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Home Heating and Asthma in New Zealand

Rachel Susan Webb and Andrea Kutinova Menclova

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Department of Economics and Finance
School of Business and Economics
University of Canterbury
Private Bag 4800, Christchurch
New Zealand

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Rachel Susan Webb[1] and Andrea Kutinova Menclova[1,*]

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Abstract: New Zealand has one of the highest asthma prevalence rates among developed countries and previous research attributes this partly to poor socioeconomic conditions in certain neighborhoods and to insufficient home heating in particular. International retrospective empirical studies suggest that home heating is associated with asthma rates. However, strong evidence of causality is lacking. In this paper, we empirically investigate the link between home heating and hospital asthma admissions in New Zealand using panel data techniques and controlling for endogeneity. The hypothesis that higher electricity prices (via less adequate heating) increase hospital asthma admissions is tested and receives strong empirical support across a number of model specifications and datasets used.

Keywords: asthma, home heating, electricity price

JEL Classifications: I12

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1. Department of Economics and Finance, University of Canterbury, Private Bag 4800, Christchurch, New Zealand

* Corresponding Author: e-mail: andrea.menclova@canterbury.ac.nz, phone: (+64-3) 364 2823, fax: (+64-3) 364 2635

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Home Heating and Asthma in New Zealand

1. Introduction.

New Zealand has one of the highest asthma prevalence rates among developed countries and previous research attributes this partly to poor socioeconomic conditions in certain neighborhoods (or among certain ethnic groups) and to insufficient home heating in particular (Ellison-Loschmann et al, 2004; Petronella and Conboy-Ellis, 2003; Butler et al, 2003; and Crane et al, 1998).

International retrospective empirical studies suggest that the lack of home heating is associated with higher asthma rates (e.g., see Borooah (2007) for recent evidence from Ireland) and a limited number of randomized controlled trials seem to support this hypothesis (Barton et al, 2007). However, the evidence to date is not conclusive, many of the studies available do not control adequately for the endogeneity of home heating, and rigorous analyses of New Zealand asthma data are sparse. In this paper, we investigate the causal link between adequate home heating and hospital asthma admissions in New Zealand. To address the endogeneity of home heating, we use quarterly regional electricity prices as a proxy for the existence and the type of home heating. Our main specification is a reduced-form, panel data model which provides strong evidence of a positive relationship between electricity prices and hospital asthma admissions. This finding withstands a series of robustness checks including different estimation procedures, changes to the definition of the dependent variable, inclusion of additional explanatory variables, and a "straw-man" (placebo test) analysis.

To verify that the effect of electricity prices indeed operates via less adequate heating, we first corroborate that electricity prices are good predictors of home heating and then undertake a two-stage-least-squares (TSLS) estimation using electricity prices as an instrument for home heating. Unfortunately, the TSLS approach is constrained by very limited data and a somewhat imprecise measure of one of the main variables of interest, home heating. Nevertheless, our results are again suggestive of the hypothesized negative relationship between adequate home heating and hospital asthma admissions.

The remainder of this paper is organized as follows: Section two describes the background literature and relevant descriptive findings from New Zealand, section three discusses the data and methods, section four presents the results, and section five concludes.

2. Background.

Asthma is a severe problem in developed countries and New Zealand has one of the highest asthma rates in the world along with other western countries like the USA and Australia (Holt & Beasley, 2002). In New Zealand, one in six adults and one in four children suffer from asthma symptoms.

Infants and children are particularly susceptible to asthma and it is a leading cause of hospital admissions of children (The Asthma and Respiratory Foundation of NZ (Inc.), 2006). Although asthma prevalence is the highest in wealthy countries, within countries, asthma is manifestly a disease of lower socio-economic groups. In New Zealand, asthma disproportionately affects Maori and Pacific-Islanders in both prevalence and severity (Holt & Beasley, 2002).

Approximately 130 deaths a year are caused by asthma attacks in New Zealand. The direct medical costs to the country of treating asthma have been estimated at $125 million a year. Including indirect costs, such as lost productivity and years lost to disability, raises that figure up to $700 million or around 0.7% of GDP (Holt & Beasley, 2002). Given this unsatisfactory state, any information that can help guide effective asthma prevention is of high importance. Our research will provide evidence regarding the effectiveness of improving home heating as a way of combating asthma.

The main avenue for home heating to influence asthma prevalence and severity is through the effect it has on house dust mites (HDM) survival. HDM require a relatively cool and humid environment to survive (Crane et al, 1998). New Zealand’s cold, humid climate provides an ideal atmosphere for the proliferation of HDM throughout households. Adequate home heating can prevent HDM from inhabiting households by reducing humidity below the level critical for the survival of HDM. Other avenues for home heating to affect asthma symptoms are through the direct effect on indoor temperature and through the effect on mold growth.

Randomized housing improvement studies have attempted to assess the causal effect of home heating on asthma rates. The Watcombe housing study conducted in the United Kingdom

(Barton et al, 2007) investigated self-reported asthma rates in households with improved heating and insulation and found a statistically significant but negligible effect on asthma prevalence. Two randomized controlled studies in New Zealand (Howden-Chapman et al, 2007, 2008) looked at the effects of housing improvement on asthma and like the Watcombe study found statistically significant but negligible effects on asthma. Crane et al (1998) investigated the effect of installing a Mechanical Ventilation Heat Exchange system on the presence of dust mites in New Zealand homes and found no significant effects. All of these controlled randomized studies plus other similar ones have a few systematic drawbacks: due to the substantial costs of the studies, the time period is often short and the sample size small; asthma is mainly measured by self-reports of symptoms; survey participants cannot be 'blinded' to the intervention ('treatment') which is especially problematic when relying on self-reports; and there are problems with participant compliance. Although some of the studies try to address some of these issues (e.g., the Watcombe study included a nurse assessment of asthma symptoms to complement a portion of the self-reports) the evidence they provide supporting the causal link between home heating and asthma is underwhelming and there is a need for further investigation.

Other studies have evaluated the correlation between asthma and home heating using cross-sectional econometric methods and some have found a negative correlation (Butler, Williams, Tukuitonga, & Paterson, 2003); (Borooah, 2007). Our own analysis using the New Zealand General Social Survey data from 2008 indicates that self-reported household dampness and cold correlate with worse general health outcomes, even after controlling for a range of individual demographic and socio-economic factors.[1] However, these studies do not fully control for the complex effects of wealth, an inherent problem with using cross-sectional data for this type of analysis. The problem stems from the fact that home heating is an endogenous determinant of asthma prevalence due to it being highly correlated with wealth (and possibly other observable and unobservable household characteristics) which can in turn affect asthma prevalence through many potential mechanisms besides home heating. Plausible connections between wealth and health found in the asthma literature include: education, childhood fruit intake, smoking, living in polluted areas, and underlying racial tendencies.

1. For example, we find that reporting that dampness is a major problem with the house decreases the likelihood of reporting excellent health by about 5% and reporting a "too cold" house decreases it by 4%, ceteris paribus.

Education is possibly the most important factor contributing to low asthma severity amongst higher socio-economic groups. Michael Grossman's classic paper (Grossman, 1972) explains that education is highly correlated with better health outcomes because people with higher education are not only more likely to have healthy lifestyles, but can also use health inputs more effectively. The nature of asthma is such that it cannot be cured or successfully prevented (at least with current medical knowledge) but it can be effectively managed through the use of inhalers. For the best management of asthma, it is vital that the patient understands how and when to use an inhaler and when to seek further assessment from a general practitioner (this may also be further exacerbated by low-income families avoiding general practitioner visits due to cost). Previous literature indicates that the role of education is important in explaining the difference between the severity of asthma amongst low-income and high-income households (Borooah, 2007).

