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Energy poverty and food insecurity: Is there an energy or food trade-off among low-income Australians?☆

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ABSTRACT

Large price rises can lead to what has been termed a 'heat or eat' trade-off, where some low-income individuals must choose between energy use and putting food on the table. Low-income individuals are particularly at risk. There are effects on physical health from either restricted energy use or restricted food intake (in terms of quantity or nutritional value) and there may also be effects on mental health due to stress associated with being unable to pay bills or buy food. Considering escalating energy and food prices, this study investigates the energy or food trade-off among low-income people in Australia. While there is some literature on the heat or eat trade-off, our contribution lies in our use of detailed longitudinal population-representative data and multivariable analysis with a focus on low-income individuals who are most vulnerable. Among all low-income households, a 1% increase in the relative price of electricity increases energy expenditure by 0.44% and reduces food expenditure by 0.09% and these effects are statistically significant. For those in poverty, we find a 1% increase in the relative price of electricity increases energy expenditure by 0.37% but has no significant effect on food expenditure. This is consistent with individuals in poverty having economised as far as possible and being unable to reduce expenditure any further. For those near poverty the increase in price reduces food expenditure by 0.20% although there is no significant effect on energy expenditure, indicating individuals are economising on energy use to offset the price increase. For the remaining low-income individuals, the price increase results in a trade-off in which energy is prioritised over food. Reduced food expenditure, however, does not seem to translate into going without meals.

1. Introduction

Australia has experienced large increases (near trebling) in energy prices over the past 20 years (with particularly strong growth since the Global Financial Crisis) (Australian Bureau of Statistics, 2021a). This energy price inflation has recently been coupled with COVID-19 related global price shocks including increasing food prices (Bai et al., 2022). This means that Australia is an ideal environment to investigate if there is an energy or food trade-off. Trade-offs occur when individuals are forced to reduce expenditure on one item to be able to afford consumption of another item. The extant literature has focused on the heat or eat trade-off where individuals have reported reducing food expenditure in order to heat their homes in winter. Most literature on the heat or eat trade-off focuses on the UK, Europe or North America (although there are some studies in warm climate countries (Basole and Basu, 2015; Nie et al., 2021)). In Australia energy demands exist throughout the year to heat homes in the winter and to cool homes in the summer as there are warm–hot summers typified by heat waves and bushfires in some areas. This makes Australian citizens potentially more susceptible to an energy or food trade-off, especially in periods of rising prices. While most individuals can accommodate increasing energy costs through a reduction in discretionary expenditure, individuals with low

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incomes cannot and may have to reduce expenditure on other necessities such as food. It is, therefore, important to investigate if there is evidence of an energy or food trade-off for low-income individuals.

Energy poverty is defined as the inability to adequately meet basic household energy needs (Hernández, 2016) where energy is used for heating, cooling, lighting, cooking, cleaning, technology and medical devices (Jessel et al., 2019). This includes being unable to afford to heat the home to an ambient temperature of 21 °C in living rooms and 18 °C elsewhere and to meet other energy needs (Awaworyi Churchill and Smyth, 2021). In warm countries, energy poverty may also lead to individuals being unable to cool their house to acceptable temperatures (recommended 24–26 °C, Tham et al., 2020; WHO, 2018), leading to problems with sleep, cardiovascular systems and blood pressure (WHO, 2018). The housing stock in Australia has poor thermal qualities compared to cold-climate countries, leading to higher burden of ill health and mortality during winter months (Daniel et al., 2021). This would imply relatively higher costs of keeping homes comfortably warm and could therefore be strongly associated with energy poverty, food insecurity or both. Energy poverty is also associated with lower subjective wellbeing, poor self-assessed health, particular health conditions such as circulatory diseases and respiratory problems, poor mental health and mortality (Awaworyi Churchill et al., 2020; Awaworyi Churchill and Smyth, 2021; Llorca et al., 2020; Marmot Review Team, 2011; Thomson et al., 2017). Fry et al. (2022) show among older Australians, Government Age Pensioners are particularly vulnerable to energy poverty.

Food insecurity is defined as 'having limited access to or availability of nutritious food or a limited/uncertain ability to acquire food in socially acceptable ways' (American Dietetic Association, 1998). Food insecurity also occurs when food is not sufficient, reliable, nutritious, safe, socially acceptable or sustainable (Temple, 2008). Food insecurity has been linked to worse health outcomes (Conklin and Monsivais, 2017) and lower wellbeing (Jessel et al., 2019; Temple, 2006). For example, food insecurity has been associated with worse self-reported general and mental health and lower consumption of healthy foods (Temple, 2008).

Low incomes and price increases mean some individuals are subject to both energy poverty and food insecurity leading to significant welfare concerns. For example, among social assistance recipients reporting food insecurity in Australia, 60% reported being unable to pay utility bills on time and almost one in three reported an inability to heat their homes (Temple et al., 2019). For others there can be a trade-off. The energy or food dilemma occurs when individuals cannot afford both energy and food and must choose between the two. Trade-offs can create loops that trap individuals in poverty through for example, energy supply disconnections leading to homelessness and using high interest payday loans to avoid energy supply disconnections (Brown et al., 2020). Of additional policy importance is that the lowest end of the income distribution contains many vulnerable subpopulations such as social welfare recipients, single parents, and those with poor physical and mental health. In a review of energy poverty studies for the Global North, Middlemiss (2022) shows that low income is a common factor across many studies and that the vulnerable subpopulations include migrants and ethnic minorities and specific demographic groups (i.e., elderly, disabled, women, young people) and particular household types (i.e., single parents, socially isolated, or very large and multiple occupancy homes). Food insecurity is more prevalent among households with children or veterans, older adults, students, migrants and members of the lesbian, gay, bisexual, transgender, intersex, queer/questioning, asexual (LGBTIQA+) community (Flores and Amiri, 2019) and is associated with younger age, being divorced or separated, lower income, education and financial resources, a high number of resident children, poor health, not owning your home, being unemployed, exposure to unanticipated shocks and spatial disadvantage (Butcher et al., 2019; Conklin et al., 2014; Lê et al., 2014; Olabiyi and McIntyre, 2014).

In this study we ask: is there empirical evidence of an energy or food trade-off in Australia and, if so, in what direction is the trade-off? To address these questions, we use data from 16 waves of the *Household, Income and Labour Dynamics in Australia* (HILDA) Survey. HILDA is a rich source of data for our purpose being a large population-based sample (approximately 16,000 responding individuals) with information on both energy and food expenditures as well as multiple individual and household characteristics. Given that climatic factors impact on energy used for heating and cooling we map into this data temperature information to ensure that the confounding effects of the climate are controlled for in our modelling. We use Bureau of Meteorology data on average minimum winter temperatures and average maximum summer temperatures in each capital city.[1]

Specifically, we investigate if there is an energy or food trade-off among low-income individuals in Australia, controlling for temperature variations. We adopt the OECD definition of low income as having income below 75% of the median income, which the OECD identifies as the lower boundary of 'middle class' (OECD, 2019). We begin by analysing the trade-off using expenditure data on energy and food and relative prices across the sample of low-income individuals and then also across several disaggregated low-income groups defined by the following categories: in poverty (<50% of median income); near poverty (50–60% of median income); and remaining low income (60–75% of median income) (Förster, 1994; OECD, 2019). Using these results, we identify the income group subject to the trade-off for further analysis. Then we conduct a series of tests to ensure the robustness of our results for our target income group. Investigating subjective (or experiential) measures of energy poverty and food insecurity provides an alternative, yet complementary perspective on the trade-off. We also experiment with different price effects, by lagging the relative price of electricity to food and by using the relative price of gas to food (noting that gas is very much a secondary source of energy in Australian homes[2]), by considering the inclusion of meals eaten outside of the home as food expenditure and an outlier analysis of household size. Finally, we investigate the importance of omitted variables in our analysis.

Our unique contribution to the extant heat or eat literature is the focus on Australia as a country with high energy prices over an extended period, rising food prices in recent times and a climate that demands high energy usage most of the year for heating and/or cooling. While the rising energy prices have resulted in several studies of energy poverty in Australia (see for example Awaworyi Churchill and Smyth, 2021; Awaworyi Churchill et al., 2020; Farrell and Fry, 2021; Fry et al., 2022) we know of no study that has empirically considered the energy or food trade-off for Australia. Moreover, among the studies of the energy or food trade-off, ours is the only one to model the expenditure on the two goods using a Seemingly Unrelated Regression (SUR) framework to allow for joint determination. This is important from a theoretical framework perspective as it allows for the joint/simultaneous determination of energy and food consumption in an individuals' decision-making processes. We also offer a statistical innovation in that we extend Oster's (2019) bounds procedure to test for the stability of our key parameter estimates and the influence of omitted variables in the context of a two equation SUR estimation procedure. To our knowledge this has previously only been conducted for single equation models.

2. Background and literature

Given inflexible incomes, increases in energy prices (directly through actual prices or indirectly through temperature shocks) and/or food prices can lead to an energy or food trade-off. Individuals may not be able to smooth consumption when energy or food prices increase as 'buffer-stock' savings (particularly for those with low incomes) may not

[1] See http://www.bom.2gov.au/climate/data/index.shtml.

[2] The ABS Energy Account shows total household expenditure on electricity was A$47.4b and for gas was A$26.7 in 2019–20 (ABS, 2021b).

be available (Cullen et al., 2005). This matters as in a fair and just society individuals across the income range should have sufficient funds to be able to afford the necessities in life. Two of those important necessities are energy and food. For most households, adjustments to price shocks will come from a reduction in discretionary spending. However, there are obvious policy and equity concerns if the lowest portion of the income distribution are having to forfeit expenditure on one necessity to fund expenditure on another necessity. The evidence presented below suggests this is in fact the case for many low-income groups.

