
| R-squared          | 0.073         | 0.079         | 0.013                 | 0.015                 |

| **Panel B: Inclusion of meals eaten out as potential channel** |               |               |                       |                       |
| Petrol price       | −0.231*       | −0.228*       | −0.039***            | 0.024*                |
|                    | (0.131)       | (0.130)       | (0.010)              | (0.013)               |
|                    | [−0.005]      | [−0.005]      | [−0.011]             | [−0.007]              |
| Meals eaten out    | 0.112*        | 0.003         |                       |                       |
|                    | (0.062)       | (0.006)       |                       |                       |
|                    | [0.005]       | [0.002]       |                       |                       |
| Observations       | 60,216        | 60,216        | 60,216                | 60,216                |
| R-squared          | 0.032         | 0.046         | 0.008                 | 0.011                 |

*Note:* All models include controls variables and FE at individual, city, month and year levels. The Arca oil prices index is used as the instrument in all specifications. Meals eaten out is measured by log of real household expenditure on meals eaten out. Physical activity is measured by individual’s frequency of participating in physical activity ranging from nothing at all to everyday. For other details, see notes to Table 1.

Abbreviation: FE, fixed effect.

### 5.3 Robustness checks and extensions

To explore the sensitivity of our results for different categories of people we conduct a series of checks focused on people with different income levels and occupation categories. First, we consider a sub-sample of participants in the top and bottom 20% of earners. We also consider a sub-sample consisting of socioeconomically disadvantaged individuals, based on the Australian Socio-Economic Indexes for Areas (SEIFA) 2001 Index of relative socio-economic advantage/disadvantage. Finally, we interact petrol prices with different income quintiles. The results, which are reported in Table 5, show that the impact of petrol prices is relatively stronger for people in the bottom 20% compared to those in the top 20%. We also observe a relatively strong effect for the socio-economically disadvantaged. Similar results are observed across the interaction terms, which show that the
The strongest effect of petrol prices on obesity is for those in the lowest income categories. Results reported in Table 6 demonstrate that the effect of petrol prices on our channels are only significant for participants in the low-income or socio-economically disadvantaged categories. This is consistent with our earlier discussion, which suggested that the effects of increase in petrol prices on the prevalence of obesity is likely to be driven by low-income groups that are more responsive to changes in petrol prices.

As another check, we focus on a sub-sample of blue-collar job workers. Given the nature of the work done by trades people, they are typically expected to be punctual and, therefore, are likely to be less responsive to changes to petrol prices. The results, reported in Table 7, show that petrol prices have no significant effect on obesity for this sub-group. The results in Table 8 also show that petrol prices have no significant effects on our potential channel variables for this sub-group, which is consistent with the earlier discussion that the results are likely to be driven by sub-groups that are more responsive to changes in petrol prices, rather than groups like trades people that are less price sensitive given the nature of their jobs.

We also examine the effects of petrol prices for other population sub-groups, for whom the hypothesized channels or sensitivity to prices are likely to differ. The results are reported in Figure A1 and discussed in more detail in online appendix B. We find that the effect of petrol prices on BMI is stronger for women than men, which reflects the fact that women in Australia are

**Table 5** Asymmetric effects across income levels

| Variables | BMI | Obesity |
|-----------|-----|---------|
| Panel A: Based on bottom 20% earners | | |
| Petrol prices | −0.595*** (0.203) | −0.054** (0.022) |
| | [−0.013] | [−0.017] |
| Observations | 17,959 | 17,959 |
| Panel B: Based on top 20% earners | | |
| Petrol prices | −0.294* (0.168) | −0.035* (0.020) |
| | [−0.007] | [−0.011] |
| Observations | 17,953 | 17,953 |
| Panel C: Most disadvantaged group | | |
| Petrol prices | −0.782*** (0.293) | −0.091*** (0.029) |
| | [−0.015] | [−0.025] |
| Observations | 10,112 | 10,112 |
| Panel D: Based on different quintiles of income distribution | | |
| Petrol prices x income quintile 1 | −0.275*** (0.051) | −0.025*** (0.005) |
| | [−0.027] | [−0.033] |
| Petrol prices x income quintile 2 | −0.234*** (0.038) | −0.014*** (0.004) |
| | [−0.023] | [−0.019] |
| Petrol prices x income quintile 3 | −0.146*** (0.030) | −0.011*** (0.003) |
| | [−0.014] | [−0.015] |
| Petrol prices x income quintile 4 | −0.135*** (0.023) | −0.008*** (0.002) |
| | [−0.013] | [−0.010] |
| Observations | 89,792 | 89,792 |