Propper & Rigg (2006) found that low childhood fruit intake was correlated with high asthma rates; it is very plausible that childhood fruit intake is higher among wealthy families. Smoking along with inhaling second hand smoke has been suggested to have a causal relationship with asthma rates (Propper & Rigg, 2006) and, in New Zealand, smoking rates are the highest amongst low-income families. Highly polluted areas can trigger asthma due to the higher particulate matter in the air; it is plausible that low-income families live in areas with more pollution.

Underlying racial tendencies may play an important role in the relationship as well, particularly in New Zealand. Maori and Pacific-Islanders are disproportionately represented in asthma prevalence and severity statistics. For example, Maori are four times more likely to die from asthma than non-Maori (The Asthma and Respiratory Foundation of NZ (Inc.), 2009). It is unclear how much of this relationship is due to the fact that both Maori and Pacific Islanders are also disproportionately represented in lower socio-economic groups; however, there does seem to be a disparity that cannot be explained by observable differences in socio-economic factors.

Our research addresses the endogeneity of home heating in a way that had not been attempted in the literature: by using electricity prices as an instrument (or a proxy) for home heating. This method is designed to establish causality and to isolate the direct effect of home heating on asthma from the confounding influence of income and other unobserved factors related to both home heating and asthma.

High electricity prices reduce electricity consumption (an ordinary good). The amount of energy used for indoor space heating by New Zealand households is the third largest component of household electricity usage at approximately 19% (behind water heating at 39% and electronics at 20%; (EECA, 2010)). As home heating is a relatively large component of household electricity usage in New Zealand it is likely that the quantity of home heating used will be highly elastic with respect to the price of electricity. Since electricity prices are not correlated with income and other household characteristics, the effect they have on asthma rates will solely be through the effect on home heating.

A concern with estimating the reduced-form relationship between electricity prices and asthma rates empirically is that higher electricity prices may cause people to substitute towards non-electric sources of heating such as gas heaters and wood burners. While this has a potential to counteract the direct effect electricity prices would have on asthma through reduced electric heating as homes may still be heated to a comparable level, the heating appliances themselves may affect asthma. Gas heating - especially unflued varieties - can increase particulate matter in the air of homes and can also increase moisture leading to mold growth plus a higher humidity which helps HDM proliferation (New Zealand Ministry of Health, 2005). Wood burners may also increase particulate matter in the homes but will also increase particulate matter in the atmosphere outside, worsening the asthma of people in the surrounding area as well as those inside the house. Consequently, the hypothesized relation between electricity prices and asthma rates remains positive – via reduced heating and/or switching to less healthy heating appliances.

3. Data and Methods.

3.1. Data.

Our data comes from several sources: hospital asthma (and, in a robustness check, cerebrovascular disease) admissions data from the New Zealand Ministry of Health; electricity price and gas price data from the New Zealand Ministry of Economic Development; population statistics, median household income, and Consumer Price Index (CPI) values from Statistics New Zealand; weather data from the New Zealand National Institute of Water and

Atmospheric Research (NIWA); and home heating data from the Census. The spatial unit of analysis is a District Health Board (DHB) region[2].

The raw asthma admissions data contains monthly numbers of hospital admissions where the primary diagnosis was identified as asthma separated by five-year age brackets, sex, and three ethnicity categories (Maori, Pacific Islander, Other) from July 2000 to June 2009, for each DHB. In our reduced form model, we use quarterly DHB-level data for the entire period. The quarters are defined as follows: first quarter (Q1) January-March, second quarter (Q2) April-June, third quarter (Q3) July-September, and fourth quarter (Q4) October-December. The second and third quarters, combined, represent New Zealand winter and the colder months of spring and autumn; the first and fourth quarters, combined, represent New Zealand summer and the warmer months of spring and autumn. Unfortunately, for our TSLS regressions, we can only use annual data from the two Census years in our study period: 2001 and 2006.

Although our results are based on hospital asthma admissions rather than asthma prevalence in general, it seems reasonable to assume the results can be generalized to give an indication of the overall asthma burden. The main reason for using hospital admissions is the availability of data but another major benefit is that the figures are (relatively) objective as they have been assessed by a health care professional. Self-reported measures of asthma prevalence may be more thorough but would suffer from the inaccuracy associated with self-assessment of health outcomes.

Since the literature suggests that infants and young children are the most affected by asthma and that once adulthood is reached, age has little effect on asthma (The Asthma and Respiratory Foundation of NZ (Inc.), 2006), we analyze the effects on infants (0-4 years), children (5-14 years), and adults (15+ years) separately. We also present some of our results separately for the following ethnic sub-categories: Maori, Pacific Islanders, and Other. We ignore gender sub-categories as we could not find any suggestion in the literature that there should be any a priori differences between the two sexes in asthma prevalence.

Age-specific population data (annual, DHB-level) has been obtained from Statistics New Zealand and includes population estimates stratified into five-year age brackets. As this data was only available up to 2008, we have assigned 2008 population estimates to observations

2. Between 2001 and 2010, New Zealand has been administratively divided into 21 DHBs.

from 2009. We have pooled the age brackets the same way as with the asthma data and have matched the two data sets. This allows us to express asthma admissions as rates per 10,000 individuals. Unfortunately, the population data is annual whereas all our other datasets are quarterly, reducing the precision of calculated admission rates to some degree. Therefore, our preferred model specification contains the absolute number of admissions as the dependent variable and population estimates as an independent variable. We report results for the rate of asthma admissions as the dependent variable in a robustness check.

Electricity price data was obtained from the Ministry of Economic Development's Quarterly Survey of Domestic Electricity Prices (QSDEP) (Ministry of Economic Development, 2010b). This survey provides quarterly retail electricity price data for each retailer purchasing from a line business between April 1998 and November 2009. Each line business services a well-defined geographical area of New Zealand and the QSDEP dataset assigns line businesses to these regions. However, these regions do not precisely coincide with DHBs so we have re-assigned line businesses into DHBs (Table A1). Most DHBs are matched very closely to one or more line businesses but there are a couple that do not fit perfectly. This is especially evident on the Lakes/Waikato border and the Southland/West Coast border. However, this should not be a cause of concern because the area of difference is very sparsely populated and given that the electricity price data is only an estimate, the loss in accuracy due to a different border definition is trivial.

For each line business region, the QSDEP dataset also identifies which retailer is the incumbent retailer. Following advice from a representative from the Ministry of Economic Development, we use the retail prices from the incumbent retailers as our primary measure of electricity prices for a line business. Where there are multiple line-businesses within a DHB, we have created a weighted average price per quarter per DHB region across incumbent retailers. The relative weight of each retailer can be estimated by the number of Installation Control Points (ICPs) each retailer controls. Data on the number of ICPs was obtained from the Electricity Commission website (The Electricity Commission, 2010). This data contains the number of ICPs per retailer for each Network Supply Point (NSP) in New Zealand. As each line business controls several NSPs, we have summed the number of ICPs per NSP data to each line business. As a robustness check, we also employ a measure of retail electricity prices calculated as a weighted average of the price for each DHB region across all retailers as opposed to just the incumbent retailers. Unfortunately, not all retailers have price data available; in some DHB/quarter observations, only 4% of the market had price data available. This is discussed further below.

To obtain a real price measure, we adjust both electricity price estimates for inflation using national, quarterly CPI provided by Statistics New Zealand. For the purposes of regional CPI calculations, New Zealand is only separated into the three main cities (Auckland, Wellington and Christchurch) and the rest of the North and South Islands and estimates are only available from the second quarter of 2006. This makes regional CPI estimates of little use in our study.

For the TSLS regressions, we take an average of the electricity price within each DHB over the four quarters of the year to produce electricity price estimates for 2001 and 2006.