In the UK, individuals have been shown to reduce the amount of money they spent on food to pay for fuel (Morgan et al., 1996) indicating a heat or eat trade-off. One study of older people showed households in greatest poverty spend less on food during the coldest winters (Beatty et al., 2014). Among older women in Wales, heating was the priority rather than eating (O'Neill et al., 2006). Children can also be affected by the trade-off. Based on a sample of children seen at an emergency department in a Boston hospital, children of families who went without heat or were at risk of utility disconnection in the previous winter were twice as likely as other children to be reported as being hungry or at risk of hunger (Frank et al., 1996). The authors concluded further investigation was needed into whether decreased calorific availability due to high heating costs was a factor leading to a 'heat-or-eat' trade off. A study of US low income households found weight-for-age was significantly lower and nutritional risk significantly higher for children in households that did not receive low income home energy assistance (Frank et al., 2006). This suggests families not receiving assistance were prioritising energy over food.

Similarly, expenditures on food decreased and fuel expenditures increased during cold months for families in poverty in the US (Bhattacharya et al., 2003), with 11% of households in poverty going without food to pay heating bills (Mercier et al., 2000). These studies suggest that the heat or eat trade-off is concentrated among the low-income members of societies in high-income countries. In a geographically large country such as Australia, heating may not be required in very warm states (such as the Northern Territory) meaning we may not observe heat or eat choices therein. However, the trade-off may involve cooling in summer months: in poor, older households in the US low food security has been associated with seasonality in heating and cooling costs, with the heat or eat effect of similar size to the cool or eat effect (Nord and Kantor, 2006). Moreover, homes in warmer climates are less likely to have insulation, leading to larger fuel expenditures when the weather is unusually cold (Bhattacharya et al., 2003). This is true for many Australian homes.

For low-income individuals, a key driver of the heat or eat trade-off is prices. Unanticipated energy price increases have been associated with lower food expenditure in the US (Cullen et al., 2005) and Canada (Emery et al., 2012). Qualitative research by Porto Valente et al. (2021) showed some older low-income individuals in Australia prioritised energy over food. Studies outside Australia show money spent on energy can lead to food insecurity (Hernández, 2016; Kearns et al., 2019; Tuttle and Beatty, 2017) and there is evidence of rationing within pensioner households whereby energy bills are prioritised over food (Gibbons and Singler, 2008). Compared to individuals using post-payment methods, Burlinson et al. (2022) found prepayment meter use in Britain was associated with consumption of almost 3 fewer portions of fruit and vegetables per week, a reduction in the probability of consuming '5-a-day' as recommended by the World Health Organization, and an increased probability of using a food bank. Thus, the energy–food trade-off may be seen in self-rationing of food and/or energy (and perhaps even self-disconnection of energy when prepayment meters are used but run out of credit) (Burlinson et al., 2022). When income is low and there is very little discretionary spending, unanticipated energy price rises appear to be being absorbed by a reduction in food consumption. Over the past 20 years, average electricity and gas prices in Australia have nearly trebled and food prices have risen by about 73% (Australian Bureau of Statistics, 2021a). In the current climate we see anticipated energy price rises and it seems likely that households may pay for increased energy bills by reducing food consumption in the same way.

The above evidence suggests that there is a systematic prioritising of energy expenditure over food expenditure for those on low income. Hence the heat or eat trade-off is influenced by the nature of the two markets, with the market for food being perceived as flexible with more opportunities to find bargains/substitute brands and with fuel bills being perceived as less negotiable (Anderson et al., 2012), inducing a substitution in expenditure from food to energy. For low-income households the nature of the food market is critical as many may already be buying the cheapest brands and so further reduction in expenditure may lead to a fall in intake and even where brand substitution is possible, there may be a fall in the nutritional and calorific content of the food consumed. Conklin et al. (2014) suggest that individuals may not go without meals but reduce variety or nutritional content to save money. Maxwell (1996) also found a variety of other coping strategies were used, including limiting portion size and borrowing food.

Such behaviours lead to additional health concerns for these vulnerable citizens. A couple of exceptions to the prioritisation of energy over food (quantity and/or quality) are Dowler et al. (2011) and Hernández and Bird (2010) who found electricity consumption was reduced to meet food bills and qualitative research directly on the heat or eat trade-off indicated a preference for eating in rural England (Lambie-Mumford and Snell, 2015). The timing of bills across energy and food markets is also an important factor in budgeting and consumption smoothing. Energy prepayment meters are used in some countries, such as New Zealand (about 3% of the market (O'Sullivan et al., 2011)) and the UK (14–15% of the market (Burlinson et al., 2022)), but in Australia prepayment meters use is rare (Allen Consulting Group, 2009; Australian Energy Regulator, 2022) and most energy bills are paid in arrears (post consumption) (Longden et al., 2022; Riley et al., 2023). However, food bills are paid up front (prior to consumption). Energy bills are typically paid quarterly/monthly, and food bills are typically paid weekly/fortnightly. This means that food expenditure is easier to control in the short run and may in part explain why low-income individuals economise on food to pay energy bills. Furthermore, in Australia, energy insecure individuals may not have the capacity to engage with energy use technologies available in some areas (such as smart meters) that translate use into energy bills (Awaworyi Churchill and Smyth, 2021). This leads to a high level of uncertainty regarding the cost of future bills when prices are rising.

In an economic climate of rising energy and food costs individuals may use adaptive strategies rather than simply 'going without'. Using gas fires rather than central heating is lower cost (Anderson et al., 2012). Adaptive strategies are varied such as avoiding hot water use (Jessel et al., 2019), wearing more clothes, heating one room or going to bed early (Brunner et al., 2012; Mercier et al., 2000) but only a minority try to obtain better energy prices (Anderson et al., 2012). Individuals may also go without lighting or cut back on the number of cooked meals to reduce energy expenditure (Gibbons and Singler, 2008). In warmer countries, there may also be energy poverty arising from cooling costs, and adaptive behaviours may include opening windows (although this may have negative health consequences due to noise and air pollution (Jessel et al., 2019)). This evidence again suggests low-income households do not accommodate the effects of weather and fuel price variations easily. In addition to energy usage reduction, individuals can reduce food costs in a variety of ways such as lowering the quality or variety of food purchased (Anderson et al., 2012; Conklin et al., 2014), using foodbanks (Snell et al., 2018) or — in the extreme — missing meals.[3] Also, some individuals purchase discounted foods near their 'sell by' dates to save money (Gibbons and Singler, 2008). The role of social inclusion is also important to recognise here. In addition to economic

[3] A less extreme response that still indicates problems is use of a food bank (Lambie-Mumford and Snell, 2015).

resources, social relationships can be an asset, and lack of both may affect energy and food consumption. Financial stress has been shown to be correlated with adverse dietary effects among US older adults, but the adverse effects were reduced by social inclusion (McIntosh et al., 1989). Friends and family are an important source of informal loans and providers of meals in hard times and these informal networks are well recognised and understood as valuable safety nets for low-income households (Ahluwalia et al., 1998; Brunner et al., 2012).

Whilst adaptive behaviours can elevate some of the financial pressures of energy and food costs, they pose a problem for the identification of a heat or eat trade-off as they may lead to a difference between subjective and objective measures of hardship. For example, individuals may not report difficulty paying their energy or food bills because they have reduced their consumption to a level of expenditure that is below what is deemed necessary for modern living (via adaptive behaviours) and are in fact experiencing significant energy poverty and/or food insecurity. Such 'hidden' energy poverty and food insecurity is a still a problem and highlights the necessity of a careful understanding and interpretation of the measures being utilised in studies of the heat or eat trade-off.

It is possible for studies to find an absence of a heat or eat trade-off arising for four main reasons. First, individuals could cut back on both areas. Rather than a direct trade-off, individuals may adapt to financial constraints by reducing spending on both food and energy (Anderson et al., 2012; Snell et al., 2018). Second, individuals could spend more on both energy and food in cold weather, cutting back in other areas such as medical care (Cullen et al., 2005; Mercier et al., 2000), dental care (Jessel et al., 2019) or on socialising[4] (Hills, 2011). Third, if families have access to savings, they may use savings to fund energy and food needs associated with price increases and/or shocks in cold weather. Fourth, there may be no cutback and the households acquire debt (Gibbons and Singler, 2008).[5] In the case of energy debt this may also be hidden as energy companies are legally required to allow customers to arrange "affordable" repayment plans in most high-income countries. This means that energy debt is often not recorded in standard expenditure surveys and may be quite large.[6] One notable exception is the *European Union Statistics on Income and Living Conditions* (EU-SILC), although that survey only asks about being in arrears on utility bills (including water) within the last 12 months but not the amount of debt (Eurostat, 2014). Importantly these possible reasons for not finding a trade-off still have important welfare implications for these low-income individuals.

Our paper contributes to this literature on the heat or eat trade-off as to our knowledge it is the first paper to investigate trade-offs of this nature empirically for Australia. While existing studies have investigated either heat or eat or cool or eat trade-offs, Australia is an interesting case study where both heating and cooling is required (although this varies across States). We will therefore use the terminology of an energy or food trade-off in respect to our empirical investigation. We also explore low-income as a group rather than investigating subpopulations within the low-income group such as pensioners or single parents. All the subpopulations that have been studied to date are characterised as low-income, so it is logical to investigate the bottom end of the income distribution comprehensively. We also examine both objective and subjective measures of energy poverty and food insecurity to explore hidden hardship as most existing studies consider one or the other. Finally, our paper connects with and contributes to the growing energy poverty in Australia literature. Specifically, we contribute to the literature on the determinants of energy poverty in Australia. To date this literature has focused on a wide range of factors such as the role of locus of control (Churchill and Smyth, 2021), gambling (Farrell and Fry, 2021), ethnic diversity (Churchill and Smyth, 2020) and retirement income sources (Fry et al., 2022) among others.

