Warming Up New Zealand: Impacts of the New Zealand Insulation Fund on Household Energy Use

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1. Introduction

Programmes aimed at retrofitting houses with insulation are considered by many to have a range of beneficial effects. Hypothesised and/or reported benefits include energy conservation, improved health outcomes, and emissions reductions. In addition to retrofitting houses with insulation, technological advances have produced cheaper, more efficient heating options which, combined with retrofitted insulation, help enhance some of these benefits.

As part of the 2009 budget, the New Zealand Government established the New Zealand Insulation Fund (NZIF) to subsidise the costs to homeowners of retrofitting insulation and installing clean heat devices. The subsidies were designed to encourage homeowners to raise the comfort (higher heat levels and lower humidity) and the energy efficiency of their homes, with the aim of reducing household energy demand and improving health outcomes in New Zealand. The NZIF provides home owners up to $1,300 (or 33%) towards the cost of retrofitting insulation and $500 towards the cost of an efficient clean heating source. Operating under the title "Warm Up New Zealand: Heat Smart", the NZIF offers greater funding than previous programmes and funding is available to all houses built prior to 2000, regardless of the income bracket that households fall into (Energy Efficiency and Conservation Authority, 2011a). Previous programmes restricted funding to lower or middle income households. The Government initially committed to the program for four years, with the intention of retrofitting one-fifth (188,500) of homes in the country (Energy Efficiency and Conservation Authority, 2011b). The programme has since been extended.

This study forms one part of a larger programme funded by the New Zealand Ministry of Economic Development analysing the impacts of the NZIF scheme on energy demand, health outcomes and employment. We analyse the effect on household energy demand of those houses that have had retrofitted insulation and efficient clean heating installed under the scheme. The purpose is to estimate whether there are significant changes in energy consumption behaviours resulting from the treatments.

The robustness of preliminary estimates is still to be checked through extensive tests of functional form, including interactions between variables, as outlined subsequently in this paper. Therefore no conclusions are yet drawn on the magnitude and nature of the energy savings from the scheme.

Section 2 of the paper provides a brief review of prior studies of the impact of insulation and related treatments on outcomes for households. Section 3 outlines our methodology, section 4 describes the data used in the study and preliminary discussion is included in section 5.

2. Prior Studies

Houses that are retrofitted with insulation or have efficient clean heating installed become more energy efficient and thus are hypothesised to conserve energy as a result of treatment. Previous studies on the effects of retrofitting houses with insulation have found that treated houses generally save energy (Chapman et al, 2009; Howden-Chapman et al, 2009). For instance, Chapman et al (2009) find that a typical household in their sample benefits from a decrease of around 5% in their metered energy consumption (electricity and gas) after they had received insulation. As technological advances improve the energy efficiency of heating, less energy is needed to produce the same amount of heating (Berkhout et al, 2000). Thus, energy savings may also be observed once a house installs more efficient heating sources.

Households can take the efficiency gains wholly as energy savings, and therefore reduce their energy consumption and cost, or they can substitute some of these savings for improvements in comfort and health outcomes (Berkhout et al, 2000; Howden-Chapman et al, 2009). As heating efficiency improves (i.e. as the effective marginal cost of heating falls), it is less costly to obtain the same level of comfort as was experienced previously, and this enables households to increase comfort levels with no addition to prior energy costs. They may even increase their energy consumption following the effective reduction in the price of heating, with the result that they further improve comfort levels. This phenomenon is known as the 'take-back' or 'rebound' effect; houses effectively 'take-back' some of the savings from being more energy efficient as increased energy consumption (Berkhout et al, 2000; Howden-Chapman et al, 2009).

In one randomised control trial, Howden-Chapman et al (2005) questioned a group of households on their energy behaviours prior to and following insulation installation. Houses were asked whether they would take any energy savings as cash savings or increased temperatures (i.e. increased comfort levels). Prior to having insulation installed, households were split evenly between the two responses; however, post-installation, the majority of houses that had insulation installed were observed to increase comfort levels, with only 16% of respondents choosing to take energy savings wholly as cash savings.

Temperatures also influence how energy savings are received. Milne and Boardman (2000) find that initial low indoor temperatures in a house induce households to increase indoor temperatures (comfort levels) as a result of energy-efficiency improvements. The size of the increase in comfort levels decreases as temperatures increase until, in their study, energy savings are taken wholly as cash savings (at temperatures higher than 20˚C).

The studies cited above all apply to small samples of treated houses (N = 1000 to 1300) and in some cases treatment is restricted to households with pre-existing conditions such as respiratory illness of a household member. One advantage of carefully designed small studies (such as Howden-Chapman et al, 2005) is that a randomised control trial (of households that meet the criteria for the trial) can be adopted, enabling a rigorous comparison of treated versus control houses.

Our study differs from the cited studies in that it pertains to a scheme that is available to all homeowners of houses built prior to 2000 and thus is not restricted to certain income or health groups. One advantage of examining the impacts of this scheme is that we can assess impacts across a large sample of houses that are not restricted by eligibility criteria (other than a small restriction on the age of the house; i.e. only house built pre-2000 are included). However, the design of the programme was such that no randomisation of treatment was considered and so our methodology has to use quasi-experimental methods to assess the energy impacts of the scheme. This methodology is outlined in section 3.