The New Zealand electricity market relies largely on hydro power with 57% of electricity being generated at hydro power plants, on average. The next largest source of electricity is gas at 20% followed by geothermal energy at 11% and coal at 7% (Ministry of Economic Development, 2010a). Due to the high proportion of energy coming from hydro sources, the electricity market is heavily influenced by rainfall in the few relatively compact lake/river regions where the majority of hydro power is generated. Over 80% is generated within four regions that are mostly sparsely populated: the Clutha Lakes (about 14%)[3], Lake Manapouri (about 13%)[4], the Waikato River (about 21%)[5] and the Waitaki Lakes region (about 33%)[6]. Also, the majority of hydro generation takes place in the South Island (where the Clutha Lakes, Lake Manapouri and Waitaki Lakes lie) and is transmitted to the much more populated North Island (representing about 64% of electricity demand) through a high voltage direct current link between the two islands. If the electricity market is highly supply-driven as evidenced by the sustained high electricity prices caused by relatively dry South Island winters in 2001, 2003 and 2006 (Hogan & Meade, 2007), the electricity price is likely to be strongly affected by weather conditions at the source of power generation (affecting supply) but not necessarily by the weather at the end-user's residence (affecting demand) which may be quite different.

3. For more information see http://www.contactenergy.co.nz/web/pdf/environmental/Hydro_brochure.pdf
4. For more information see http://www.meridianenergy.co.nz/NR/rdonlyres/B496C006-3F64-4F0E-8305-C22CAE732A4E/24507/0102MEDManapouriwebBro2.pdf
5. For more information see http://www.mightyriverpower.co.nz/Generation/PowerStations/HydroStations/Default.aspx
6. For more information see http://www.meridianenergy.co.nz/NR/rdonlyres/B496C006-3F64-4F0E-8305-C22CAE732A4E/24505/0104MEDWaitakiwebBro12.pdf

Nevertheless, to allow for the theoretical possibility that weather simultaneously impacts electricity prices and asthma admissions in a particular location, we control for DHB-level quarterly weather conditions in all of our panel-data models. The average values per DHB/ quarter have been calculated from monthly weather records obtained from NIWA's CliFlo database (NIWA 2013). Our main model contains information on the mean temperature, mean daily minimum temperature, and mean daily maximum temperature at a weather station representing each DHB (typically located in the largest town of each DHB). In a robustness check, we add information on average monthly rainfall and average 9 am temperature in each DHB/quarter (this information is missing for Counties Manukau and Taranaki DHBs so is not included in our main model).

To at least partly control for the simultaneous effects of wealth on home heating and health, we use annual, DHB-level median household income estimates from Statistics New Zealand in all of our panel-data models.

To conduct a "straw-man" analysis (explained in detail below), we have obtained data on cerebrovascular disease admissions, of which stroke admissions are a major component, from the Ministry of Health. This data is stratified by DHB and age brackets. As stroke admissions have a different age distribution than asthma admissions, it seems unnecessary to compare age categories.

Gas price data was obtained from the Ministry of Economic Development and adjusted for inflation using the national CPI. The dataset contains monthly gas prices for 31 cities and towns in the North Island in 2001. We use the data from cities and towns to represent the DHBs they are in, which provides data for all North Island DHBs except Wairarapa. Unfortunately, there are many missing observations so in total only 178 DHB/quarter cells can be used. No data is available on the number of customers subscribing to each price plan in individual towns and cities, so there is no way to produce an accurate weighted average price. To address this limitation, two measures of gas price were produced: 1. the lowest price in the DHB and 2. an un-weighted average of all pricing plans available in the DHB. Both approaches are problematic but are the best achievable with limited data. In the raw gas price dataset, the Ministry of Economic Development assumes any available discounts were taken advantage of, for example duel fuel and prompt payment discounts. This assumption carries over to our two gas price measures.

The Census (Statistics New Zealand, 2006) - conducted in New Zealand every five years – provides data on the number of people in each region using different forms of home heating as well as the total number of households. On the dwelling form, respondents are asked to identify any fuels that are ever used to heat the dwelling. The list includes: 'don't ever use any form of heating in this dwelling', 'electricity', 'mains gas (from street)', 'bottled gas', 'wood', 'coal', 'solar heating equipment', and 'other'. This data is reported for DHB regions in the 2001 Census but in the 2006 Census, it is only available for regions that closely, but not perfectly, resemble DHBs. Hence, we had to combine some DHBs to fit the regions in the 2006 Census, reducing the number of available observations to fourteen.

Ideally, we would use a continuous measure of the quantity of home heating people use. The closest measure available in the Census is the number of dwellings in each region using different sources of heating. We therefore focus on the number of households using electric heating as the 'healthiest' form of heating available in New Zealand.

3.2. Methods.

In our main specification, we regress asthma rates on real electricity prices to establish their reduced-form relationship, initially using Ordinary Least Squares (OLS).

$$asthma\ admissions_{jt} = \beta_0 + \beta_1 electricity\ price_{jt} + \beta_2 population_{jt} + \beta_3 median\ HH\ income_{jt} + \beta_4 mean\ temp_{jt} + \beta_5 min.temp_{jt} + \beta_6 max.temp_{jt} + \gamma + \delta + \theta + \varepsilon_{jt}$$

where j indexes DHB regions and t indexes quarters. As long as the dependent variable is the number of admissions (as opposed to the rate of admissions), it is critical that population be included in the regression, as regions with higher populations are likely to have a higher number of admissions, ceteris paribus. In addition, we control for the real median weekly household income, mean temperature, mean daily minimum temperature, and mean daily maximum temperature in all of our panel-data models in recognition of their potentially simultaneous effects on home heating and health. Regional (γ), yearly (δ), and quarterly (θ) fixed effects are included to control for time-invariant DHB characteristics and for national time trends and seasonal effects, respectively. We weight observations by population to obtain nationally representative results. As some regions have more variable asthma rates than others, we correct standard errors for heteroskedasticity and cluster them by DHB.

In a series of robustness analyses, we adjust the functional form and estimation method of the main specification above, including the following checks: transforming the dependent variable to a proportion (admission rate) rather than an absolute number of admissions; transforming the model to log-linear, log-log and linear-log specifications; adding a one-quarter lag of the dependent variable as an explanatory variable; and estimating the regressions with Panel-Corrected Standard Errors (PCSE). We repeat this process with the dependent variable stratified by age and ethnicity categories with the corresponding population statistics.

To check that our results are not unduly sensitive to the definition of our main explanatory variable, we repeat the baseline regression with a more comprehensive weighted-average electricity price. As mentioned in the previous section, the weighted-average electricity price measure is problematic due to missing data. To address this problem, we rerun the model on two different subsamples with problematic observations omitted. First, we drop the five DHBs with the smallest average percentage of the market accounted for (all less than 60%); second, we drop all DHB/quarter cells with the percentage of the market accounted for less than 30%.

To check whether the effect of electricity prices on asthma admissions is due to the 'quantity' of home heating or substitution to alternative fuels, we include data on gas prices as an additional explanatory variable. If the 'substitution effect' is the more important of the two, we would expect to see the magnitude and significance of the coefficient on electricity price to drop notably, and the coefficient on gas prices to be negative and significant (as gas heating is less beneficial to asthma-sufferers than electric heating).

For a "straw man" robustness check, we test whether the method used for asthma gives a significant relationship between home heating and cerebrovascular disease, pointing to a spurious correlation in our asthma findings. Cerebrovascular disease was chosen for the straw-man analysis because it is an acute condition so the time of admission should be a reasonable estimate of the onset of the condition, it is common, and most importantly there is no prominent evidence or theory that it could be correlated with home-heating.

If home heating is driving the correlation between asthma and electricity price, then electricity price should have a larger effect in colder regions and/or quarters. To test for this, we run a series of regressions interacting electricity prices with both quarter and DHB dummies to see if electricity prices have a larger effect in winter quarters (Q2 and Q3) and/or in colder regions (mainly the South Island). We also repeat the price interaction using binary variables for winter and the South Island instead of the full set of quarter and DHB dummies. If home heating is the driving factor behind the relationship between electricity price and asthma, we would expect the interaction between the winter dummy (or Q2 and Q3) and price, and the interaction between the South Island dummy and price to be positive indicating that electricity prices matter more (via their effect on heating) in colder areas. We also run a three-way interaction between electricity prices, winter and the South Island dummies to test if electricity prices have the expected larger effect on asthma admissions during winter in the South Island.