3. Data and methods

Data for our study are from the HILDA survey. The annual survey began in 2001, with the most recent wave being 2020. It is large (approximately 7000 households) and nationally representative, focussing on family and household dynamics, income, welfare and wealth, labour market activity (work, unemployment and joblessness) and individual wellbeing and health. Being longitudinal, we can capture individual food insecurity and energy poverty over time, allowing us to assess the extent and nature of any energy or food decisions among low-income people in Australia. Initial survey details are available in Watson and Wooden (2012) and more recent findings are in Wilkins et al. (2020).

Our focus is on energy poverty and food insecurity among low-income people in Australia. While the literature shows the heat or eat trade-off to be a low-income phenomenon, there is no consistent definition of low-income and many of the studies focus on subpopulations such as older people. While the identification of vulnerable groups is important from a targeted policy perspective it seems likely that the mechanisms from vulnerable groups to an energy or food trade-off is through low income. Our aim is to establish the presence, nature and extent of this trade-off among four groups: those in low income, and, within this, those in poverty, those near poverty and the remaining low-income individuals. Each of these four groups is defined with reference to median equivalised household disposable income (excluding housing costs) in a wave.[7] Specifically, income up to 75% of median income (the full low-income sample) then disaggregated low-income groups defined as: income ranges up to 50% of median income (in poverty), 50–60% of median income (near poverty) and 60–75% of median income (remaining low income), based on Förster (1994) and OECD (2019). Equivalisation is based on the OECD modified scale with equivalence factor: 1/ [1 + 0.5*number of individuals aged 15 and over in the household apart from the household head +0.3*number of children aged under 15 in the household]. Individuals are only allocated to a group in the waves for which their income falls into these ranges.

In our main analysis we use the available objective expenditure data from 2005 to 2020 on annual household expenditure on energy (electricity bills, gas bills and other heating fuels) and on food (groceries, excluding alcohol and meals eaten out).[8] Additional analysis uses two other key subjective variables available in 2001–2009 and 2011–2020: i) going without heating and ii) skipping meals. Specifically, the survey asks "*Since January 20XX did any of the following happen to you because of a shortage of money? Was unable to heat home (yes/no) Went without meals (yes/no)*". Among those living in low-income households, 3.3% are unable to heat, 4.4% go without meals and 3.2% go without both. We use these consensual (subjective) measures of energy poverty and food insecurity as they focus on lived experiences, rather than expenditure (as per the poverty literature (Snell et al., 2018)).

The energy or food decision is likely influenced by relative prices. For this reason, we include energy and food prices in our analysis. These data come from the Australian Bureau of Statistics (ABS) and contribute

[4] Leading to social exclusion.

[5] Although this response is less common among retirees due to negative attitudes to debt (Gibbons and Singler, 2008).

[6] AER (2021) estimated 130,000 electricity customers in Australia were in debt (90 days overdue) by an average of $1151 in March 2021.

[7] We exclude housing costs as they may be quite different for older people who may own their homes compared to renters or mortgagees (Davidson et al., 2020).

[8] In the survey, grocery expenditure data are reported for an average week and energy expenditure reported on an annual basis (last 12 months). We note that there may be a negative bias in the expenditure data reported in HILDA with energy expenditure 20% lower and groceries 9% lower compared to estimates from the Household Expenditure Survey (Wilkins and Sun, 2010).

to the Consumer Price Index (CPI) as electricity, gas and food price groups, based as March 2000 = 100 (Fig. 1). It should be noted that our price measure for food includes restaurant meals, take away and fast foods, whereas our expenditure measure does not. As we do not have a measure of the CPI for electricity and gas combined and electricity is the main source of energy in Australian homes, we focus on electricity prices and test the robustness of our results using gas prices.

Indices used represent average prices in a capital city for a specific bundle of goods, rather than prices paid by individuals. However, each index is State/Territory based, so price increases in, say, Melbourne should only affect individual consumption decisions in Victoria.

Using data from the HILDA survey to measure national estimates, from 2001 to 2020, average electricity prices faced by low-income people in Australia grew by 272% and gas prices 262% while food prices increased by 160%. With average disposable incomes rising by 211% over the period, this suggests food became relatively more affordable while energy did not. In particular, many individuals were left worse off by rising energy prices that outstripped income growth. While price determines expenditure, relative prices impact resource allocation and so in our empirical modelling we include the relative price of energy to food given our focus is on the allocation of resources across energy and food.

The energy or food decision is also affected by extreme variations in weather. We measure temperature shocks using Bureau of Meteorology data on average minimum winter temperatures and average maximum summer temperatures in each capital city[9] and define a hot shock as at least one standard deviation above the mean maximum summer temperature and a cold shock as at least one standard deviation below the mean minimum winter temperature. Within each state there may be local variations in temperature, biasing results towards zero. Recent literature has adopted localised temperature readings (Awaworyi Churchill et al., 2022). However we employ the General Release HILDA dataset and so only have State level locational identifiers. Therefore, we adopt the argument of Beatty et al. (2014) that prolonged periods of severe cold or hot weather tend to occur across wide areas and so, in large states like Western Australia the temperature level may differ significantly, but a relative hot or cold snap is likely to affect most of the areas in the state where our respondents are located. Given that the focus of our paper is the relationship between energy and food expenditure, temperature is a control variable and so this level of precision in the estimate of temperature effects is sufficient for our analysis purposes.

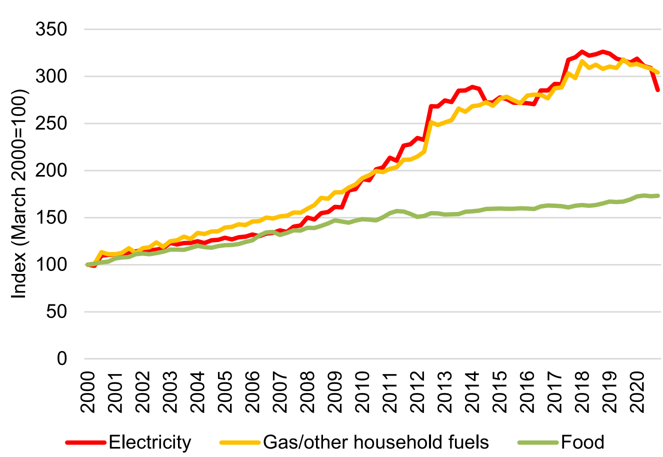

Fig. 1. Key prices of Electricity, Fuel and Food, Australia 2000–2020.
Note: weighted average of eight capital cities.
Source: ABS (2021a).

Given that we are investigating the existence of an energy or food trade-off we adopt a joint estimation framework and apply an SUR model. This allows for joint decision making across energy and food expenditures. Our main SUR model is as follows.

$$\log energy\ exp_{it} = \begin{array}{l} \beta_{e0} + \beta_{e1}\log(pelec/pfood)_{st} + \beta_{e2}hot_{st} + \beta_{e3}cold_{st} + \\ \sum_j \gamma_{ej}X_{jit} + \beta_{e4}beds_{it} + \mu_{es} + \delta_{et} + u_{eit} \end{array} \quad (1)$$

$$\log food\ exp_{it} = \begin{array}{l} \beta_{f0} + \beta_{f1}\log(pelec/pfood)_{st} + \beta_{f2}hot_{st} + \beta_{f3}cold_{st} + \\ \sum_j \gamma_{fj}X_{jit} + \beta_{f4}household\_size_{it} + \mu_{fs} + \delta_{ft} + u_{fit} \end{array} \quad (2)$$

$$E\left(u_{eit}u_{fit}\right) = \sigma_{ef} \quad (3)$$

where log energy exp is annual household expenditure on energy, log food exp is annual expenditure on groceries, log(pelec/pfood) is our measure of the relative price of electricity, hot is a dummy indicating the state had a mean summer maximum temperature more than one standard deviation above the 20-year mean for the state, cold is a dummy indicating the state had a mean winter minimum winter temperature more than one standard deviation below the 20-year mean for the state. X is a set of sociodemographic covariates and variables informed by the existing literature and comprise of: the numbers of financial problems (asked for financial help from friends or family, could not pay the rent or mortgage on time, pawned or sold something, asked for help from welfare/community organisations) (Koomson and Danquah, 2021), age, sex, marital status, disability, labour force status, highest level of education, homeowner, on income support,[10] log household disposable income, Australian born (Churchill and Smyth, 2020), and urban locality (Liu and Judd, 2019). Beds denotes the number of bedrooms in the dwelling and household size indicates number of persons in the household. We control for the number of bedrooms in the energy equation to proxy the size of the home being heated/cooled etc. and we control for the number of persons in the home using the household size variable in the food expenditure equation to control for the number of mouths being fed (Fiegehen and Lansley, 1976). μ is a state dummy, δ is a year (wave) dummy and *u* is the error term. The subscripts i, t, s, e and f denote individual, time (year), state, energy and food, respectively. The SUR estimation strategy allows for the error terms from the two equations to be correlated as per eq. 3.