3. Methodology

To analyse the effect on energy use of being treated under the NZIF scheme, we adopt a "difference-in-difference" approach. We estimate the difference in energy use between treated house *i* and its control houses in month *t* before and after treatment ($EnergyDiff_{it}$). For each specification we define energy use respectively as electricity use and alternatively as "total" energy use, defined as electricity plus gas. The electricity data are more complete than the gas data, so these estimates may be more reliable but total usage is conceptually superior. Hence both sets of results are presented. The manner in which we select the control houses means that $EnergyDiff_{it}$ represents the change in energy use of a treated house from what it would have used if remained untreated.

We run a series of model specifications which progressively disentangle the effects of treatment. We begin with the most parsimonious model, (1), in which the difference in energy use is explained by individual house fixed-effects and time fixed-effects plus two dummy variables, $insulation_{it}$ and $heatpump_{it}$ (defined below). Significant coefficients found on the treatment variables (γ and δ) would indicate a significant change in energy use of houses treated under the NZIF scheme (relative to the respective control houses) as a result of treatment.

$$EnergyDiff_{it} = \alpha_i + \mu_t + \gamma \, insulation_{it} + \delta \, heatpump_{it} + \varepsilon_{it} \tag{1}$$

$EnergyDiff_{it}$ represents monthly difference in energy use (electricity or total) of treated house i relative to the mean of its control houses in time t; α_i represents the individual house fixed-effect of house i (i.e. the "standard" difference in energy usage of treated house i relative to its controls); μ_t are the time fixed-effects, covering each month in our sample from 2008m1 to 2010m11 (to account for any "standard" monthly seasonal pattern in difference of energy use[1]); $insulation_{it}$ is a dummy variable that is 1 if house i has received insulation treatment under the NZIF scheme in period t or any period prior to t, zero otherwise; $heatpump_{it}$ is a dummy variable equal to 1 if house i has received a heat pump heater under the NZIF scheme in period t or any period prior to t, zero otherwise; ε_{it} is a residual term. In this specification, and all subsequent specifications, June 2009 (2009m6) is our reference time period, being the period prior to the start of the scheme.

The simple specification in (1) provides a fairly crude inference on the effects of treatment since it hypothesizes the same energy saving in every month as a result of treatment. In (2), we extend (1) to allow the coefficients (γ_t, δ_t) on the treatment variables ($insulation_{it}$ and $heatpump_{it}$) to vary each month. It is likely that the effect of treatment on energy consumption will vary at different times of the year. For example, houses which have been insulated under the scheme may save more energy in the middle of winter relative to non-treated houses, but there may be no significant difference during summer months. Thus we estimate:

$$EnergyDiff_{it} = \alpha_i + \mu_t + \gamma_t \, insulation_{it} + \delta_t \, heatpump_{it} + \varepsilon_{it} \tag{2}$$

Generally, higher energy consumption occurs in colder periods, thus observed temperatures may provide a better measure of the effect on the energy use behavior as a result of treatment. Equation (2) attempts to capture this effect through allowing coefficients to vary over time in order to analyse their magnitudes during different seasons. However this specification imposes the same energy savings across every region in a given month even if temperatures varied widely between regions in that month. An alternative approach is to capture this effect by

[1] This could account for a selection effect whereby, for instance, those who adopt treatment would normally use extra heating over winter compared with the controls (who have chosen not to receive treatment).

regressing energy consumption on an interaction term between treatment and the monthly average temperature for the region in which the house is located ($temp_{it}^{r}$). Equation (3) adopts this approach, whilst allowing for the effect of temperature on energy savings to vary non-linearly.

$$EnergyDiff_{it}^{r} = \alpha_i + \mu_t^r + \sum_{s=0}^{S} \gamma_s \left(insulation_{it} * \left[temp_{it}^{r} \right]^s \right) + \sum_{s=0}^{S} \delta_s \left(heatpump_{it} * \left[temp_{it}^{r} \right]^s \right) + \varepsilon_{it} \qquad (3)$$

In this specification, the μ_t^r term is a region-time fixed-effect; thus each of New Zealand's sixteen regions has its own "standard" monthly seasonal pattern in energy use difference, unlike μ_t in (1) and (2) which restricts regions to follow the same monthly seasonal pattern. The coefficients γ_s and δ_s allow us to test for non-linear impacts on energy use outcomes as temperature increases or decreases. Specifically, S=0 implies a constant effect unaffected by temperature, S=1 implies a linear effect of temperature on energy savings, S=2 implies a quadratic effect, S=3 a cubic effect, and S=4 a quartic effect.

4. Data Description

4.1. EECA Data

The Energy Efficiency and Conservation Authority (EECA) is charged with the operation of the NZIF scheme, and holds records on each treatment received under the scheme. We obtained data from EECA detailing which houses had received treatment, the type of treatment received, and the costs associated with each treatment over the period from initiation (July 2009) through to May 2010. A total of 46,655 houses received at least one form of treatment under the NZIF scheme during this period. Addresses of these treated houses were then supplied to Quotable Value New Zealand (QVNZ) to be matched to records in the QVNZ database. Once addresses were successfully matched, characteristics of houses were extracted to allow identification of suitable properties to be used as controls for each treated property (see section 4.2 for details).