Finally, to explore the mechanism behind the observed relationship - or, more specifically, to confirm that electricity prices affect asthma admissions via changes to home heating – we attempt estimation of a structural model. For an initial check to ascertain whether electricity prices are an appropriate proxy/instrumental variable for home heating, we regress the number/proportion of households using electric heating on electricity prices. Since the two available Census home heating estimates are annual, we use an average of electricity prices over the four quarters of 2001 and 2006. Then, using electricity prices as an instrument for the number of dwellings with electric heating, we conduct a TSLS estimation of hospital asthma admissions:

$$hospital\ asthma\ admissions_j = \beta_0 + \beta_1 number\ of\ households\ with\ electric\ heating_j + \beta_2 number\ of\ households_j + u_j$$

$$number\ of\ households\ with\ electric\ heating_j = \gamma_0 + \gamma_1 electricity\ price_j + \gamma_2 number\ of\ households_j + v_j$$

where j indexes DHB regions. We repeat the regressions with infant admissions as the dependent variable. All regressions are estimated using the white diagonal standard error adjustment and contain analytic weights by whichever measure of population is used in the regression (i.e., total population or infant population).

4. Results.

4.1. Descriptive Findings.

Our descriptive findings based on the full dataset from years 2000-2009 are consistent with the literature in showing that asthma is the highest amongst infants and children (Figure 1). In particular, there is a distinctive trend of asthma admissions decreasing until adulthood is reached and changing very little from then on (the drop after 50 years is most likely explained by fewer people above that age rather than lower asthma in that group). As previously documented, Maori are disproportionately represented in asthma admission statistics. In our sample period, Maori only represent 15% of the New Zealand population but 34% of hospital asthma admissions. Finally, initial observations indicate that asthma admissions may have been decreasing over the time period of the sample (Figure 2); this is at odds with previous studies which suggest asthma prevalence has been increasing in recent times (Holt & Beasley, 2002).

There is substantial variation in the real electricity price both over time and across DHBs (Figure 3 displays the minimum, unweighted mean, and maximum price as well as prices in two North Island DHBs and two South Island DHBs – one rural and one urban in each). For all DHBs, we can observe a sizeable increase between July 2000 and June 2009 by about 6c/kWh (or over 30%), on average. This is comparable in magnitude to the difference between the maximum and the minimum electricity price in any given quarter. Sparsely populated DHBs tend to have substantially higher electricity prices than DHBs with a large urban center (e.g., compare Northland vs. Auckland in the North Island or West Coast vs. Canterbury in the South Island; Figure 3). Importantly for the identification of our reduced form models, the timing of price increases varies widely across DHBs.

The mean price of the incumbent retailer is very similar to the mean weighted price of all retailers within a DHB – both are just slightly over 19c/kWh (Table 1). Interestingly, the percentage of households using electric heating changed little between 2001 and 2006 (the two Census years in our sample period) and stayed below 70% (Table 1).

New Zealand has a relatively cool climate (Table 1) with the mean daily temperature just over 13°C (55°F) and the mean daily minimum around 9°C (48°F) and maximum around 18°C (64°F). As mentioned above, we control for DHB-level weather patterns in all of our reduced-form models.

4.2. Reduced-Form Model.

As hypothesized, the effect of electricity prices on asthma admissions is positive and highly significant in our baseline specification (first column of Table 2), indicating that if the real electricity price increases by one cent per kilowatt, holding population constant, the number of hospital admissions for asthma will increase by around six people, on average, in any quarter in any DHB region. This represents an 8% increase from the average of 82. This result withstands most robustness checks (available on request). For example, adding a lag of the dependent variable does not substantially affect the magnitude or significance of the coefficient on price. Similarly, various log transformations of the dependent and independent variables do not greatly affect the significance of the main relationship. Applying the coefficients to an average region and quarter produces similar magnitudes of effects as the linear model. However, converting the dependent variable to the form of rates (second column of Table 2) eliminates the significance of the price coefficient. It is plausible that this result is due to the fact that population numbers are annual rather than quarterly and hence produce inaccuracies in the measurement of rates. Also, including population estimates in the denominator of the dependent variable rather than as an explanatory variable makes the specification of the role of population less flexible.

Repeating our baseline regression using cerebrovascular disease admissions instead of asthma admissions (last column of Table 2) produces a highly insignificant – and negative - coefficient on electricity price. This suggests that the results of our baseline regression are not merely due to spurious correlation and thus supports our main findings above.

The reduced-form model indicates that median household income significantly reduces the number of asthma admissions in a DHB (Table 2). This is consistent with previous observations that asthma disproportionately affects lower socio-economic groups. None of our weather variables (mean temperature, mean daily minimum temperature, and mean daily maximum temperature in Table 2 and mean 9 am temperature and total rainfall in a robustness check available on request) come close to reaching statistical significance and their addition to the model does not change the coefficient on the electricity price. The robustness of the price coefficient to the inclusion of local weather information is consistent with supply-driven electricity prices in New Zealand where local weather does not substantially affect local electricity prices. The coefficients on the year dummy variables become increasingly negative for later years, confirming that asthma admissions have been decreasing throughout time (results available on request). The coefficients on the quarterly dummies indicate that asthma admissions are highest in the first quarter of the year (January to March) and lowest in the third (July to September) indicating that asthma is a bigger problem in the warmer months than the colder ones. Coefficients on the regional dummies suggest that South Canterbury has consistently the highest asthma admissions and Waitemata and Auckland have the lowest, holding all else constant.

Next, we apply the baseline specification to the separate age and ethnicity categories (columns 3-10 of Table 2). The effect of electricity price on asthma admissions is positive for all age groups but decreases with age and is only statistically significant for infants and children. In particular, an increase in the real electricity price by one cent per kilowatt increases asthma hospital admissions by nearly 13% among infants, 8% among children, and over 3% among adults. The large effect on infants makes intuitive sense firstly because infants are by far the most likely to be admitted to hospital for asthma and also because infants probably spend more time at home than any other age group, so would be affected the most by housing conditions. Given the prominence of the result for infants, we repeat all of our robustness checks for the infant subsample and find the main finding very robust. The results from the ethnicity specific regressions show only the majority 'other ethnicity' category to have a positive and significant coefficient on price. However, the electricity price coefficient is significant and potentially very large for Pacific Islander infants. Maori infants also seem more responsive than Maori children and adults.

To verify that our results are not too sensitive to the definition of the DHB-level electricity price, we estimate the baseline regressions for all admissions and infant admissions using the more comprehensive weighted-average electricity price (Table 3). As mentioned above, we use three different subsamples for these estimations (depending on how representative electricity data we could obtain). Overall, while the estimated effects are statistically weak for all admissions (and vary with sample changes), they remain significant, positive, and reasonably large for infant admissions. Due to the data limitations surrounding this definition of electricity price, the original measure is used in all subsequent analyses.

Results of the models including gas prices (available on request) tentatively indicate that substitution from electric heating to gas heating is not the cause of the relationship between electricity prices and asthma admissions. In particular, once the substantially reduced sample size is accounted for, the inclusion of gas prices as an explanatory variable has negligible effect on the size and significance of the electricity price coefficient and the gas price coefficients is itself statistically insignificant.