While expenditure is often modelled as a function of price, we include the relative price of energy and food (log(pelec/pfood)) as this is more relevant for low-income households facing an energy or food dilemma and attempting to budget accordingly (De Hoyos and Medvedev, 2011). Our use of logarithms means the trade-off is measured in percentage change terms. A comparison of Akaike's Information Criteria, Bayesian Information Criteria and a likelihood ratio test showed prices could be combined.[11] Consistent with the existing literature we estimate expenditures rather than budget shares. Moreover, the total income data in HILDA is not perfectly reliable and hence a budget share approach would create noise and may result in incorrect inferences.

Our expenditure data come from HILDA's self-completion questionnaire. Individuals are asked to report on annual expenditure on electricity bills, gas bills and other heating fuel (energy) and average weekly expenditure on groceries (excluding meals eaten out) (food). Household income relates to the financial year, includes all sources of

[9] See http://www.bom.gov.au/climate/data/index.shtml.

[10] Income support is a low-income state benefit payment in Australia intended to provide a minimum standard of living. Eligibility and the rate of payment is determined by age, residency in Australia, level of income and assets.

[11] AIC = 196,735.1 (combined prices) and 196,734.3 (separate prices). BIC = 197,474.7 (combined prices) and 197,491.5 (separate prices). LRT = 4.83 (p = 0.0894).

income (such as wages/salaries, investment income and government allowances/income support payments) and is net of tax.

It is important to consider the possible causes of potential endogeneity in the key explanatory variable, here relative prices. Endogeneity can arise from simultaneity, measurement error and omitted variables. Simultaneity issues are unlikely as prices are known at the time of consumption for food, however energy bills are paid in arears. We therefore test for this using lagged relative prices. Measurement error is unlikely as the price indices are generated by the Government using rigorous methodology. However, we can test the sensitivity to using electricity prices as our measure of energy costs by considering gas prices instead. Finally, omitted variables are possible as it is not feasible in our data to control for the quality of food consumed or the energy efficiency of homes etc. We employ a bounds analysis to measure the sensitivity of our estimates to the presence of omitted variables. Here we extend the psacalc procedure in Stata based on Oster (2019) to the case of a two equation SUR model. The original procedure is based on a single equation model.

The empirical analysis is conducted as follows. We begin by investigating the presence, nature and extent of any trade-off for low-income individuals by estimating our main SUR model. We then examine how the trade-off varies within the low-income group by separately considering individuals in households in poverty (<50% of median income); near poverty (50–60% of median income); and those in the remaining low income (60–75% of median income). This set of results are our primary results of the paper.

We then explore the robustness of our modelling strategy in several ways. As we have longitudinal data, we estimate fixed effects (FE) models for our two dependent variables for comparison with the SUR results. While the FE specification accounts for the longitudinal nature of the data is does not account for the joint decision making as each expenditure equation is estimated separately. Next, there may be differences between subjective experiential measures and objective expenditure measures (Snell et al., 2018), so we also use the subjective measures of being unable to heat the home and going without meals as dependent variables. This allows us to consider hidden poverty as noted in the literature section. As already noted, there may be a timing issue with prices and expenditure whereby individuals plan their expenditure in response to earlier prices that are known rather than potentially unknown coincident prices, so we investigate lagged relative prices. This also allows us to test for endogeneity through simultaneity (as noted above). Our measure of energy expenditure includes gas, so we investigate the extent to which energy expenditure responds to the relative price of gas (to food). This allows us to test for measurement error but may also be thought of as a falsification test as gas is not a significant energy source in Australian homes. Next, we consider the impact of including food eaten outside of the home in our food expenditure variable again testing for potential measurement error. We also undertake an outlier analysis of household size to test for the presence of influential observations in terms of unusually large households. Finally, we provide a bounds analysis to investigate the robustness of our main results to the influence endogeneity through omitted variables (such as the energy efficiency of homes). Unobservables like this should have been captured in the State and Year effects in our models to the extent that they are driven by policy. For example, residential estates in Victoria are currently being built as electricity-only homes as the use of gas for household energy use is being phased out (The State of Victoria Department of Environment, Land, Water and Planning, 2022).

Table 1 below shows the descriptive statistics for our estimation sample of all individuals with (equivalised, disposable) income below 75% of the median in a given wave.

Table 1
Descriptive statistics.

	All low income				In poverty		Near poverty		Remaining low income	
Variable	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Log food expenditure	8.844	0.554	3.951	9.902	8.721	0.588	8.832	0.543	8.962	0.505
Log energy expenditure	6.838	1.011	0.693	9.868	6.699	1.067	6.821	0.989	6.975	0.957
No meals	0.073	0.260	0	1	0.097	0.296	0.068	0.251	0.055	0.228
Unable to heat	0.065	0.247	0	1	0.087	0.282	0.063	0.243	0.047	0.212
Log relative price of electricity to food	0.396	0.262	−0.279	0.731	0.377	0.266	0.409	0.260	0.404	0.260
Log relative price of gas to food	0.384	0.188	−0.003	0.674	0.368	0.190	0.396	0.187	0.390	0.187
Number of other financial problems	0.444	0.893	0	4	0.495	0.938	0.411	0.873	0.422	0.863
Hot temperature shock	0.158	0.365	0	1	0.154	0.361	0.160	0.366	0.160	0.366
Cold temperature shock	0.120	0.325	0	1	0.113	0.317	0.122	0.327	0.125	0.331
Age	51.793	21.961	15	101	53.705	22.345	55.687	21.998	47.273	20.768
Female	0.572	0.495	0	1	0.581	0.493	0.582	0.493	0.556	0.497
Married/de facto	0.524	0.499	0	1	0.442	0.497	0.534	0.499	0.591	0.492
Separated/widowed/ divorced	0.233	0.423	0	1	0.292	0.454	0.250	0.433	0.168	0.374
Single	0.243	0.429	0	1	0.266	0.442	0.216	0.411	0.241	0.428
Disability	0.464	0.499	0	1	0.519	0.500	0.512	0.500	0.381	0.486
Employed	0.304	0.460	0	1	0.206	0.404	0.233	0.423	0.444	0.497
Unemployed	0.061	0.240	0	1	0.078	0.268	0.053	0.223	0.053	0.224
Not in the labour force	0.634	0.482	0	1	0.716	0.451	0.714	0.452	0.503	0.500
Higher education	0.102	0.303	0	1	0.086	0.281	0.096	0.294	0.121	0.326
Further education	0.288	0.453	0	1	0.259	0.438	0.276	0.447	0.323	0.468
High school	0.610	0.488	0	1	0.655	0.475	0.628	0.483	0.556	0.497
Homeowner	0.578	0.494	0	1	0.539	0.498	0.591	0.492	0.603	0.489
On income support	0.152	0.359	0	1	0.196	0.397	0.131	0.338	0.127	0.333
Log income	10.444	0.549	6.908	12.501	10.023	0.513	10.472	0.397	10.801	0.391
Australian	0.767	0.423	0	1	0.758	0.428	0.752	0.432	0.785	0.411
Household size	2.626	1.651	1	17	2.260	1.589	2.526	1.598	3.026	1.656
Number of bedrooms	3.024	1.000	0	20	2.850	1.012	2.980	0.991	3.212	0.964
Urban	0.814	0.389	0	1	0.825	0.380	0.812	0.391	0.806	0.396

Note: Among all low income, $N = 49{,}210$ for no meals, N = 49,188 for unable to heat, N = 49,265 for all other variables. Among those in poverty, $N = 16{,}842$ for no meals, N = 16,825 for unable to heat, N = 16,864 for all other variables. Among those near poverty, $N = 13{,}558$ for no meals, N = 13,558 for unable to heat, N = 13,571 for all other variables. Among remaining low income, $N = 18{,}810$ for no meals, N = 18,805 for unable to heat, N = 18,830 for all other variables.

4. Results

4.1. Is there evidence of an energy or food trade-off?

Table 2 presents the results of our SUR analysis of energy and food expenditures of low-income individuals. We see clear evidence of an energy or food trade-off. A 1% increase in the relative price of electricity increases energy expenditure by 0.44% and reduces food expenditure by 0.09% and these effects are statistically significant. Very low price elasticities are consistent with the status of these goods as necessities in the household budget. Interestingly, the effect on energy expenditure is less than the rise in relative prices and this indicates there is some cutback in energy use in inflationary times. It is important to note that it is not possible to tell from our data whether the reduced food expenditure is due to reductions in quality (e.g., brand substitution) or quantity. In monetary terms, at sample means these results imply for a 10% increase in relative prices there would be an average $AU60.38 increase in low-income annual household energy expenditure and an $AU69.95 reduction in annual household food expenditure. This suggests that individuals overcompensate in terms of the reduction in food expenditure. This maybe a result of the disconnect between the timing of food expenditure (typically weekly) and energy expenditures (typically quarterly). Even where individuals attempt to smooth energy expenditure through advance monthly payments there is still likely to be additional adjustment payments during times of extreme weather (hot or cold) or rapid energy price inflation. As we are looking at those in the lowest part of the income distribution the consequences of under budgeting are likely to be more severe than overbudgeting and this may be what motivates the overcompensation. Unfortunately, our data do not allow for us to directly test these potential behavioural explanations.

Table 2
Expenditure measures for low-income individuals, SUR.