Note: The “most disadvantaged” group is classified based on decile 1 and decile 2 of the SEIFA 2001 Index of relative socio-economic advantage/disadvantage. Reference category for income is quintile 5 (those in the top 20% of income distribution). For other details, see notes to Table 1.

Abbreviation: SEIFA, Socio-Economic Indexes for Areas.
generally more physically active than men and are, therefore, more likely to substitute towards more active means of transport (Lowrey, 2017). The results for heterogeneity across age groups suggest that the effect size of petrol prices on BMI is strongest for those over the age of 64, reflecting the level of sensitivity of retirees to changes in petrol prices.

Second, we disaggregate the BMI scale into weight categories and severity of obesity to examine the heterogeneous effect of petrol prices. The results are reported in the online appendix in Table A3. We find that the effect of petrol prices is consistently negative and significant with relatively higher effects for those who are suffering from Class II obesity.

Third, we extend our analysis to examine the effect of petrol prices on other body weight categories and alternative measures of obesity in Table A4. Our results suggest that petrol prices have a favorable impact on maintaining healthy body weight. The results on waist to height ratio and waist circumference as outcome variables suggest that the effect of petrol prices based on these alternative measures of obesity are consistent with the baseline results.

Fourth, we examine the asymmetric effects of upward or downward petrol price volatility. The results are reported in the online appendix in Table A5. Our results suggest that a one unit increase in upward price volatility reduces the probability of being overweight or obese, while the effect of downward price volatility on weight and obesity is insignificant.

Fifth, we examine the robustness of our results to alternative instruments and to the inclusion of additional controls. We also examine the robustness of our results to the use of alternative fuel data. The details are discussed in online appendix D and presented from Table A6 to Table A9. We find that our results are robust to these checks as well.

Sixth, we use correction equations to account for possible reporting bias with self-reported height and weight data. Finally, we examine the robustness of our results to alternative way of clustering our standard errors and to treating expenditure on petrol prices as a household decision. The results for this final set of robustness checks are discussed in online appendix D and

Table 6: Asymmetric effects across income levels on potential channels

| Variables | Physical activity | Meals eaten out |
|-----------|-------------------|-----------------|
| Panel A: Based on bottom 20% earners | | |
| Petrol prices | 0.295*** | −0.066*** |
| Observations | 17,844 | 13,941 |
| Panel B: Based on top 20% earners | | |
| Petrol prices | 0.121 | −0.018 |
| Observations | 17,915 | 10,091 |
| Panel C: Most disadvantaged group | | |
| Petrol prices | 0.393** | −0.041 |
| Observations | 10,078 | 6915 |

Note: Reference category for income is quintile 5 (those in the top 20% of income distribution). The “most disadvantaged” group is classified based on decile 1 and decile 2 of the SEIFA 2001 Index of relative socio-economic advantage/disadvantage. For other details, see notes to Table 1.

Abbreviation: SEIFA, Socio-Economic Indexes for Areas.

Table 7: Effects for those in blue-collar jobs

| Variables | BMI | Obesity |
|-----------|-----|---------|
| Petrol prices | −0.194 | −0.021 |
| Observations | 10,248 | 10,248 |

Note: Those classified in “blue-collar” jobs are jobs that are predominantly associated with trades and that are often physical. We use the Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006 industry classification to group those in “Agriculture, Forestry and Fishing”, “Mining”, “Manufacturing”, “Electricity, Gas, Water and Waste Services” and “Construction” jobs as in “blue-collar” jobs. The rest of the employed groups are classified in “white-collar” jobs. For other details, see notes to Table 1.
presented from Table A10 to Table A12. We find that the effect of petrol price on BMI and obesity in all instances are negative and significant, consistent with the main results.