The addition of seasonal and regional interactions with the electricity price (Table 4) suggests that home heating plays an important role behind the observed relationship between electricity prices and asthma admissions. Although there are fewer asthma admissions in winter (as indicated by the negative coefficients on Q2 and Q3 in column 1), the sensitivity of asthma admissions to the price of electricity seems to increase during winter (as indicated by the positive, but statistically insignificant, coefficients on the Price*Q2 and Price*Q3 variables). This is at least weakly consistent with our hypothesis that poor home heating contributes to increased asthma admissions. Interacting electricity price with a dummy variable for the South Island (column 2) produces a negative coefficient, which seemingly contradicts our hypothesis that in colder regions asthma admissions should be more sensitive to the electricity price. However, the fact that most admissions occur during summer may be confounding this result. To address this, we add a three-way interaction between electricity price, winter, and the South Island (column 3) and find that: 1. Electricity prices do matter more during winter (the Price*Winter coefficient is now highly statistically significant) and 2. If anything, electricity prices during winter have a greater positive effect on asthma admissions in the South Island than in the North Island. Finally, interacting electricity price with DHB regions, we have been able to produce a measure of the elasticity of asthma admissions with respect to the electricity price in each region (Figure 4; darker colors represent higher elasticity). Although not overwhelmingly clear, there appears to be a pattern of more Southern regions having higher elasticities. It is important to keep in mind that the estimated elasticity is related to the proportion of people who actually use electric heating (Figure 5; darker colors represent higher proportions) and are therefore affected by increasing electricity price.

4.3. Role of Home Heating.

Next, we turn our attention to the direct role of home heating in the observed effect of electricity prices on asthma admissions. As expected, electricity price appears to be significantly negatively correlated with households' use of electric heating for both Census years in our sample (Table 5). In 2001, an increase of the real electricity price by one cent per kilowatt would be associated with a reduction in the proportion of households using electric heating by 7.2 percentage points. Looking at absolute values appears to tell a similar story with higher electricity prices leading to fewer households using electric heating, albeit with very different magnitudes across the two years (likely due to the very small numbers of observations in each regression). The 2006 regression for the proportion of houses using electric heating shows a negligible positive relationship. Even though there is some inconsistency in the above results, they indicate at least weakly that households do respond to electricity prices when consuming electric power for home heating.

Results of the TSLS regressions are volatile but suggestive (Table 6). While 2001 regressions show the number of households with electric heating to be an insignificant predictor of hospital asthma admissions, the 2006 results are highly significant, have the predicted sign, and are stronger for infants. Even the 2006 results are very small, however. In particular, the 2006 regression implies that increasing the number of households with electric heating in a DHB by 1,000 would reduce the number of infant hospital asthma admissions by 2 (or close to 2%). Keeping the severe data limitations in mind (we have only 20 observations for 2001 and 14 for 2006), these results are at least weakly consistent with the observed effect of electricity prices on asthma admissions operating via changes to home heating.

5. Conclusion.

Our reduced form estimation implies that hospital asthma admissions are strongly correlated with electricity prices and an instrumental variable approach further indicates that electricity prices are a good proxy for the type of home heating people use and that home heating specifically affects asthma admission rates. Robustness checks of the functional form indicate that the relationship between asthma admissions and electricity price is stronger and more robust for infants than it is for the general population. However, even the general findings remain qualitatively consistent across model specifications. Moreover, previous studies suggest that childhood asthma has long-term impacts on adult health (Fletcher et al, 2010). Redefining the electricity price measure to account for a more comprehensive weighted average of retailers supports the above findings.

Including gas prices as an additional explanatory variable unfortunately cannot contribute much to the analysis due to the low number of observations with available data. Since the magnitude and significance of the coefficient on electricity price are not largely affected by the inclusion of gas prices, it could be tentatively suggested that substitution to alternative fuels that are detrimental/less beneficial to asthmatics is not the main driver of the correlation between electricity prices and asthma admissions. However, the paucity of the data renders any strong conclusions unreliable.

Estimates of seasonal and regional interactions with electricity price further support the hypothesis that electricity prices affect asthma through their effects on home heating. Although asthma admissions are higher in summer, the effect of electricity prices on asthma admissions is higher in winter. There also appears to be a suggestive regional pattern with the elasticity of asthma admissions with respect to electricity price increasing towards the colder South. All of these observations are consistent with the hypothesis that increasing electricity prices increase asthma admissions by reducing the level of home heating.

Insignificant results from the straw-man analysis strengthen the baseline findings as they indicate there is no spurious relationship between electricity prices and hospital admissions underlying the significance.

Further work is warranted to fully investigate the relationship between asthma and indoor heating for school children (age 5+ in New Zealand). These children spend considerable amount of time in school and while our reduced form model is not strictly limited to electricity usage at home, the incentive of a school to save on electricity by reducing heating is presumably less direct than at home. School terms, in particular the start of the school year, have a well-documented effect on asthma hospital admissions (Julious, Osman, & Jiwa, 2007). It has been suggested that the increase in social contacts and the associated increase in viral susceptibility is the culprit (Lincoln, Morgan, Sheppeard, Jalaludin, Corbett, & Beard, 2006). It is also plausible that being at school might influence the reported number of asthma attacks and potentially admissions without affecting the underlying prevalence or severity of asthma if schools are more inclined to refer a child for medical intervention than parents who may feel more comfortable handling the symptoms themselves. An interesting area of investigation would be to look at the effect school terms have on asthma admissions via changes to the indoor heating children are exposed to.

Another possibility to consider is that insulation or substitution to more efficient forms of heating may be influencing our results. The concern is that high electricity prices would encourage people to invest in more energy efficient forms of heating such as heat pumps and/or better insulation of their homes. Although this is a probable reaction to higher electricity prices, it is more likely to be a decision made over a longer period of time than what this paper is analyzing. It seems unlikely that many people would adjust their heating in the quarter of a price increase. Therefore, it is doubtful that the effect of people improving their insulation or form of heating in the same season would bias our results. Moreover, even if that was the case, it would bias our results downwards. In particular, if people adjust to higher electricity prices by improving the efficiency of their home heating allowing them to have increased heating for the same cost, this should improve asthma symptoms and thus lower the number of asthma admissions, ceteris paribus. This makes our results conservative estimates of the effects of home heating levels on asthma admissions.

Overall, our results suggest that there is a highly significant, positive relationship between the lack of home heating and asthma hospital admissions. This relationship seems independent of other socio-economic factors such as income. Since asthma is such a prominent problem in developed countries, these findings may have important implications for public health policy.

Figure 1. Number of Hospital Asthma Admissions by Age; New Zealand, July 2000 – June 2009