VARIABLES	log_energy_exp	log_food_exp
log relative price of electricity to food	0.4416***	−0.0881**
	(0.0806)	(0.0393)
hot temperature shock	0.0445**	0.0046
	(0.0174)	(0.0085)
cold temperature shock	0.0123	0.0005
	(0.0179)	(0.0088)
Number of other financial problems	0.0034	−0.0051**
	(0.0053)	(0.0026)
Age	0.0007	0.0010*
	(0.0012)	(0.0006)
age squared	−0.0000***	−0.0000***
	(0.0000)	(0.0000)
Female	0.0295***	0.0347***
	(0.0090)	(0.0044)
separated/widowed/divorced	−0.0760***	−0.1763***
	(0.0119)	(0.0058)
Single	−0.1152***	−0.0998***
	(0.0136)	(0.0067)
Disability	0.0392***	0.0015
	(0.0095)	(0.0046)
Unemployed	−0.0761***	−0.0273***
	(0.0197)	(0.0096)
not in the labour force	−0.0833***	−0.0113**
	(0.0112)	(0.0055)
Higher education	0.0907***	0.0244***
	(0.0149)	(0.0073)
Further education	0.0458***	0.0214***
	(0.0101)	(0.0049)
Homeowner	0.2711***	0.1273***
	(0.0103)	(0.0049)
on income support	−0.1153***	−0.0581***
	(0.0130)	(0.0064)
log income	0.2299***	0.2111***
	(0.0102)	(0.0066)
Australian	0.0225**	−0.0256***
	(0.0105)	(0.0051)
number of bedrooms	0.1056***	
	(0.0048)	
Urban	−0.0295***	−0.0399***
	(0.0112)	(0.0055)
household size		0.0859***
		(0.0022)
Constant	3.9275***	6.6576***
	(0.1307)	(0.0744)
States	Yes	Yes
Waves	Yes	Yes
R-squared	0.1257	0.3084

Note: SE in parentheses. Rho: 0.1584***. N = 49,265. Base categories are: Married, employed, school education. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

In terms of temperature shocks we find that although cold shocks (when the average minimum winter temperature (June to August in Australia) is more than 1SD below the 20-year average) have no significant impact, heat shocks (when the average maximum summer temperature (December to February in the current year in Australia) is more than 1SD above the 20-year average) do significantly increase energy expenditure. This reinforces the importance of considering the need for cooling (as well as heating) in studies of energy consumption in Australia. We acknowledge that our temperature measure is perhaps a little blunt given the limited locational information in our data. It is also important to note that energy expenditure is annual and so we look at seasonal variation in temperatures for the 12 months prior to the individual's month of interview. We cannot track energy usage in response to temperature fluctuations across short periods of time with these data. Nevertheless, there is variation across time and State in terms of the number of individuals in our data who experience hot and cold shocks. The fact that we only find significance for hot shocks in our results may be a result of several factors i) the sensitivity of the analysis given that the window of observation is annual, ii) Australia being warm climate country so cold shocks are still relatively mild in terms of the actual temperature compared the much of the literature based in the US and the UK, so the demand for energy may not be as acute. Unfortunately, we have no way of identifying between any of these competing hypotheses with our data.

We include a measure of the number of other financial problems outside the energy or food problem (not paying a mortgage or rent, pawning something, asking for financial help from friends/family or asking for help from welfare/community organisations). We find lower food expenditure associated with greater financial problems, consistent with being able to substitute to lower quality foods in hard times (or perhaps take advantage of food banks). However, there appears to be no significant scope to reduce energy expenditure.

Females are spending more on energy and food, perhaps making savings elsewhere in the household budget during precarious times. Compared to married or cohabiting people, separated, widowed, divorced and single people spend less on energy and food as we would expect. Disability affects energy expenditure but not food expenditure, consistent with having higher energy requirements associated with medical conditions (heating, use of therapeutic appliances and perhaps lighting associated with spending more time at home). Being employed increases both energy and food expenditure (negative coefficients on unemployed and NILF). Increasing levels of education are associated with higher expenditure on both goods. Being a homeowner is associated with increased expenditure for both food and energy. Those on income support spend less on both food and energy. As we would expect, higher incomes are associated with higher expenditures. Australian-born individuals spend less on food and more on energy than overseas-born counterparts. Individuals living in urban areas spend less on both food and energy than those in rural/remote areas. Larger household size increases total food expenditure. Larger houses with more bedrooms increase heating requirements and therefore expenditure.

Given that we have chosen to consider low-income individuals it is important to investigate the trade-off within this low-income group. In Table 3 we explore the effects of price changes on expenditure for different segments of low income: in poverty (<50% of median income);

Table 3
Expenditure measures for low-income groups, SUR.

	In poverty		Near poverty		Remaining low income	
VARIABLES	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp
log relative price of electricity to food	0.3726**	0.0529	0.1652	−0.1966***	0.7151***	−0.1298**
	(0.1504)	(0.0737)	(0.1505)	(0.0743)	(0.1217)	(0.0577)
hot temperature shock	0.0725**	0.0150	0.0445	−0.0047	0.0135	0.0094
	(0.0320)	(0.0157)	(0.0324)	(0.0160)	(0.0267)	(0.0127)
cold temperature shock	0.0366	−0.0079	0.0125	−0.0044	−0.0074	0.0146
	(0.0331)	(0.0162)	(0.0334)	(0.0165)	(0.0273)	(0.0130)
Number of other financial problems	−0.0048	−0.0070	0.0168	0.0043	0.0016	−0.0065*
	(0.0091)	(0.0045)	(0.0103)	(0.0051)	(0.0082)	(0.0039)
Age	0.0032	−0.0001	−0.0011	0.0019	0.0034*	0.0040***
	(0.0022)	(0.0011)	(0.0024)	(0.0012)	(0.0020)	(0.0009)
age squared	−0.0000**	−0.0000	−0.0000	−0.0000***	−0.0001***	−0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Female	0.0275*	0.0456***	0.0422**	0.0356***	0.0224	0.0264***
	(0.0163)	(0.0080)	(0.0171)	(0.0084)	(0.0136)	(0.0065)
separated/widowed/ divorced	−0.0956***	−0.2100***	−0.0467**	−0.1100***	−0.0464**	−0.1189***
	(0.0208)	(0.0102)	(0.0228)	(0.0118)	(0.0200)	(0.0096)
Single	−0.1129***	−0.1492***	−0.0986***	−0.0716***	−0.0886***	−0.0638***
	(0.0247)	(0.0122)	(0.0275)	(0.0136)	(0.0206)	(0.0098)
Disability	0.0426**	0.0004	0.0556***	−0.0082	0.0231	−0.0033
	(0.0171)	(0.0084)	(0.0177)	(0.0088)	(0.0148)	(0.0071)
Unemployed	−0.1045***	−0.0558***	−0.0953**	−0.0675***	−0.0750**	−0.0144
	(0.0339)	(0.0166)	(0.0403)	(0.0199)	(0.0310)	(0.0147)
not in the labour force	−0.1408***	−0.0534***	−0.0967***	−0.0141	−0.0430***	0.0020
	(0.0222)	(0.0109)	(0.0229)	(0.0113)	(0.0161)	(0.0076)
Higher education	0.1128***	0.0425***	0.1122***	0.0461***	0.0746***	0.0211**
	(0.0289)	(0.0141)	(0.0289)	(0.0143)	(0.0216)	(0.0103)
Further education	0.0620***	0.0277***	0.0478**	0.0270***	0.0372**	0.0252***
	(0.0188)	(0.0092)	(0.0192)	(0.0095)	(0.0151)	(0.0072)
Homeowner	0.2914***	0.1203***	0.2373***	0.1057***	0.2622***	0.1250***
	(0.0190)	(0.0089)	(0.0198)	(0.0094)	(0.0156)	(0.0073)
on income support	−0.1048***	−0.0699***	−0.1287***	−0.0589***	−0.1094***	−0.0708***
	(0.0220)	(0.0108)	(0.0260)	(0.0128)	(0.0209)	(0.0099)
log income	0.1993***	0.2440***	0.3251***	0.5510***	0.3715***	0.6016***
	(0.0185)	(0.0124)	(0.0317)	(0.0371)	(0.0246)	(0.0254)
Australian	−0.0082	−0.0450***	0.0400**	−0.0233**	0.0486***	0.0028
	(0.0189)	(0.0092)	(0.0195)	(0.0096)	(0.0165)	(0.0078)
number of bedrooms	0.1229***		0.0834***		0.0894***	
	(0.0086)		(0.0094)		(0.0078)	
Urban	−0.0507**	−0.0471***	−0.0465**	−0.0338***	0.0073	−0.0375***
	(0.0211)	(0.0103)	(0.0212)	(0.0104)	(0.0168)	(0.0080)
household size		0.0884***		0.0202**		0.0055
		(0.0041)		(0.0082)		(0.0054)
Constant	4.2155***	6.3361***	3.1036***	3.2580***	2.1778***	2.4867***
	(0.2327)	(0.1353)	(0.3763)	(0.3858)	(0.2915)	(0.2711)
States	yes	Yes	yes	yes	yes	yes
Waves	yes	Yes	yes	yes	yes	yes
R-squared	0.1186	0.3031	0.1031	0.2740	0.1280	0.2962
Rho	0.1598***		0.1572***		0.1600***	
N	16,864	16,864	13,571	13,571	18,830	18,830

Note: In poverty = income <50% of median; Near poverty = income between 50 and 60% of median; Remaining low income = income between 60 and 75% of median. SE in parentheses. Base categories are: Married, employed, school education. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

near poverty (50–60% of median income); and the remaining low income (60–75% of median income).