Our study period extends through to the end of November 2010; therefore we require additional information on houses that received treatment between May 2010 and November 2010; houses originally treated may have received additional treatment since May 2010, and, more importantly, houses initially identified by QVNZ as suitable controls may have received treatment, invalidating them as a control. The updated dataset, after address matching by QVNZ, allows us to identify and remove any initially suitable control house that subsequently received treatment and update previously treated houses that received additional treatment after May 2010.[2]

[Table 1 about here]

Treatment is classified into two broad categories; insulation and heater installation. Table 1 details the uptake of each treatment category; the majority of treated houses received only insulation treatment, while 8% received heating only and 15% received both insulation and heating. Each broad treatment category is further distinguished by the particular type of treatment carried out. Insulation treatment is broken down into work relating to ceiling insulation, under-floor insulation, draught-proofing, hot-water cylinders, etc, while heater treatment is divided between the types of heater installed (flued gas heater, heat pump, pellet burner and wood burner). Table 2 provides the number of houses that received each respective type of treatment.

[Table 2 about here]

Treatments are not restricted to only one type, making it possible for properties to receive multiple treatments at different times. Table 3 details the number of houses that have received multiple treatments and the type of treatments they received. For example, 7,096 houses that received ceiling insulation also received draught-proofing, while 685 houses that received underfloor insulation also received a wood/pellet burner.

[Table 3 about here]

[2] Though desirable, identifying and obtaining suitable controls for ALL additional treated houses treated after May 2010 to November 2010 to generate a comprehensive sample proved to be infeasible.

The total costs of receiving treatment under the scheme are split between the two treatment categories, and the costs of each treatment category is subsequently divided into the proportion paid by EECA and the proportion paid by the homeowner. (We do not use the cost data in the present study but it has been computed for use in subsequent work).

4.2. QVNZ Data

Addresses of houses treated under the NZIF scheme were supplied to QVNZ to obtain characteristics of the treated houses that were used to derive the set of suitable control houses. Matching addresses of treated houses returned a 77% successful match ratio, i.e. 36,003 (of 46,655) treated houses were successfully matched.[3] Characteristics of the matched treated houses are then extracted and used to select suitable control houses. Suitable control houses have similar house characteristics as their respective treated house and will not have received any form of treatment under the NZIF scheme over the entire study period.[4]

House characteristics used to determine suitable control houses are as follows; location (Census area unit), dwelling and house type, number of levels, age (decade of build), floor area and number of bedrooms, whether there is a garage under the main roof and its size (number of vehicles), house construction material (walls and roof), whether or not the house was modernised, and quality (building and roof condition) of the dwelling. Location, dwelling and house type, and the number of levels are all mandatory matching criteria, while the remaining characteristics form non-mandatory matching criteria. Controls are chosen firstly according to the mandatory matching criteria, and, secondly, the non-mandatory matching criteria, for which a matching score was calculated and on which potential suitable controls were prioritised. 269,110 suitable control houses are found. Of the 36,003 matched treated houses, 31,423 houses possess at least one suitable control house, leaving 4,580 matched treated houses without a suitable control. Table 4 shows that for those properties with suitable controls there is an average of 8-9 controls per treated house. We use all matched controls in our analysis, calculating the mean energy use of all eligible control houses for a specific treated house. We use all eligible controls in order to reduce noise in our energy use data.

[3] Unmatched houses are subsequently removed from our sample.

[4] We cannot directly determine whether suitable control houses have been insulated or had a heater installed independently or through other schemes, or whether they are insulated or have a heater at all. The house fixed effects in our equations account for all insulation and heating characteristics of control houses that are consistent over the sample period.

[Table 4 about here]

4.3. Energy Data

To identify the energy impact of the NZIF scheme on treated houses, we require monthly energy use for the houses within our sample. In total, our sample contains 305,113 houses (treated and controls). Energy use is classed in two forms, electricity and reticulated gas.

New Zealand currently has five major suppliers of energy who collectively supply over 90% of the electricity market: Contact Energy (24.7% market share), Genesis Energy (23.9%), Mercury Energy (20.2%), Meridian Energy (12.5%), and Trustpower (11.5%).[5] While all five companies are electricity retailers, Contact Energy, Genesis Energy and Mercury Energy also supply natural gas. Gas is only reticulated to certain areas in the North Island; there is no gas reticulation in the South Island, and no data is available on use of bottled gas.

Energy use data is recorded at ICP (installation control point) level and each energy supplier must submit monthly ICP level volumes of electricity and gas use to reconciliation managers at the respective centralised authority; the Electricity Authority for electricity volumes, and the Gas Industry Company Limited for gas volumes. Submission volumes are expressed in kilowatt hours (kWh) for both electricity and gas, and include modelled and estimated levels of usage. There are distinct advantages of using these data over actual meter readings; each energy company submits data using a similar approach, thus submission volumes are consistent and comparable across companies. Also, gas meter readings cannot be easily converted into gas usage, whereas submission volumes of gas are modelled to represent usage measured in units consistent with electricity (kWh).

Requests were sent to each of the five major companies for data on monthly submission volumes for each house over the period January 2008 through to November 2010. Data on ICP level submission volumes were successfully received from four of the companies (Genesis Energy, Mercury Energy, Meridian Energy and Trustpower). Each ICP can only be associated

[5] Market shares are calculated as the percentage of energised ICPs per energy retailer. Figures are taken at November 2010. Source: Electricity Authority (http://www.ea.govt.nz/industry/market/statistics-reports/percentage-of-icps-per-retailer-graphs/).

with one address; however, addresses may have multiple ICP numbers.[6] ICP numbers and their associated addresses received from the energy suppliers were sent to QVNZ to obtain an address matching file to allow us to link houses within our sample to their respective energy usage (across all ICP numbers for that address).