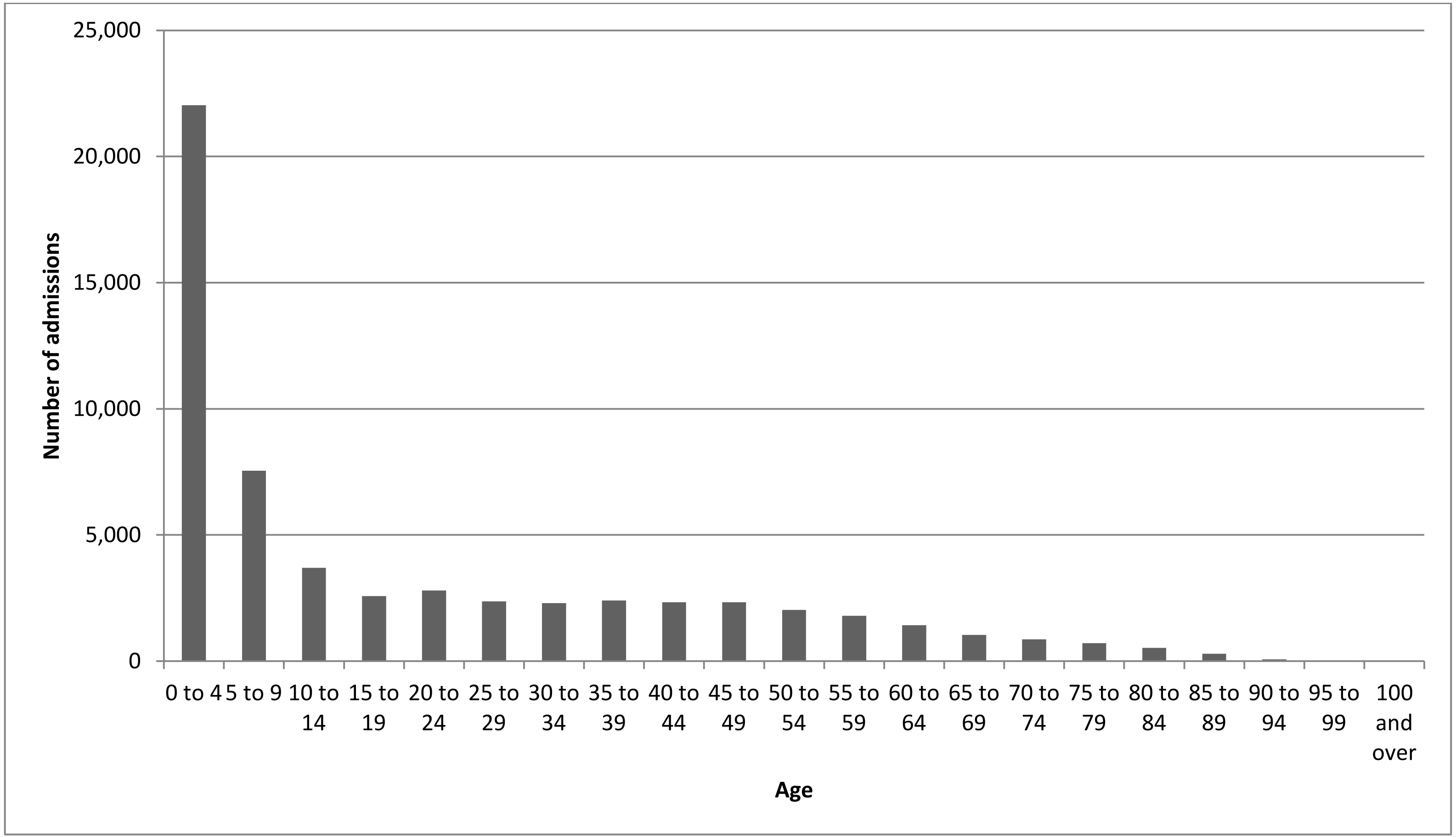
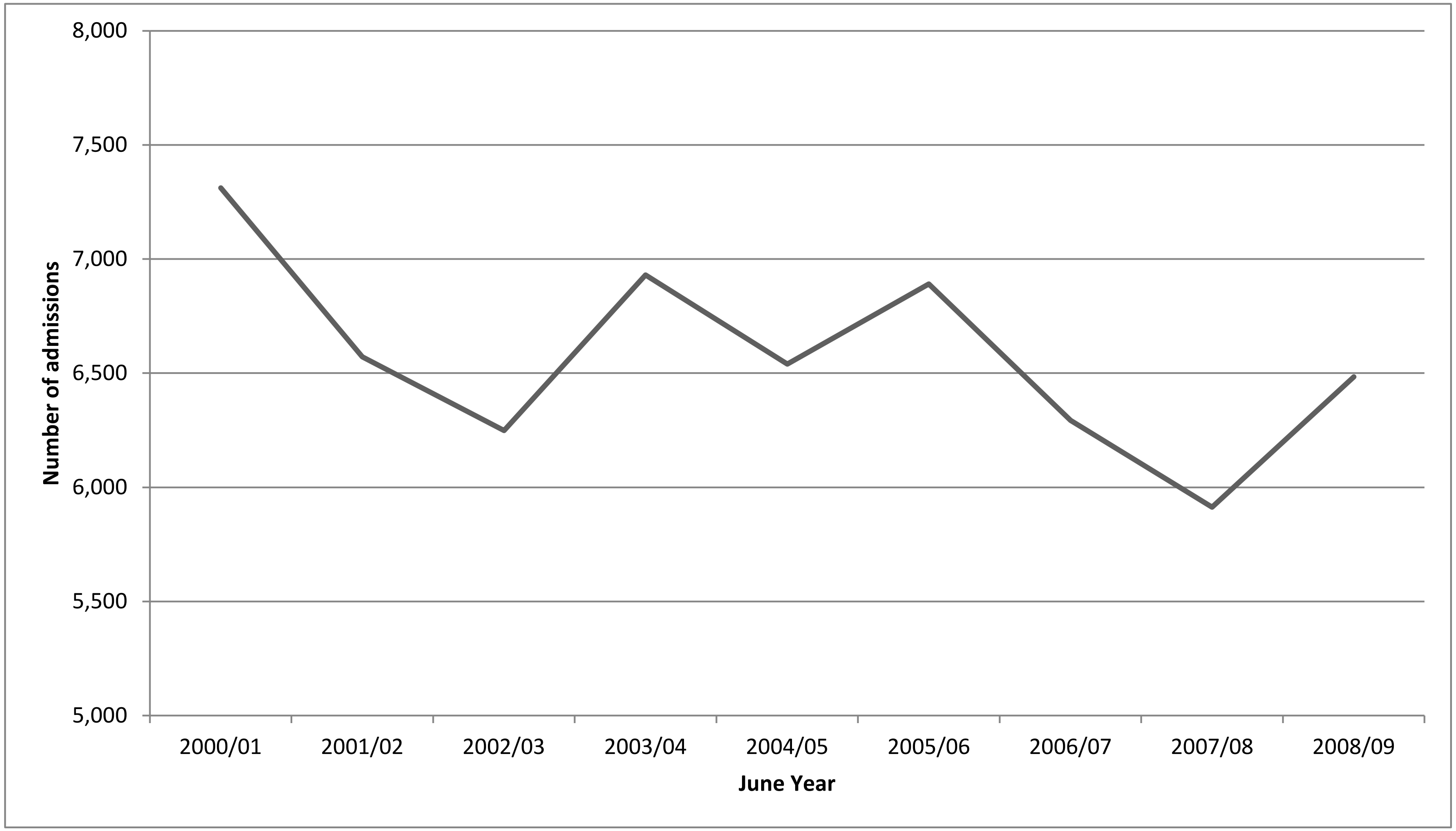


Figure 2. Annual Numbers of Hospital Asthma Admissions; New Zealand; July 2000 – June 2009