We see the trade-off observed earlier is driven by individuals with incomes between 60 and 75% of the median income (the remaining low-income). However, for individuals in poverty an increase in the relative price of electricity increases energy expenditure but has no significant effect on food expenditure. This is consistent with the poorest individuals having economised as far as possible on food and being unable to save any more. For those near poverty we see a significant impact coming through in terms of decreases in food expenditure. This indicates individuals are reducing expenditure on food perhaps in anticipation of large energy bills. For those in poverty we observe significant increases in energy expenditure but no significant reduction in food expenditure. This suggests these individuals have economised as far as possible on food and no further reduction is possible. For those near poverty there is a significant reduction in food expenditure but no significant increase in energy expenditure. With prices rising, this suggests these individuals are economising to some extent on energy use as well as on food, as the increase in energy prices would automatically result in an increase in expenditure if energy use remained unchanged.

Fig. 2 illustrates the energy or food trade-off given the estimated coefficients in Table 3. The first bar chart considers the annualised estimated changes in energy and food expenditures that would be predicted for a 10% increase in the relative price of electricity. Negative values imply a reduction of consumption and positive values represent an increase in expenditure. For individuals identified as in poverty, there is no trade-off. Although electricity expenditure increases significantly, food expenditure does not decline. This suggests individuals in poverty cannot economise any further on food. For those near poverty, we see no significant increase in energy expenditures, indicating economising behaviour (or perhaps energy debt) but a significant reduction in food expenditure. Overcompensation over a year by this group is also very evident. Among individuals in the remaining low-income group, we see there is a significant trade-off but no overcompensation, suggesting

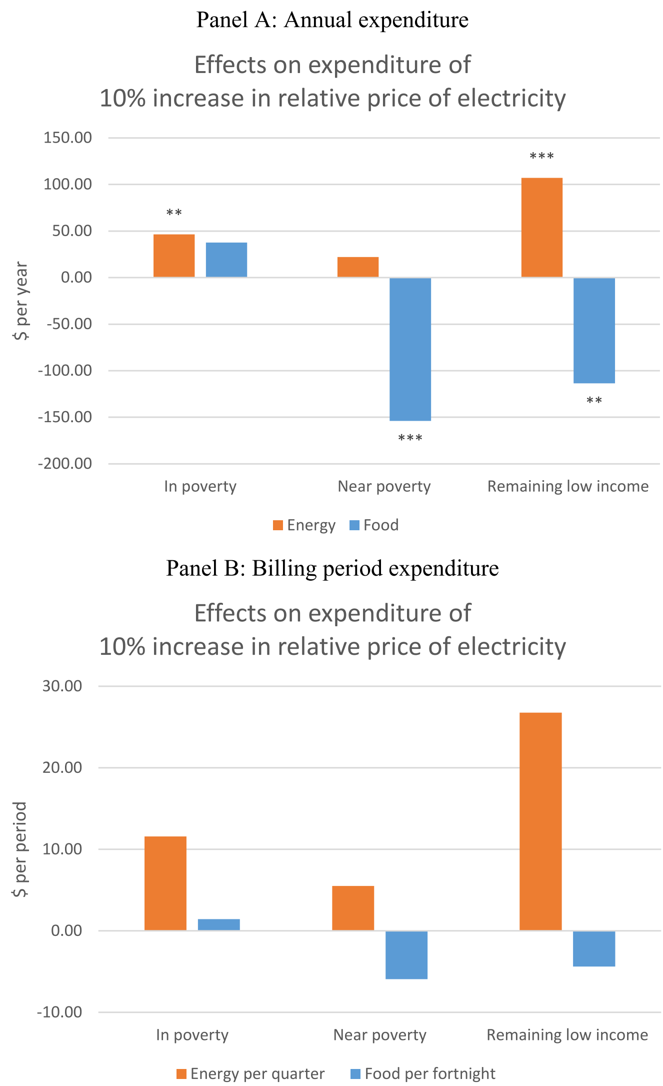

Fig. 2. The energy or food trade-off from the SUR analysis illustrated.
Note: In panel A, annual expenditures are based on coefficients for which * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$. Significance cannot be derived for panel B since the billing periods are different.

these individuals may have better budgeting skills/capacity than the other groups.

The second bar chart shows expenditures per 'period' where we examine 'bill shock' in terms of expenditure outlays and savings from a fortnightly pay cycle when a quarterly energy bill arrives (when savings on food are made in advance of consumption over the fortnight and can be adjusted but the energy bill arrives in arrears for a quarter and is less negotiable). The chart shows that when the relative price of electricity rises by 10%, individuals in poverty must find an extra $11.60 without any counterbalancing savings from food. For those near poverty, they manage to economise from the fortnightly food budget in order to pay their quarterly energy bills. For those in the remaining low-income group, when the bill arrives, they manage to save less than $5 on fortnightly food but must find $27 for the quarterly energy bill. From the previous chart we see that these additional funds come from earlier economising behaviour.

4.2. Robustness analysis

We begin by testing the robustness of the SUR analysis to the estimation strategy.[12] A FE specification is more typically used in the case of panel data. A FE approach should allow us to control for the panel nature of our data more accurately but does not allow for joint estimation of energy and food expenditure which is our principal hypothesis. While the data spans some 17 years of HILDA, individuals only appear in our sample when they fall into low-income. Approximately half of the sample, 48%, only experience low-income once and another 20% experience it twice (and there are only a small percentage who experience persistent low-income). See Fig. 3 below for the distribution of the number of waves observed for each estimation sample. For those who experience repeated low-income, the period between these low-income episodes also differs across individuals and so our data is very different in its' time series characteristics than typical longitudinal datasets.

That said, the energy or food trade-off results for the full low-income sample estimated as a SUR model (Table 2) and as FE (columns 1 and 2 of Table 4) are highly consistent. We do note, however, that there are some differences when we look at the disaggregated low-income groups results. While there is variation in terms of statistical significance across the groups, where we do find statistical significance (in either specification) the signs on these coefficients are consistent. Looking at the R-squared results across Tables 2, 3, and 4 we see a consistent pattern of improved goodness of fit of the model, in the case of the SUR specification versus the FE specifications. This is, in part, due to the high significance of the correlation coefficient (Rho) in the SUR models that captures the importance of the joint estimation approach. Given the average number of waves is short, it is important to consider a FE versus a random effects (RE) specification. The FE may not be as precisely estimated given limited waves available per individual (due to moving in/out of low-income samples and, to a lesser extent, attrition). We use a Hausman test to look for evidence of model misspecification in comparing RE and FE for each of the expenditure equations and reject RE in favour of FE ($p < 0.002$). To summarise, these results suggest that the SUR models are preferred to the FE models and, due to the atypical characteristics of the data, standard FE models do not provide a good fit. The high significance of Rho in the SUR models suggests that our joint decision-making hypothesis is correct. Given the focus of the paper is on the trade-off in the energy and food decision making processes, we have a clear theoretical and empirical justification for the SUR specification.

We next check the robustness of the objective analysis by utilising subjective measures of energy poverty and food insecurity that identify more closely with lived experience than expenditure measures that can mask adaptive behaviour. Our two subjective measures are *being unable to heat the home* and *going without meals*. While the first measure is not ideal as it does not identify foregoing air conditioning in summer, it does capture the heat or eat trade-off. Table 5 shows findings that are consistent with the existent literature, and with the SUR results, that an energy or food trade-off exists in the case of the full low-income sample. We find that as the energy/food relative price increases i.e., energy becomes more expensive, individuals are more likely to struggle to pay their bills and to skip meals. This is consistent with an energy or food trade-off found using the objective measures. There is less consistency for the disaggregate income groups analysis.

For individuals identified as in poverty, an increase in the relative price of electricity to food has a significant impact on the probability of going without meals. This is consistent with the expenditure results in which individuals in poverty spend more on energy under this scenario Table 3, column 1). Among those near poverty, there is no apparent trade-off based on the subjective measures, even though food expenditure declines (Table 3, column 4). This suggests individuals in this group

[12] For brevity, in the section we only report results for the key coefficient on relative prices.

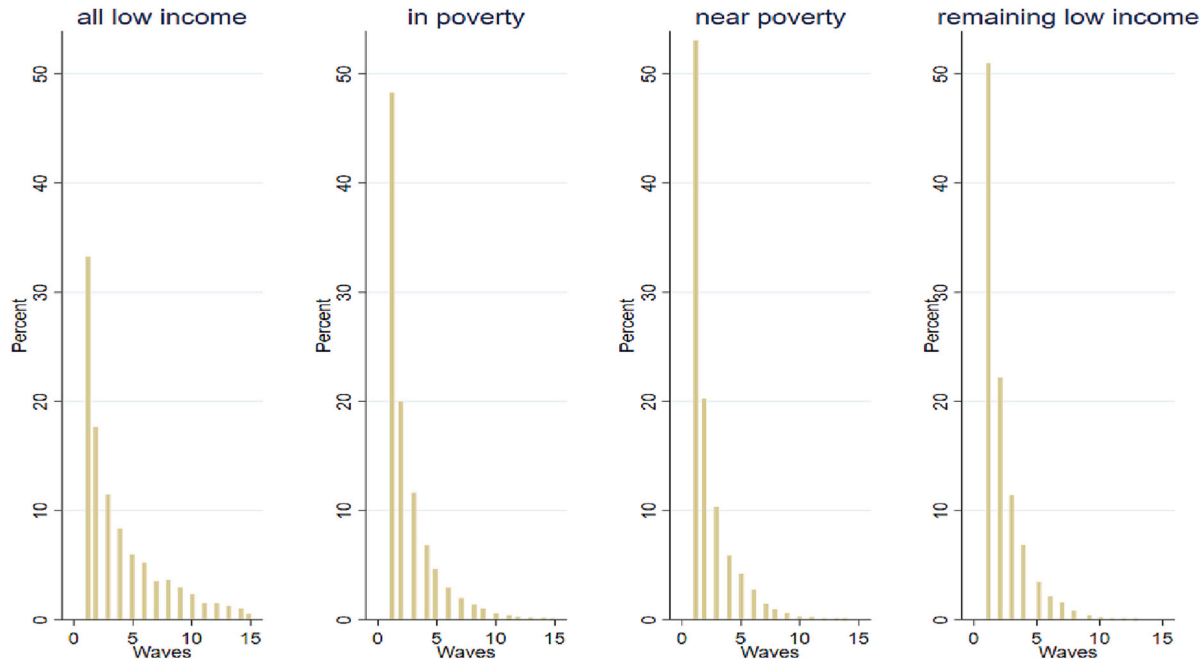

Fig. 3. Distribution of number of waves for each analysis sample.