5.4 | Effect of lagged prices petrol prices on obesity

We extend our analysis to examine short– and long–run effects of changes in petrol prices on body weight. Some studies suggest that weight loss occurs with a lag following exercise (Donnelly et al., 2003; Jakicic et al., 2008; Schoeller et al., 1997). Many of these studies find that weight loss occurs between 6 and 12 months following the intervention and that there is not significant further weight loss after 24 months (Donnelly et al., 2003; Jakicic et al., 2008).

On the basis of these findings, we expect that allowing for up to two periods is sufficient to observe the long-run effects of weight loss resulting from behavioral changes due to the effect of rising petrol prices. Thus, in Table 9 we use our preferred specification from Column 8 of Table 2 in the main text, but allow for up to two annual lags. In panel A we use the first lag of petrol prices and find a negative and significant impact of petrol prices on current BMI and obesity rates. The magnitude of the first year lagged prices are higher than current year petrol prices as reported in column 8 of Table 2 in the main text. In panel B of Table 9, we include only the second lag of petrol prices, which is insignificant. In panel C of Table 9, we combine current, first lag and second lag of petrol prices in the same model specification. The estimates show that the contemporaneous and first year lag effect of petrol price on BMI and obesity is negative and significant, while the second-year lag effect is not significant. This finding is consistent with the literature suggesting that the lagged effect of some intervention – in our case rising petrol prices – on weight is observed within the first 12 months, with no significant further changes by 24 months.

The total effect over the current and previous two periods suggests that a $1.00 increase in petrol price reduces BMI by 0.388 units, while the probability of being obese is reduced by 3.6% points. These magnitudes are considerably larger than those estimated using only current petrol prices, suggesting petrol prices gradually influence body weight. These estimates, however, are smaller than in Courtemanche (2011) who found that by incorporating lagged effects, a $1 increase in petrol price per gallon reduces the propensity of being obese by 3.1% points in the United States. Courtemanche’s (2011) estimates, in terms of Australian dollars per liter, suggest that the effect in the United States is about four times larger than in Australia. One possible explanation for this difference is that obesity rates are higher in the United States. The United States has the highest obesity rates in the OECD, while Australia ranks fifth in the OECD. Hence, the marginal returns to higher petrol prices in terms of effect on weight loss can be expected to be larger in the United States than in Australia.

5.5 | Economic significance of the results

We consider the economic significance of the results obtained from panel C of Table 9 by estimating the percentage of the rise in obesity from 2006 to 2018 that can be explained by the decline in real petrol prices during that period using the formula:

\[
\text{Obesity}_{2018} - \text{Obesity}_{2006} = \sum_{k=0}^{2} (\hat{\beta}_{1,k} P_{2018-k} - \hat{\beta}_{1,k} P_{2006-k})
\]

Recall that the real petrol price in Australia decreased over the period studied (see Figure 2). The average real petrol prices in each of 2004-2006 were $1.23, $1.36 and $1.47 while in 2016-2018 it was $1.10, $1.19 and $1.31, respectively. These
numbers and the coefficients from the obesity column in panel C of Table 9 are substituted into Equation (6) to calculate changes in obesity rates due to changes in petrol prices. We find that the reduction in real petrol prices increased obesity rates by 0.63% over the sample period. Using the National Health survey numbers, Obesity Australia (2019) reports that adult obesity rates in Australia increased by 13.3% over the 2006-2018 period, which, based on estimates from Equation (6), suggests that decreases in petrol prices accounted for 4.8% of the increase in obesity rates during that period.