Given that submission values contain modelled data, it is possible for submission volumes to be less than zero. These are obviously erroneous measures of actual energy usage; therefore, any house containing a negative submission volume is removed.[7] Splicing together data from each energy company, we generate a comprehensive energy data file of raw ICP level submission volumes of energy use (divided between electricity and gas), along with energy company indicators, one for electricity and another for gas for each address.[8] Using the QVNZ address matching file, we are able to match data on energy use to 151,383 houses within our sample; 149,287 houses for electricity use, 20,637 houses for gas use; 18,541 houses have both electricity and gas use. Table 5 and Table 6 provide figures of house counts by energy company for houses matched to electricity and gas use data respectively.[9]

[Table 5 and Table 6 about here]

We choose to analyse two samples of energy use data in this study; electricity use only and total energy use. Total energy use is defined to be the sum of electricity and reticulated gas use levels. We clean our raw energy use data to obtain datasets for analysis. Houses are not contracted to an energy supplier indefinitely, and may switch supplier at any given time for a number of reasons; for example, new tenants or owner-occupiers may have a different energy

[6] Multiple ICP numbers occur due to addresses having multiple meters. The obvious example of a property having multiple ICP numbers is when a property has both gas and electricity installed, but multiple electricity meters also occur.

[7] To preserve consistency in our energy data series, any observation that is dropped results in all observations (electricity or gas) for that particular house being removed, since it is very likely that other submission volumes adjacent to that period will also be erroneous.

[8] Energy company indicators allow us to identify which company provided the energy (electricity or gas) to the property in each period.

[9] These counts may over-represent the true number of houses in the sample, as houses may have switched suppliers during the sample period; i.e. a particular house that switched from Genesis Energy to Mercury Energy during the sample period will have matching data from both Genesis Energy and Mercury Energy, and thus be included in both Genesis Energy and Meridian Energy counts. We account for such switches when combining data across suppliers.

supplier preference to the previous occupiers. A change in occupier may result in energy use outcomes that alter during the sample period due to the change in occupiers and so may introduce some unfavourable heterogeneity that will not be accounted for by the house fixed effect. Hence, we remove any house that has switched electricity supplier at any time during the study period.[10] The result is a loss of 6,866 houses (882 treated houses, 5,984 controls) from the sample.

Figure 1 (Figure 2) provides a histogram of raw monthly electricity (gas) energy use for all houses.[11] Both figures show a skewed distribution with a right-hand tail. Figure 2 also shows a spike around zero. We proceed to clean the raw energy use data by removing houses with outlying observations. Outliers for electricity are defined to be observations outside the bottom and top 1%; i.e. observations below 30 kWh and above 2,235 kWh, and for gas, observations outside the top 1%, i.e. above 3,470 kWh[12].

[Figure 1 and Figure 2 about here]

Table 7 provides summary statistics for the raw electricity and gas use. Average use between the two forms of energy are broadly comparable; gas use is a little lower on average, but is more variable – possibly due to gas being used for more seasonal purposes (e.g. heating in winter). Removing houses with outlying electricity observations reduces the sample by a total of 19,570 (14%) houses.[13]

[Table 7 about here]

The distribution of the cleaned monthly levels of electricity use is shown in Figure 3, using data on 14,940 treated houses and 107,830 controls. Removing houses with outlying gas

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[10] Houses that switch gas supplier are retained.

[11] For graphical purposes only, houses with submission volumes greater than 5,000 kWh within a month are graphed as having 5,000 kWh for that month.

[12] Low, even zero, gas submission volumes are not deemed to be outlying; if houses only use reticulated gas for heating purposes, over summer months they will have very low (possibly zero) gas use level. Therefore, we retain the lower extreme gas submission volumes.

[13] Any observation removed results in all observations for that particular house being removed.

observations, results in 1,126 (6%) of houses with observed gas use being removed. Houses with observed gas use that is incomplete over the full sample period are removed from our sample. There are two reasons why we observe incomplete gas use across the study period. The first is that a particular house only started using (or ceased using) gas at some time during the period; the second is that the particular house switched to (from) another supplier that is not included in our data (Contact Energy). It is impossible for us to distinguish the reason that a particular house has incomplete data; therefore we remove any house with incomplete gas use. The cleaned distribution of monthly gas use is presented in Figure 4. The resultant total energy sample has 117,678 houses. Of these, 107,158 houses only have observed electricity use, 1,030 houses have only observed gas use, and 9,490 houses have both observed gas and electricity use. Houses that have only observed gas use are removed from the sample.[14] We form the total energy variable by summing the electricity and gas energy use levels for each house.

[Figure 3 and Figure 4 about here]

4.4. Climate Data

Climatic conditions are hypothesised to be a major influence on energy consumption patterns. Colder conditions generally induce higher energy demand through heating. Likewise, hot periods may increase energy demand for cooling (air conditioning) purposes.

New Zealand's national climate database provides atmospheric and climatic data across New Zealand. Currently, over 600 weather stations supply the database with climatic and atmospheric data. The National Institute of Water and Atmospheric Research (NIWA) provides access to the national climate database through its web-based system, Cliflo.[15]

We restrict the number of weather stations from which we extract data to those that have comprehensive operation across our study period, January 2008 to November 2010. 180 weather stations across New Zealand meet this condition. We map these 180 weather stations to 2006 Statistic New Zealand (SNZ) regional council boundaries to identify climatic conditions for each house's region. Regional councils (RC) that have more than one eligible weather station have one

[14] These are either erroneous or have electricity supplied by an energy company that we do not have data for.