Table 4
Expenditure measures, FE.

	All low income		In poverty		Near poverty		Remaining low income	
VARIABLES	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp
log relative price of electricity to food	0.3609***	−0.1058***	0.1400	−0.0366	0.3240*	−0.0371	0.6804***	−0.2067***
	(0.0815)	(0.0369)	(0.1766)	(0.0820)	(0.1694)	(0.0785)	(0.1432)	(0.0625)
Controls	yes	yes	yes	yes	yes	yes	yes	yes
Constant	yes	yes	yes	yes	yes	yes	yes	yes
States	yes	yes	yes	yes	yes	yes	yes	yes
Waves	yes	yes	yes	yes	yes	yes	yes	yes
R-squared	0.0295	0.1156	0.0209	0.0901	0.0325	0.0926	0.0501	0.1269
N	49,265	49,265	16,864	16,864	13,571	13,571	18,830	18,830

Note: In poverty = income <50% of median; Near poverty = income between 50 and 60% of median; Remaining low income = income between 60 and 75% of median. Robust SE in parentheses. Base categories are: Married, employed, school education. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

Table 5
Subjective measures, SUR.

	All low income		In poverty		Near poverty		Remaining low income	
VARIABLES	Unable to heat	No Meal	Unable to heat	No Meal	Unable to heat	No Meal	Unable to heat	No Meal
log relative price of electricity to food	0.0278*	0.0361**	0.0336	0.0598**	0.0308	0.0017	0.0161	0.0326
	(0.0146)	(0.0147)	(0.0281)	(0.0281)	(0.0273)	(0.0270)	(0.0207)	(0.0212)
Controls	yes	yes	yes	yes	yes	yes	yes	yes
Constant	yes	yes	yes	yes	yes	yes	yes	yes
States	yes	yes	yes	yes	yes	yes	yes	yes
Waves	yes	yes	yes	yes	yes	yes	yes	yes
R-squared	0.1385	0.2510	0.1625	0.2832	0.1327	0.2380	0.1117	0.2165
Rho	0.2948***		0.3068***		0.2825***		0.2745***	
N	61,946	61,946	21,915	21,915	16,867	16,867	23,164	23,164

Note: In poverty = income <50% of median; Near poverty = income between 50 and 60% of median; Remaining low income = income between 60 and 75% of median. SE in parentheses. Base categories are: Married, employed, school education. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

are using adaptive behaviours to avoid going without meals, such as use of food banks or substituting less expensive brands. The remaining low-income individuals also show no significant trade-off on subjective measures although they had a significant trade-off in expenditures. This analysis shows that despite expenditure responses to increasing prices, low-income individuals for the most part do not perceive themselves to be suffering energy poverty or food insecurity any more than usual. It suggests that they are making budgetary decisions that avoid being unable to heat or eat at the extreme, but this does not mean they are not experiencing financial hardship or welfare effects.

We also need to consider the timing of the price effects on expenditure and so consider lagged price effects. Because energy is paid for post consumption, individuals may not respond to current relative prices if they only become known 'when the bill arrives'. It is possible that they respond to past prices and may or may not anticipate continued inflation. We therefore examine the effects of relative prices in the previous year on expenditures in the current year. This also has the advantage that lagged prices are predetermined and not subject to endogeneity through simultaneity arguments. Table 6 shows most of the coefficients are very close to those of Table 3. This shows that the results in Table 3 are not being driven by a simultaneity bias.

To further understand the role of energy prices we also investigate the choice of electricity prices in our relative price measure. Energy expenditure may relate to gas as well as electricity. Homes may have gas heating and/or cooling, so gas prices may affect the energy or food trade-off. In Table 7 we investigate the effects of the relative price of gas to food and find no highly significant effects on energy expenditure or food expenditure. This is likely because Australian household gas bills are typically much smaller than electricity bills. Indeed, survey estimates for New South Wales, Victoria, Queensland, South Australia and Western Australia put the average electricity bill at $355 per quarter and gas bill at $234 per quarter (Canstar, 2021) and about one-third of Australian homes have no gas connection (especially in rural areas) (Energy Networks Australia, 2021). Given the low usage of gas as a form of household energy in Australia, this specification acts like a falsification test. We would expect to find little or no trade-off of gas against food and this is exactly what we find in Table 7. It also shows that these results are not being impacted by measurement error in the use of electricity prices to capture energy costs.

Next, we investigate the inclusion of meals eaten outside of the home in our measure of food expenditure. Meals eaten out are usually seen as discretionary expenditure. As the focus of the paper is the substitution between expenditure on necessities, meals out were excluded from the analysis (but we note that they are included in the food price index). However, expenditure on meals outside of the home for those in the low-income group tends to be a small component of total food expenditure. HILDA does contain information on meals eaten out and so we have re-estimated the SUR models for the four estimation samples including expenditure for meals eaten out. It is possible to hypothesise that individuals might opt to eat out as an energy saving option. The results in Table 8 show consistent findings but as it is not typical in the heat or eat literature to include them, for the reasons noted, we excluded them from the main SUR analysis in Tables 3 and 4.

Also, it is worth noting that we define the income partitions in sample using equivalised income however in the regression analysis we choose to control for household size using the number of bedrooms in the energy expenditure equation and the number of people in the household in the food expenditure equation. This is preferable to equivalising as we then have an estimate of how these important control variables impact expenditure. However, looking at Table 1 we can see there is the possibility of outliers and so we conduct an outlier analysis and re-estimate the main SUR models (Table 2 and Table 3) excluding 171 observations who reported >8 bedrooms and/or >10 people in the home. The results for the main variable of interest are presented in Table 9 below. We can see that the findings are unchanged. As low-income individuals often live in larger households, and we have no reason to doubt individuals' ability to accurately report these measures, we choose to retain the full sample in the main analysis above.

Finally, we note that there may be concerns about omitted variable bias (particularly in the context of factors like energy efficiency, therapeutic diets and financial self-efficacy). To investigate the veracity of our findings, we conduct a bounds analysis of the significant price coefficients.[13] The results are presented in Table 10. The first stage compares the baseline and controlled effects of relative prices on expenditure. Among all low-income individuals (panel A) for energy expenditure the confidence intervals for the baseline and controlled effects are overlapping at 5%, indicating no significant difference. This indicates coefficient stability and suggests omitted variables are of limited importance (Altonji et al., 2005). The second stage of the bounds analysis considers R^2 in the models with and without covariates. This is done to ensure coefficient stability is not due to uninformative covariates (Oster, 2019). The much higher R^2 with controls compared to baseline indicates the control variables are informative and not a cause of coefficient stability, lending support to our proposition about the limited importance of omitted variables. We then examine the bounds on the relative price coefficient. The bounds represent the range containing the true estimate of the coefficient on relative price. As these bounds exclude zero, we can conclude we have a significant causal effect on energy expenditure (Burlinson et al., 2021). Given R^2_{MAX}, we then estimate the δ that would be required for the causal effect to be zero. The absolute value of delta is less than one and suggests there remain important omitted variables affecting energy expenditure that we have not captured such as rates of time preference, financial self-efficacy or energy efficiency. However, the effects we capture are still important and robust and not biased by omitted variables, given the bounds on the estimates exclude zero. For food expenditure, the confidence intervals do not overlap indicating omitted variables are potentially important. This is confirmed by the very low value of δ. However, the bounds still exclude zero and this indicates we have still measured a significant causal effect and that there is a trade-off towards energy as prices rise.

For individuals in poverty (panel B), we see 95% CIs for baseline and controlled effects overlap and R^2 is higher with controls indicating limited effects of omitted variables in the energy equation. This confirms our earlier result that as relative prices rise, energy expenditure also rises for these individuals but food expenditure does not decline significantly, consistent with having no capacity to further economise on food. Among individuals who are near poverty (panel C), our main results indicated a significant reduction in food expenditure in response to price increases but no significant effect on energy expenditure. There is no overlap in CIs for food, indicating there are potentially important omitted variables in this equation. Although δ is low, the bounds for energy and food exclude zero, indicating our estimate is not biased by omitted variables. This confirms our finding that these individuals reduce food expenditure and, as energy expenditure does not rise significantly when prices rise, they must also be economising to some extent on energy. For the remaining low-income individuals (panel D), the 95% CIs for each of food and energy do not overlap. δ remains low but in each case the bounds exclude zero, suggesting we have identified the causal effect and that there is a significant trade-off in favour of energy.

5. Conclusion

The empirical literature on the energy or food trade-off suggests that this phenomenon is concentrated in population subgroups associated with low-income. In this paper we offer a methodological contribution by employing a joint decision-making framework and a statistical expansion of the parameter sensitivity analysis through the extension of bounds analysis to the context of a two equation model. We deep dive into the Australian low-income population to understand if the trade-off is homogeneously experienced across all low-income households. We find that this is not the case and that there are differential experiences and responses to the challenges of heating/cooling homes and the provision of food at different points within the low-income population subgroup.