We next use these estimates to provide some back of the envelope calculations on the potential benefits of petrol price rises in terms of prevalence of obesity and annual cost savings related to treating obesity. The percentage of adults who are obese in 2018 is estimated to be 31.3%. Our total lagged price effects in Table 9 suggest that petrol price rises reduce the percentage of adults who are obese by 3.6%. Thus, our results suggest that a permanent $1 per liter increase in petrol prices would reduce obesity rates by 11.5%, assuming that the full effect of petrol prices on obesity is realized within 2 years. According to Obesity Australia (2019), in 2017-18, the cost of obesity was estimated to be $11.8 billion dollars and there were 5.8 million adults who were obese. Based on these numbers, our calculations suggest that a $1 per liter increase in petrol prices would reduce the number of people who were obese by 672,000 and save $1.4 billion dollars in medical expenditure related to obesity each year. Based on projections suggesting that 7.8 million people will be obese by 2025 (Obesity Australia, 2019), our estimates suggest that increasing petrol prices by A$1 per liter could prevent almost 900,000 people from becoming obese over that period. These estimates are conservative and do not include the costs of those in the overweight category at risk of becoming obese.

The estimates, taken from Obesity Australia (2019), which we use for our back of the envelope calculations focus on the direct and indirect cost of obesity, and, therefore, are subject to the methodological limitations discussed in the cost of illness literature. Specifically, it is argued that the technique used to provide such costs do not fully capture all dimensions that are affected by a given illness given that some dimensions are intangible. Accordingly, such methods, at best, provide only partial

| Variables | BMI | Obesity |
|-----------|-----|---------|
| Panel A: Effects of lag 1 prices | | |
| Petrol price – lag 1 | -0.250** | -0.024** |
| (0.101) | (0.011) |
| [-0.006] | [-0.007] |
| Observations | 81,348 | 81,348 |
| Panel B: Effects of lag 2 prices | | |
| Petrol price – lag 2 | 0.148 | 0.015 |
| (0.092) | (0.011) |
| [-0.004] | [-0.005] |
| Observations | 74,824 | 74,824 |
| Panel C: Effects of combined lags | | |
| Petrol price | -0.179** | -0.028* |
| (0.082) | (0.015) |
| [-0.004] | [-0.008] |
| Petrol price – lag 1 | -0.195** | -0.020* |
| (0.091) | (0.012) |
| [-0.005] | [-0.006] |
| Petrol price – lag 2 | -0.014 | 0.012 |
| (0.113) | (0.013) |
| [-0.000] | [-0.004] |
| Observations | 73,613 | 73,613 |
| Sum of all lags | -0.388* | -0.036** |
| (0.223) | (0.017) |
| [0.009] | [0.018] |

Note: The regression analysis is based on a panel fixed effects model, controlling for demographic variables and fixed effects at individual, city, month and year levels. The NYSE Arca oil stock prices index is used as the instrument in all model specifications. For other notes, see notes to Table 1.
estimates of the cost of illness (Shiell et al., 1987). This implies that our estimates of the economic costs should be regarded as being conservative.

## 6 | CONCLUSION

We have examined the relationship between petrol prices and body weight using nationally representative longitudinal data for Australia over the period 2006-2018. We find that petrol prices have a significant negative effect on measures of body weight (BMI and obesity). This finding is robust to a number of checks for endogeneity, incorporating additional controls, correcting for self-reporting biases, using alternative fuel prices and databases. While there might be some undesirable effects or consequences of higher petrol prices as shown in other contexts, our findings suggest that there is a silver lining of higher petrol prices in contributing to lower rates of obesity. Our crude estimates suggest that a permanent $1 per liter increase in petrol prices would reduce the number of people who were obese by approximately 670,000 and save $1.4 billion dollars in medical expenditure related to obesity every year.

Increasing excise taxes on petrol prices represents one policy lever to reduce obesity rates. Given that petrol prices in Australia are among the lowest in the OECD, this might be a more viable option for Australia than other countries. There are potential costs. Studies such as Prakash et al. (2020) suggest that higher petrol prices lower subjective wellbeing. Any decision to increase petrol prices is unlikely to be politically popular.