[15] cliflo.niwa.co.nz.

weather station chosen to represent climate data for all houses located within that particular RC. This avoids complications with aggregating statistics within regions with more than one suitable weather station. To choose representative weather stations for RCs, we map weather stations to the Census area units (CAU) they are located within (or nearest to) and calculate the population density of the CAU.[16] The weather station located within the most densely populated CAU is selected as the representative station for that particular RC.[17]

For the purposes of this study, we obtain data on mean monthly air temperatures (˚C) for each of the 16 regions in New Zealand.[18]

4.5. Working Datasets

We combine the EECA, QVNZ and climate datasets into one comprehensive panel dataset that details which houses are treated and the month of treatment, characteristics of treated and control houses, and monthly climatic conditions (mean air temperature).

In this study, we distinguish between two broad categories of treatment, insulation and heating. Given that the vast majority (>80%) of heating treatments are heat pump installations, we concentrate on the effects from heat pump installations; any house that has had heating treatment other than heat pump is removed from the sample. By removing non-heat pump treatments, we clarify the direct effect on energy use from heat pump treatment.[19] We create dummy variables for each treatment type equal to 1 once a house has received treatment, and zero otherwise. Houses that receive multiple treatments of insulation have the date of treatment taken as the first period in which treatment of insulation was received.

Each energy sample, electricity and total energy, is matched to the comprehensive panel dataset to provide levels of energy use for each property (treated and control). In the final

[16] The population density is defined as the usually resident population (URP) in 2006 divided through by the area of the CAU in hectares.

[17] Although we choose one representative weather station per RC, all weather stations located within a particular RC have readings that are highly correlated with each other, so choice of station within an RC is immaterial.

[18] Data are also available from NIWA's Cliflo system for: standard deviations of daily temperatures (˚C), monthly extreme maximum air temperature (˚C), monthly extreme minimum air temperature (˚C), mean vapour pressure (hPa), and mean 9am relative humidity (%).

[19] Flued gas heaters would also provide a direct effect on energy use; however, given there are so few observations, we simplify our analyses by focusing solely on heat pump heater installation.

sample, 119,459 houses (including 14,236 treated houses) have matching electricity use data, while 113,493 houses (including 14,236 treated houses) have matching total energy use data.

4.5.1. The Dependent Variable

To analyse the impact on energy use of being treated under the NZIF scheme, we use the respective control houses for each treated house to form the explicit difference in energy use (electricity or total) between treated and control houses. Each treated house is matched to the mean of its control houses. The difference in energy use ($EnergyDiff_{it}$) between a treated and its control houses is calculated by subtracting the average energy use (electricity or total) of the relevant control houses from the energy use (electricity or total) of the treated house in each period:

$$EnergyDiff_{it} \equiv Energy_{it}^{Tr} - \overline{Energy_{it}^{C}}$$

where $Energy_{it}^{Tr}$ is the energy use of treated house *i* in period *t*; and $\overline{Energy_{it}^{C}}$ is the average energy use of the respective control houses for treated house *i* in period *t*.

Control houses must contain a data series of energy use that is consistent with that of their treated house. If no controls have data consistent with the treated house data, the house(s) with the longest consistent data series are used, provided there are a sufficient number of observations pre- and post treatment. (Thus we utilise an unbalanced panel dataset.) Treated houses which do not have any suitable control houses are removed.

4.5.2. Working Dataset Descriptive Statistics

The resultant sample size for electricity is 12,056 treated houses, with 324,468 (house-month) observations, and the resultant sample size for total energy is 11,381 treated houses, with 310,220 (house-month) observations. Table 8 provides summary statistics for both working datasets. The average treated house for both datasets is very similar; they are built during the 1950s, have floor areas of approximately 134m^2 split across two levels, and contain three bedrooms. The average monthly mean temperature across the study period is just below 14°C.

Figure 5 display the distributions of mean monthly air temperatures for electricity.[20] For both datasets, over 95% of mean temperatures lie between 7˚C and 20˚C.

[Table 8 about here]

[Figure 5 about here]

The average treated house uses 614 kWh of electricity per month, 24 kWh less per month than the mean of its control houses, and 672 kWh of total energy per month, approximately 30 kWh less per month than the mean of its controls. Summing the energy difference for the 12 months prior to the scheme, we find that treated houses used on average 189 kWh (228 kWh) electricity (total energy) less than their control houses. Simple t-tests are carried out to find that these values are significantly different from zero (Table 9). This suggests that houses seeking treatment under the NZIF may already have been 'energy-conscious' households.

[Table 9 about here]

Figure 6 shows that the majority of treated houses are bungalow-type buildings (i.e. detached houses with one or two stories). Over 90% of treated houses are classed as residential dwellings (i.e. single-family, detached or semi-detached houses); the remainder are predominantly flats/apartments. The number of treated houses in each RC is presented in Figure 7. The Auckland region has the most treated houses, followed by Wellington and Canterbury. Figure 8 present the number of houses in each RC as a percentage of the total residential dwellings within that RC. Once we take into account the total number of residential dwellings within each RC, we see that treated houses represent 1-1.5% of the total number of dwellings; Hawke's Bay, Tasman and Southland, have smaller representation.