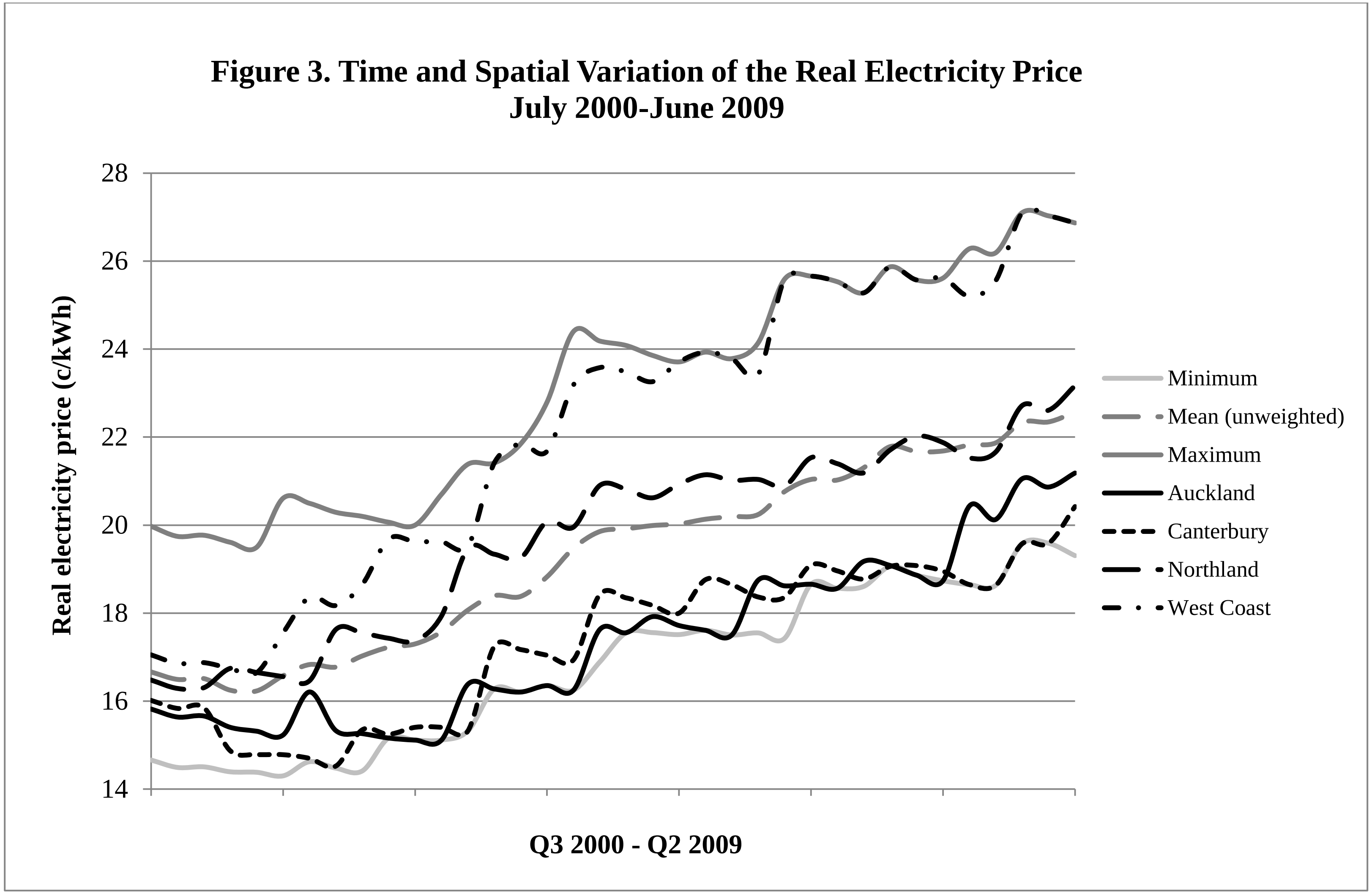
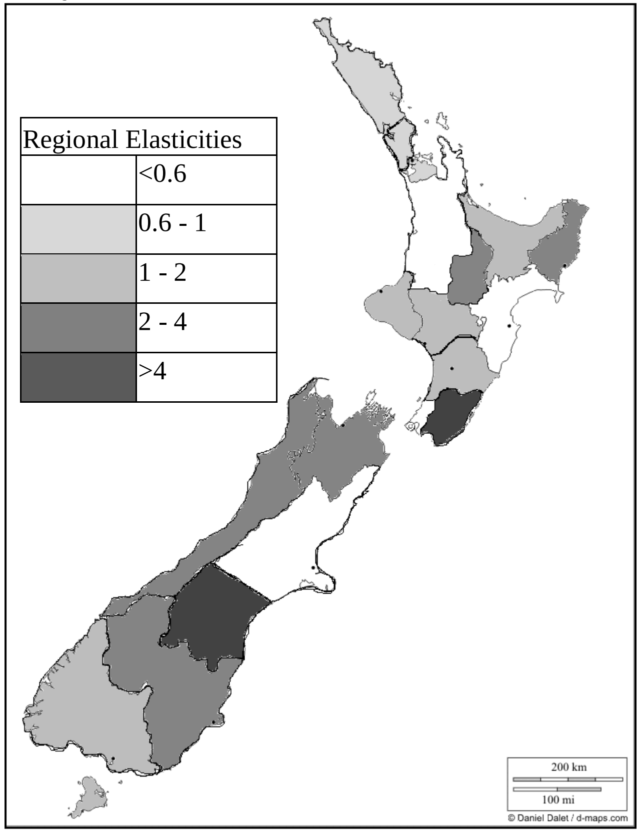


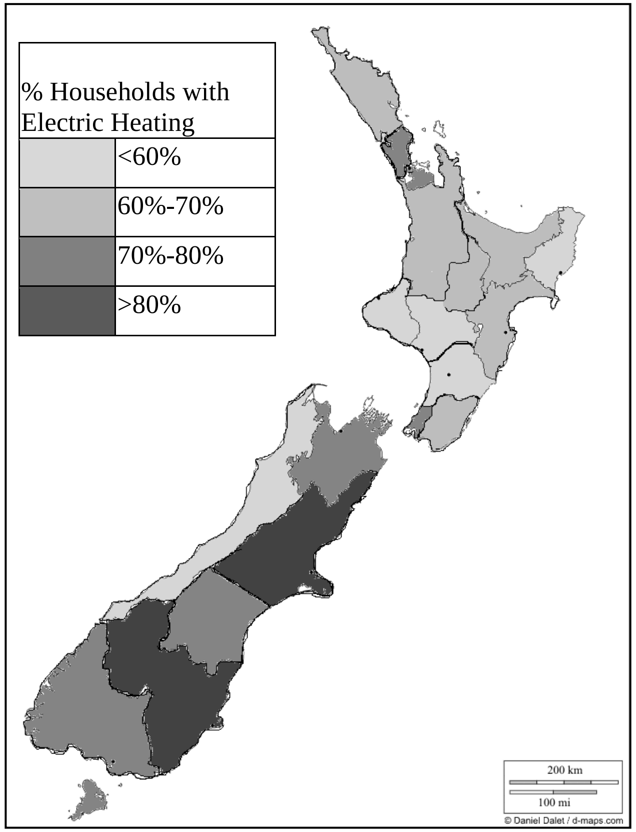
Figure 3. Time and Spatial Variation of the Real Electricity Price
July 2000-June 2009
28
26
24
22
20
18
16
14
Real electricity price (c/kWh)
Q3 2000 - Q2 2009
Minimum
Mean (unweighted)
Maximum
Auckland
Canterbury
Northland
West Coast

Figure 4. Estimated Regional Electricity Price Elasticities; July 2000 – June 2009 [a]



[a] Elasticity=change in asthma admissions for a given change in electricity price (coefficient on electricity price + regional dummy coefficient) *(average electricity price/total admissions)

Figure 5. Percentage of Households Using Electric Heating; 2001 [b]



[b] Percentage of households using electric heating = number of households with electric heating/number of households *100

Table 1. Descriptive Statistics
July 2000 – June 2009

Variable	Mean (Standard deviation)
All asthma admissions	81.8 (65.2)
Infant asthma admissions	30.5 (25.3)
Real electricity price (c/kWh) of the incumbent retailer	19.3 (2.7)
All retailer (weighted) real electricity price (c/kWh)	19.1 (2.7)
Population (1,000s)	204.6 (155.2)
Infant population (1,000s)	14.4 (11.3)
Real median weekly household income ($)	990.5 (143.1)
Mean temperature (°C)	13.3 (3.3)
Mean daily min. temperature (°C)	8.8 (3.4)
Mean daily max. temperature (°C)	17.8 (3.5)
Percentage of households with electric heating, 2001 Census year, DHB-level annual estimate	67.7 (10.1)
Percentage of households with electric heating, 2006 Census year, DHB-level annual estimate	66.4 (10.7)

Unless stated otherwise, the unit of analysis is a DHB/quarter.