We also examine the role of physical activity and consumption choices as channels through which petrol prices influence body weight. We find that both of these are important channels, although our results indicate that physical activity is the more important channel. This finding suggests that policies aimed at directly promoting physical activity and healthy consumption choices may achieve the desired impact on body weight, while keeping petrol prices at levels that do not hinder wellbeing. Other relevant policies could include increased investment into alternative transportation infrastructure that require physical activity. For instance, increased investment in walking and cycling infrastructure along with promoting a culture of cycling to work. Such policies can include incentive schemes to promote the uptake of active lifestyles.

One limitation of this study is that we have used monthly petrol prices as opposed to petrol prices of lower frequency. Some retailers in Australia adjust petrol prices based on a weekly fuel price cycle, and this could mean that changes in petrol prices are averaged out with the use of monthly petrol price data. Thus, we are not able to rule out major changes in demand that are driven by petrol price changes on specific days. Another limitation is that physical activity is a noisy measure of active modes of commuting and transportation, although evidence exists that walking and cycling are very popular forms of physical activity in Australia.

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## CONFLICT OF INTEREST

None.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available to researchers who apply access to the HILDA data at: https://melbourneinstitute.unimelb.edu.au/hilda/for-data-users.

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ENDNOTES

1 In 2020, Australia had the third lowest prices in the OECD for unleaded petrol (only higher than Canada and the United States) and fifth lowest prices in the OECD for diesel (only higher than New Zealand, Chile, Canada and the United States) (AIP, 2020).

2 See Watson and Wooden (2012) and Summerfield et al. (2019) for detailed discussion on the design, sampling and structure of the HILDA survey.

3 HILDA has a better response rate than the National Health Survey for information on body weight across genders and all age groups. This likely reflects how the two surveys collect the data. HILDA collects information on body weight through a written questionnaire, which participants complete in the privacy of their own home. This is likely to make participants more comfortable with reporting their weight. In the National Health Survey participants report their weight directly to the interviewer (Wooden et al., 2008).

4 The data is available at http://www.aip.com.au.

5 The data on state-level diesel prices is only available for 2007–2018.

6 The data is available at http://www.fuelwatch.wa.gov.au.

7 Following the COVID-19 induced stock market crash in March 2020, a number of first-time investors entered the Australian stock market – these are so-called Robinhood investors, named after the no-fee app that many first-time investors have used (Vickovich, 2020). The entry of Robinhood investors following the COVID-19 crash is after our sample period ends and most Robinhood investors are known for investing relatively small amounts in a few specific tech stocks, such as Afterpay or Zip, or travel stocks, such as Flight Center or Webjet.

8 The full set of results showing all control variables are reported in online appendix Table A2. The direction of effect sizes and significance of the other variables are generally consistent with the literature (see for e.g. Avsar et al., 2017; Courtemanche, 2011). Based on the results in Column (8) of Table A2, the effect size of petrol price is relatively weaker than covariates such as being employed, having a university level qualification and being single, but is stronger than the coefficient on suffering from long-term illness.

9 This is calculated as follows: We multiply 3.1 by 3.785 to get Courtemanche's (2011) estimates in liters. We then use the average exchange rate between the United States and Australian dollars over our sample period, which is 1.191, to convert Courtemanche's (2011) estimates to Australian dollars. One proviso is that Courtemanche's (2011) estimates do not control for unobserved individual fixed effects and do not control for endogeneity. We show that the panel fixed effect estimates are upward biased relative to the IV panel fixed effect estimates. The estimate of a fourfold effect, thus, is likely to be an upper-bound estimate on the true difference in the effect of petrol price increases on obesity rates between the two countries.

10 In 2015, 38.2% of the population in the United States was obese, while the comparable figure in Australia was 27.9% (OECD, 2017).

11 The obesity rate in Australia in 2017-2018 period was estimated to be at 31.3%, compared with 18.0% in 2004-2005 Obesity Australia (2019). The 2017-2018 figure of 31.3% is consistent with the figure of 27.9% for 2015 reported in OECD (2017) that we cite above when comparing obesity rates in Australia with the United States.

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