[Figure 6 – Figure 8 about here]

[20] For Figure 5 through to Figure 8, the total energy equivalent figures are almost identical and therefore are not presented.

5. Discussion

The Warm Up New Zealand: Heat Smart programme, also known as the New Zealand Insulation Fund (NZIF), involves a major part-publicly-financed effort to improve the insulation and heating of New Zealand houses. Prior research had shown that many New Zealand houses are poorly insulated, draughty and rely on inefficient or poorly performing heat sources(such as unflued gas heaters or open fires).

In the first 11 months of the programme, which began in July 2009, over 43,000 houses received insulation treatment and over 10,000 houses received heating treatment, of which the overwhelming majority involved installation of electric heat pumps. Households that receive treatment may use the thermal benefits obtained from insulation in two ways. First, they may maintain the same energy usage with the result that the house will be warmer than it would have been had it not been treated; it is even possible that energy usage could rise in cold weather if households considered it beneficial and cost-effective to heat more rooms than they had done previously in the absence of insulation. Second, at the other extreme, they can maintain the same internal temperature as they had prior to treatment and take all the benefits through reduced energy usage for heating.

A non-corner solution suggests that the thermal benefits may be taken as a mix of increased internal temperatures and reduced energy usage. Another possible effect is some variant of the "take-back" or "rebound" effect whereby households may become accustomed to a warmer house in winter and thereby increase their energy usage at other times when they would otherwise not have used heating. This could raise energy use in some months relative to the untreated case.

Installation of heat pumps is considered likely to increase energy usage for treated homes as they have access to improved heating technology. In addition, the potential to use heat pumps as air-conditioning units may increase energy use in summer months, particularly in the hotter parts of the country. There is nevertheless the possibility that, in cooler months, installed heat pumps could displace other, less efficient, forms of heating and so reduce total energy usage for treated houses.

Given the range of energy outcomes that could result from insulation and heating treatment, and the lack of knowledge of the size (or even direction) of these effects, it is important to evaluate how energy usage has changed for treated houses. This information is useful in contributing to an overall evaluation of the outcomes (including health outcomes) of the NZIF programme.

Each of the specifications outlined in section 3 will be estimated using a fixed-effects OLS estimator. Fixed effects will be included for each house in all specifications, and time (month) fixed-effects will be included. For those equations that interact temperature with treatment variables, we will replace time fixed-effects with region*time fixed-effects (in addition to the house fixed-effects).

Preliminary results need to be subjected to the extensions outlined in section 3 before they can be adopted as final results, and so no conclusions are drawn at this stage on the degree of savings engendered by the NZIF scheme.

A sample of over 11,000 treated houses covering the first 17 months of the scheme is used. Houses covered by four of the major five energy companies are included in our sample but we do not have data for houses that purchase their energy (electricity or gas) from Contact Energy. While we do not expect this to cause any material problems for our electricity estimates, this missing data could contaminate our results for total energy usage where households purchase electricity from one of the four included suppliers but purchase their gas from Contact. In addition, the impossibility of obtaining reliable data for non-reticulated gas usage (especially for the South Island) creates some difficulties for total energy usage estimates. For these reasons, we will place most emphasis on the reliability of the electricity results although conceptually, the total energy impacts may be of most relevance.

Other features of the data may also affect our results. The temperature-based models in section 3 specify the use of average monthly regional temperatures to assess the magnitude of the treatment effects, but this may lead to attenuation bias in the presence of non-linear effects related to temperature. One possible extension that we will investigate is to add minimum monthly temperature, a monthly temperature range, or a daily standard deviation measure to our model to estimate if further non-linear aspects are at work in this manner.

This study forms just one component of a broader evaluation of the NZIF programme; other components examine the health impacts of the scheme and the employment and output effects of the scheme. Together, these components can be used to assess the costs and benefits of the scheme as a whole. No such conclusions can be drawn on the basis of the energy study alone, or from any one of the other studies. Overall conclusions will, however, be drawn once all the studies have been completed.

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Table 1: Treatment Category Uptake

Treatment Category	No. Houses Treated
Insulation Only	36,102
Heating Only	3,611
Both Insulation and Heating	6,942
Total Houses	46,655

Table 2: Treatment Uptake by Type

Treatment Type	No. Houses Treated
Ceiling Insulation	36,606
Draught-proofing	7,834
Hot Water Cylinders	6,507
Underfloor Insulation	30,723
Other Insulation-related	1,400
Flued Gas Heater	56
Heat Pump	8,862
Wood/Pellet Burner	1,636

Table 3: House Counts of Multiple Treatment Types

Treatment Type	Draught-proofing	Hot Water Cylinder	Underfloor Insulation	Other Insulation-related	Flued Gas Heater	Heat Pump	Wood/Pellet Burner
Ceiling Insulation	7,096	5,841	24,400	1,103	30	4,985	966
Draught-proofing	-	3,263	6,098	178	8	582	158
Hot Water Cylinders	-	-	5,035	267	3	546	200
Underfloor Insulation	-	-	-	1,112	26	3,438	685
Other Insulation-related	-	-	-	-	4	215	20
Flued Gas Heater	-	-	-	-	-	0	0
Heat Pump	-	-	-	-	-	-	1

Table 4: Controls per Matched Treated House

No. of Controls	No. of Treated Houses
1	1,067
2	985
3	1,043
4	958
5	973
6	964
7	1,003
8	948
9	962
10	22,520
Total	31,423
Mean	8.65

Table 5: Electricity Usage - Counts of Matched Houses by Energy Company

Energy Company	Treated Houses	Control Houses	Total
Genesis	4,552	37,485	42,037
Mercury	4,271	31,902	36,173
Meridian	6,301	40,188	46,489
Trustpower	4,260	31,352	35,612
Total*	19,384	140,927	160,311

* This total may overrepresent the true number of matched houses (see footnote 9 for more detail).