Table 2. The Effects of Electricity Prices on Hospital Asthma Admissions
DHB-Level Analysis, July 2000 – June 2009

	All asthma admissions	All asthma admissions per 10,000 population	Infant (0-4 years) asthma admissions	Child (5-14 years) asthma admissions	Adult (15+ years) asthma admissions	Maori asthma admissions	Pacific Islander asthma admissions	Other ethnicity asthma admissions	Maori infant asthma admissions	Pacific Islander infant asthma admissions	Cerebrovascular admissions (straw man analysis)
Real electricity price (c/kWh)	6.436*** (2.172)	0.025 (0.081)	3.812* (1.891)	1.192** (0.544)	1.205 (0.909)	0.699 (0.939)	0.252 (0.727)	4.664** (1.643)	0.731 (0.793)	1.624*** (0.482)	-0.364 (1.790)
Implied change from baseline	*7.9%*	*0.6%*	*12.5%*	*7.7%*	*3.4%*	*2.5%*	*2.2%*	*10.9%*	*5.9%*	*32.0%*	*-0.3%*
Relevant population (1,000s)	0.565*** (0.137)	-	1.564 (1.908)	1.125*** (0.360)	0.253*** (0.071)	1.105 (0.706)	0.685*** (0.074)	0.135 (0.093)	0.489 (2.398)	0.887* (0.497)	0.232 (0.203)
Real median weekly household income ($)	-0.058* (0.028)	-0.002*** (0.001)	-0.031 (0.020)	-0.009 (0.008)	-0.030** (0.010)	-0.026* (0.014)	-0.017 (0.017)	-0.028* (0.014)	-0.017* (0.009)	0.002 (0.013)	-0.042 (0.038)
Mean temperature (°C)	1.614 (53.942)	0.073 (1.498)	19.419 (38.857)	-4.999 (12.979)	-18.453 (25.910)	-13.082 (15.584)	-0.454 (22.937)	9.674 (41.490)	1.188 (8.657)	-14.745 (22.144)	81.045** (28.252)
Mean daily min. temperature (°C)	-1.434 (26.734)	-0.017 (0.754)	-9.768 (19.757)	3.594 (6.295)	7.656 (14.039)	6.946 (7.950)	0.802 (12.051)	-4.955 (19.288)	-0.605 (4.339)	7.809 (11.200)	-37.602** (13.962)
Mean daily max. temperature (°C)	-5.949 (27.066)	-0.137 (0.753)	-10.432 (19.782)	0.722 (6.503)	6.632 (13.898)	5.729 (7.628)	-3.140 (10.607)	-8.064 (20.991)	-0.307 (4.210)	6.693 (11.315)	-42.823*** (14.696)
Observations	720	720	720	720	720	720	720	720	720	720	720

The unit of analysis is a DHB/quarter.
White diagonal robust standard errors clustered by DHB are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

Table 3. The Effects of Electricity Prices on Hospital Asthma Admissions
DHB-Level Analysis, July 2000 – June 2009
Electricity Prices of All Retailers

	All asthma admissions	Infant (0-4 years) asthma admissions	All asthma admissions (excluding least representative DHBs)[a]	Infant asthma admissions (excluding least representative DHBs)[a]	All asthma admissions (excluding least representative observations)[b]	Infant asthma admissions (excluding least representative observations)[b]
All retailer (weighted) real electricity price (c/kWh)	1.194 (1.676)	1.837 (1.364)	2.537 (2.026)	2.800* (1.393)	1.449 (1.619)	2.242* (1.221)
Observations	720	720	540	540	595	595

[a] DHBs that contain data representing less than 60% of the market are excluded.
[b] DHB/quarter cells that contain data representing less than 30% of the market are excluded.

The unit of analysis is a DHB/quarter. All models also control for the relevant population, real median weekly household income, and temperature (mean daily average, minimum and maximum).
White diagonal robust standard errors clustered by DHB are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

Table 4. The Effects of Electricity Prices on Hospital Asthma Admissions
DHB-Level Analysis, July 2000 – June 2009
Seasonal and Regional Interactions

	All asthma admissions	All asthma admissions	All asthma admissions
Real electricity price (c/kWh)	6.078** (2.535)	10.396*** (3.312)	8.343** (3.485)
Quarter 2	-93.211*** (19.274)	-49.604*** (13.160)	-
Quarter 3	-117.719*** (25.971)	-72.503*** (16.616)	-
Quarter 4	-8.695 (13.947)	-22.339*** (6.205)	-
Electricity price × Quarter 2	1.411 (1.202)	-	-
Electricity price × Quarter 3	1.169 (1.852)	-	-
Electricity price × Quarter 4	-1.073 (1.235)	-	-
South Island × Quarter 2	-	-	-
South Island × Quarter 3	-	-	-
South Island × Quarter 4	-	-	-
South Island	-	68.424* (32.989)	81.821 (47.917)
Electricity price × South Island	-	-3.730** (1.583)	-4.285** (2.030)
Winter	-	-	-72.540*** (19.720)
Electricity price × Winter	-	-	2.388** (0.912)
Electricity price × Winter × South Island	-	-	0.542 (2.335)
South Island × Winter	-	-	11.952 (52.485)
Observations	720	720	720

The unit of analysis is a DHB/quarter. All models also control for population, real median weekly household income, and temperature (mean daily average, minimum and maximum).
White diagonal robust standard errors clustered by DHB are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

Table 5. The Effects of Electricity Prices on Electric Heating Use
DHB-Level Analysis, 2001 and 2006 Census Years

	Percentage of households with electric heating, 2001	Number of households with electric heating, 2001	Percentage of households with electric heating, 2006	Number of households with electric heating, 2006
Real electricity price (c/kWh)	-0.072*** (0.016)	-3,993.627** (1,691.162)	0.004* (0.002)	-152.929** (50.196)
Number of households	-	0.805*** (0.036)	-	1.538*** (0.254)
Observations [a]	20	20	14	14

[a] Annual observations for available regions.
White diagonal robust standard errors are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

Table 6. The Effects of Electric Heating Use at Home on Hospital Asthma Admissions Two-Stage Least Squares, 2001 and 2006 Census Years

	All asthma admissions 2001	Infant asthma admissions 2001	All asthma admissions 2006	Infant asthma admissions 2006
Number of households with electric heating (1,000s)	-1.422 (6.384)	1.922 (3.927)	-0.099*** (0.028)	-2.117** (0.730)
Number of households (1,000s)	5.380 (5.655)	-0.269 (3.483)	0.072*** (0.020)	3.450*** (0.562)
Observations [a]	20	20	14	14

[a] Annual observations for available regions.
White diagonal robust standard errors are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.
In the first stage, the number of households with electric heating = f(real electricity price, number of households)

Table A1. Mapping of Line Businesses to DHB Regions

DHB Domicile Code	DHB Name	Line Business
11	Northland	Top Energy Northpower
21	Waitemata	UnitedNetworks (Waitemata)
22	Auckland	Vector
23	Counties Manukau	Counties Power
31	Waikato	Waipa Networks WEL Networks Powerco (Thames Valley) The Lines Company (Waitomo) The Lines Company (King Country)
42	Lakes	Unison (Rotorua) Unison (Taupo)
47	Bay of Plenty	Horizon Energy Distribution Powerco (Tauranga)
51	Tairawhiti	Eastland Network (Eastland) Eastland Network (Wairoa)
71	Taranaki	Powerco (Hawera) Powerco (New Plymouth) Powerco (Stratford)
61	Hawke's Bay	Unison (Hawke's Bay) Centralines
81	Mid Central	Scanpower Electra Powerco (Manawatu)
82	Whanganui	Powerco (Wanganui)
91&92	Capital and Coast & Hutt Valley	Wellington Electricity Lines (North) Wellington Electricity Lines (South)
93	Wairarapa	Powerco (Wairarapa)
101	Nelson Marlborough	Marlborough Lines Nelson Electricity Network Tasman
111	West Coast	Westpower Buller Electricity
121	Canterbury	Orion NZ MainPower MainPower (Kaiapoi)
		Electricity Ashburton
123	South Canterbury	Alpine Energy
131	Otago	OtagoNet Network Waitaki Aurora Energy (Central Otago Clyde/Crom) Aurora Energy (Dunedin) Aurora Energy (Queenstown)
141	Southland	Electricity Invercargill The Power Company

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