Specifically, for those living in low-income, we find a 1% increase in the relative price of electricity increases energy expenditure by 0.44% and lowers food consumption by 0.09%. This is evidence of an energy or food trade off but interestingly a more detailed story arises if we

[13] For completeness, we also report bounds for the insignificant price coefficients.

Table 6
Lagged prices.

	All low income		In poverty		Near poverty		Remaining low income	
VARIABLES	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp
log relative price of electricity to food	0.5415***	−0.1070***	0.6445***	−0.0161	0.1631	−0.1995***	0.7343***	−0.1175**
	(0.0790)	(0.0385)	(0.1444)	(0.0707)	(0.1491)	(0.0736)	(0.1203)	(0.0571)
Controls	yes	yes	yes	yes	yes	yes	yes	yes
Constant	yes	yes	yes	yes	yes	yes	yes	yes
States	yes	yes	yes	yes	yes	yes	yes	yes
Waves	yes	yes	yes	yes	yes	yes	yes	yes
R-squared	0.1260	0.3084	0.1193	0.3031	0.1031	0.2740	0.1281	0.2962
Rho	0.1586***		0.1600***		0.1572***		0.1600***	
N	49,265	49,265	16,864	16,864	13,571	13,571	18,830	18,830

Note: In poverty = income <50% of median; Near poverty = income between 50 and 60% of median; Remaining low income = income between 60 and 75% of median. SE in parentheses. Base categories are: Married, employed, school education. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

Table 7
Gas prices.

	All low income		In poverty		Near poverty		Remaining low income	
VARIABLES	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp
log relative price of gas to food	0.0290	−0.0405	0.0275	0.0070	−0.0461	−0.0349	0.1100	−0.0967*
	(0.0778)	(0.0379)	(0.1435)	(0.0703)	(0.1441)	(0.0711)	(0.1194)	(0.0566)
Controls	yes	yes	yes	yes	yes	Yes	yes	yes
Constant	yes	yes	yes	yes	yes	Yes	yes	yes
States	yes	yes	yes	yes	yes	Yes	yes	yes
Waves	yes	yes	yes	yes	yes	Yes	yes	yes
R-squared	0.1252	0.3084	0.1183	0.3031	0.1030	0.2737	0.1264	0.2961
Rho	0.1582***		0.1599***		0.1569***		0.1592***	
N	49,265	49,265	16,864	16,864	13,571	13,571	18,830	18,830

Note: In poverty = income <50% of median; Near poverty = income between 50 and 60% of median; Remaining low income = income between 60 and 75% of median. SE in parentheses. Base categories are: Married, employed, school education. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

Table 8
Main SUR results when meals eaten out is included in food expenditure.

	All low income		In poverty		Near poverty		Remaining low income	
VARIABLES	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp
log relative price of electricity to food	0.4448***	−0.1076***	0.3728**	0.0191	0.1546	−0.2403***	0.7335***	−0.1148**
	(0.0805)	(0.0395)	(0.1501)	(0.0745)	(0.1505)	(0.0737)	(0.1215)	(0.0582)
Controls	yes	yes	yes	yes	yes	Yes	yes	yes
Constant	yes	yes	yes	yes	yes	Yes	yes	yes
States	yes	yes	yes	yes	yes	Yes	yes	yes
Waves	yes	yes	yes	yes	yes	Yes	yes	yes
R-squared	0.1254	0.3106	0.1179	0.2980	0.1025	0.2825	0.1282	0.2850
Rho	0.1530***		0.1554***		0.1563***		0.1482***	
N	49,442	49,442	16,935	16,935	13,610	13,610	18,897	18,897

Note: In poverty = income <50% of median; Near poverty = income between 50 and 60% of median; Remaining low income = income between 60 and 75% of median. SE in parentheses. All other variables included in the models as in Tables 2 and 3. Base categories are: Married, employed, school education. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

disaggregate the low-income subpopulation into poverty defined groups. For individuals living in poverty, we find a 1% increase in the relative price of electricity increases energy expenditure by 0.37% but has no significant effect on food expenditure. This is consistent with the poorest individuals having economised as far as possible and being unable to reduce food expenditure any further. This is clearly a concern. For those individuals near poverty, the same increase in price reduces food expenditure by 0.20% although in this case there is no significant effect on energy expenditure, indicating individuals are also economising on energy usage to offset- the price increase. For the remaining low-income individuals, the price increase results in a trade-off in which energy is prioritised over food.

To date the studies that look at the energy or food trade-off by socio-demographic subpopulations have missed these important aspects of the role of the income distribution. Low-income individuals face strict expenditure constraints and the responses to rising energy and/or food prices are not the same across this group. This knowledge is critically important to allowing precisely targeted policy interventions including tax rates and welfare payments. For example, food and energy goods and service taxes can be adjusted to ease affordability issues of these essential goods during times of high inflation or welfare payments might be more heavily supplemented at times of extreme heat or cold. While extreme weather payments are common in many countries including Australia, they are often not guaranteed and paid in arrears and for low-income individuals this is problematic. Another potential solution to the energy or food trade-off would be to increase income through welfare

Table 9
Main SUR results when the outliers are excluded.

	All low income		In poverty		Near poverty		Remaining low income	
VARIABLES	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp	log_energy_exp	log_food _exp
log relative price of electricity to food	0.4582***	−0.0738*	0.4001***	0.0665	0.1694	−0.2001***	0.7326***	−0.1085*
	(0.0806)	(0.0393)	(0.1506)	(0.0738)	(0.1505)	(0.0743)	(0.1218)	(0.0578)
Controls	yes	yes	yes	yes	yes	Yes	yes	yes
Constant	yes	yes	yes	yes	yes	Yes	yes	yes
States	yes	yes	yes	yes	yes	Yes	yes	yes
Waves	yes	yes	yes	yes	yes	Yes	yes	yes
R-squared	0.1264	0.3094	0.1197	0.3033	0.1039	0.2729	0.1283	0.2974
Rho	0.1563***		0.1551***		0.1578***		0.1588***	
N	49,094	49,094	16,808	16,808	13,530	13,530	18,756	18,756

Note: In poverty = income <50% of median; Near poverty = income between 50 and 60% of median; Remaining low income = income between 60 and 75% of median. SE in parentheses. All other variables included in the models as in Tables 2 and 3. Base categories are: Married, employed, school education. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

Table 10
Bounds analysis.

Treatment variable	Baseline effect $\dot{\beta}$ (SE) $[\dot{R}]$	Controlled effect $\hat{\beta}$ (SE) $[\hat{R}]$	Bounds $[\hat{\beta}, \beta^*(Min\{1, 1.3\hat{R}^2\}, \delta = 1)]$	Exclude zero?	$|\delta|$ for $\beta = 0$ given R^2_{MAX}
Panel A: all low income					
Log energy expenditure					
log relative price of electricity to food	0.4970*** (0.0172) [0.0166]	0.4416*** (0.0806) [0.1257]	[0.4224,0.4416]	Yes	0.1224
Observations	49,265				
Log food expenditure					
log relative price of electricity to food	0.1748*** (0.0095) [0.0068]	−0.0881** (0.0393) [0.3084]	[−0.1688,-0.0881]	Yes	0.0668
Observations	49,265				
Panel B: In poverty					
Log energy expenditure					
log relative price of electricity to food	0.4744*** (0.0307) [0.0140]	0.3726** (0.1504) [0.1186]	[0.3380,0.3726]	Yes	0.0993
Observations	16,864				
Log food expenditure					
log relative price of electricity to food	0.2270*** (0.0169) [0.0105]	0.0529 (0.0737) [0.3031]	[−0.0012,0.0529]	No	0.0292
Observations	16,864				
Panel C: Near poverty					
Log energy expenditure					
log relative price of electricity to food	0.4526*** (0.0324) [0.0141]	0.1652 (0.1505) [0.1031]	[0.0653,0.1652]	Yes	0.0521
Observations	13,571				
Log food expenditure					
log relative price of electricity to food	0.1081*** (0.0179) [0.0027]	−0.1966*** (0.0743) [0.2740]	[−0.2889,-0.1966]	Yes	0.2366
Observations	13,571				
Panel D: Remaining low income					
Log energy expenditure					
log relative price of electricity to food	0.5048*** (0.0265) [0.0189]	0.7151*** (0.1217) [0.1280]	[0.7151,0.7890]	Yes	0.2011
Observations	18,830				
Log food expenditure					
log relative price of electricity to food	0.1319*** (0.0141) [0.0046]	−0.1298** (0.0577) [0.2962]	[−0.2095,-0.1298]	Yes	0.1326
Observations	18,830				

Note: In poverty = income <50% of median; Near poverty = income between 50 and 60% of median; Remaining low income = income between 60 and 75% of median. Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

payments and, additionally in the case of energy, affordability through price regulation. However, all of these measures tend to be short term and they do not address the causes of energy and food unaffordability. In Australia, welfare payments remain associated with food insecurity (Temple et al., 2019). By targeting energy efficiency upgrades or redirecting environmental levies for low-income households that increase the cost of non-renewable energy on which they rely, long-term energy poverty may be alleviated, freeing up income to be allocated towards food. While energy and food are substitute products, low-income individuals remain at risk of resultant poor health outcomes, adding significantly to income gradients in health and hence health inequality.

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CRediT authorship contribution statement

Jane M. Fry: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Software, Writing - original draft, Writing - review & editing. **Lisa Farrell:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Jeromey B. Temple:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2023.106731.

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