Table 6: Gas Usage - Counts of Matched Houses by Energy Company

Energy Company	Treated Houses	Control Houses	Total
Genesis	1,862	15,015	16,877
Mercury	478	3,470	3,948
Total*	2,340	18,485	20,825

* This total may overrepresent the true number of matched houses (see footnote 9 for more detail).

Table 7: Summary Statistics of Raw Monthly Energy Data

Summary Statistic	Electricity (kWh)	Gas (kWh)
Mean	677.62	656.26
Std. Dev.	514.05	785.94
Percentiles:		
1%	32.15	0
5%	182.87	2.97
10%	254.13	35.94
25%	386.8	221
50%	576.35	451.18
75%	846.9	833.82
90%	1211	1466.59
95%	1501.18	2014.68
99%	2235	3467.19
Monthly Observations	3,881,129	547,569

Table 8: Summary Statistics for Working Datasets

	Electricity Sample			Total Energy Sample		
Variable	Observations	Mean	Std. Dev.	Observations	Mean	Std. Dev.
Build Decade	324,400	1955	22.37	310,152	1956	22.11
Floor Area	324,244	134.30	47.35	310,012	133.58	46.85
Number of Bedrooms	318,788	3.07	0.66	304,682	3.07	0.66
Main Roof Garages	300,293	0.50	0.76	286,078	0.50	0.76
Levels	324,468	1.87	0.33	310,220	1.87	0.33
Monthly Mean Temperature	324,468	13.74	3.71	310,220	13.72	3.71
Energy Use (Treated House)	324,468	613.95	334.45	310,220	672.37	405.80
Energy Use (Control Houses)	324,468	638.25	266.44	310,220	701.92	336.89
EnergyDiff	324,468	-24.30	343.67	310,220	-29.56	407.41

Table 9: t-test Results for 12 Month Pre-NZIF EnergyDiff

	Electricity	Total Energy
Mean	-189.47	-228.27
Standard Error	28.51	34.56
H_a: mean<0 (p-value)	0.0000	0.0000
H_a: mean≠0	0.0000	0.0000

Figure 1: Distribution of Raw Monthly Electricity Usage

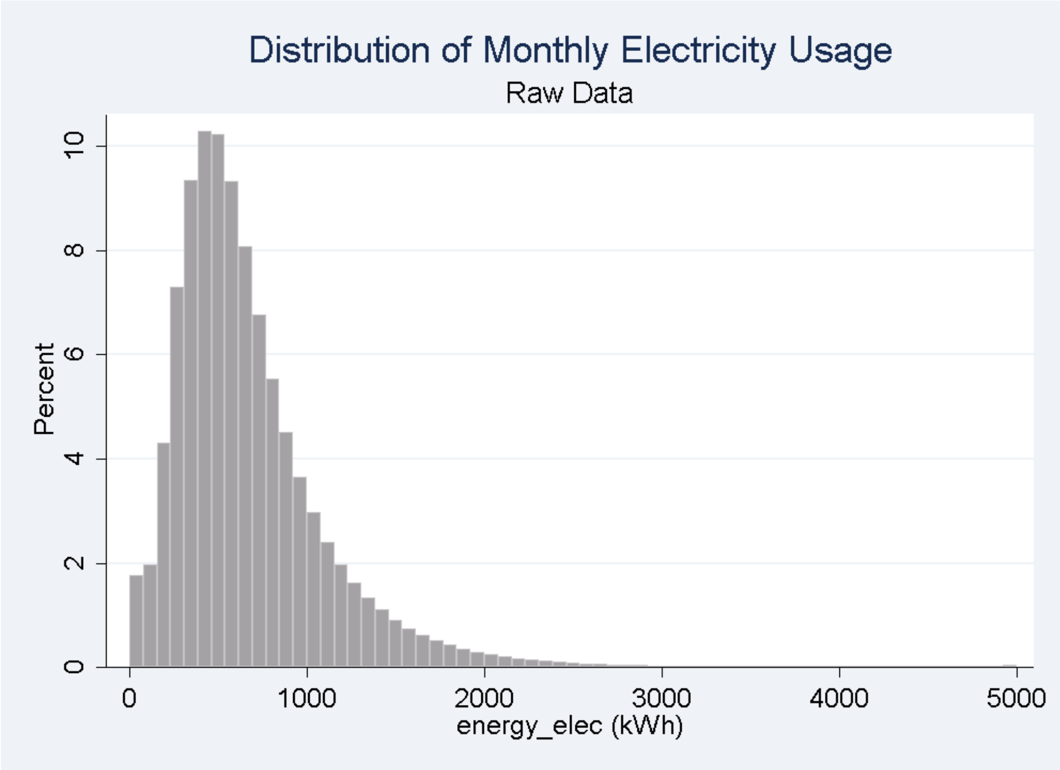

Figure 2: Distribution of Raw Monthly Gas Usage

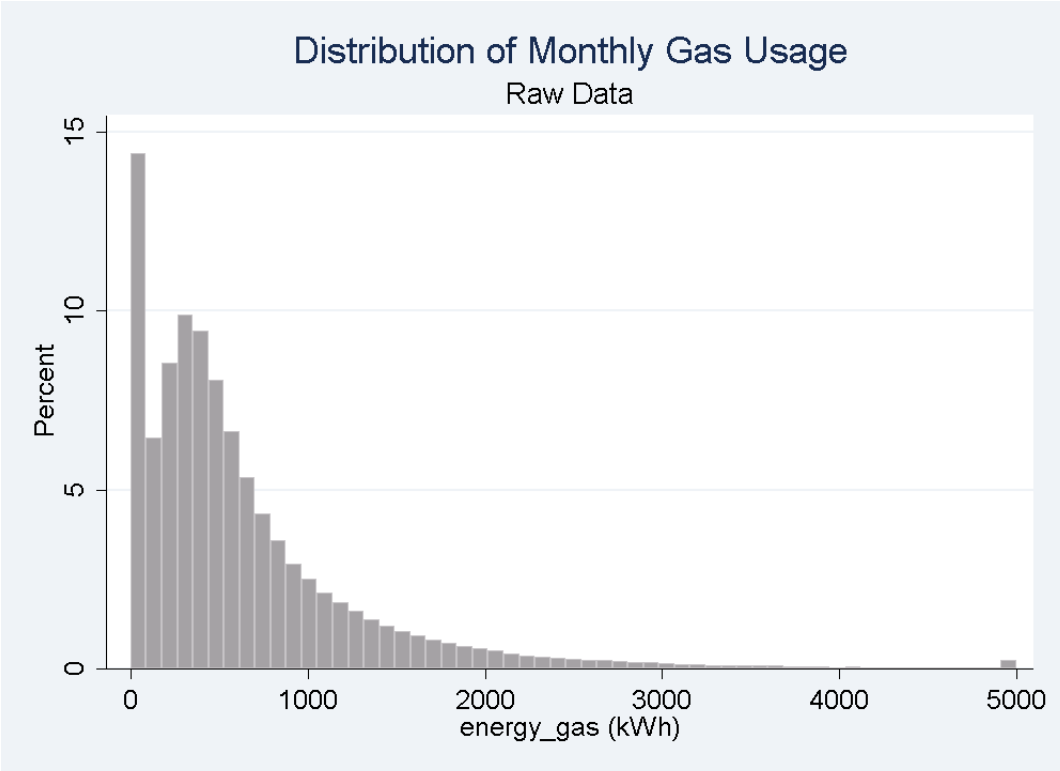

Figure 3: Distribution of Cleaned Monthly Electricity Usage

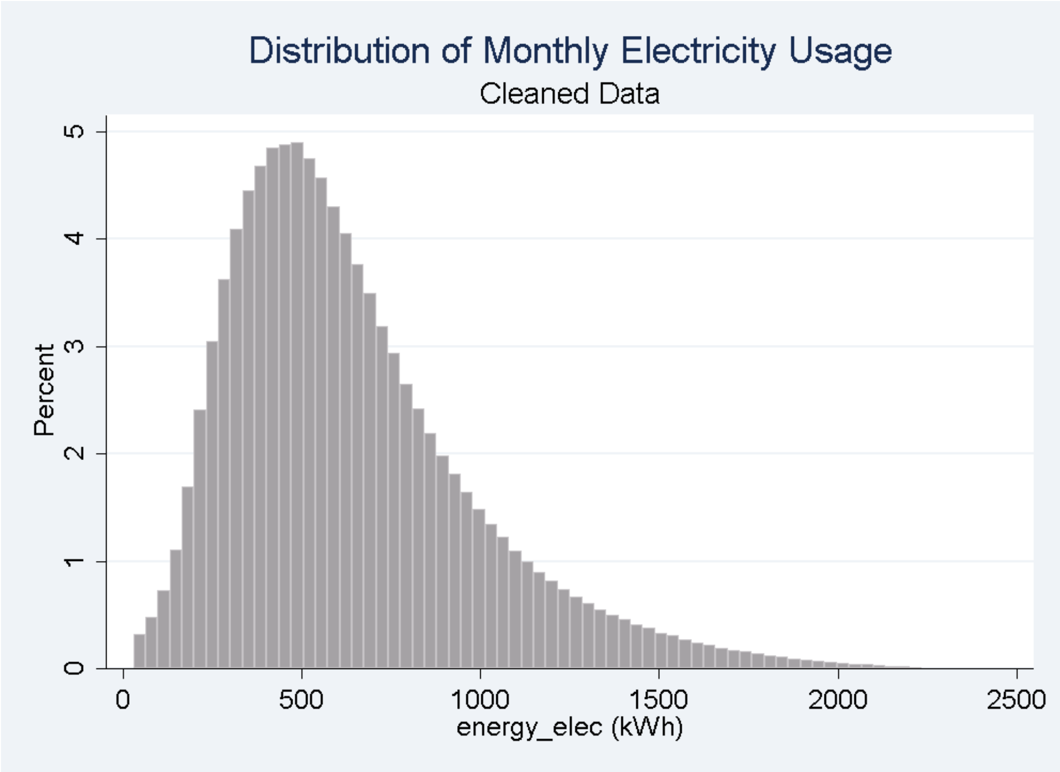

Figure 4: Distribution of Cleaned Monthly Gas Usage

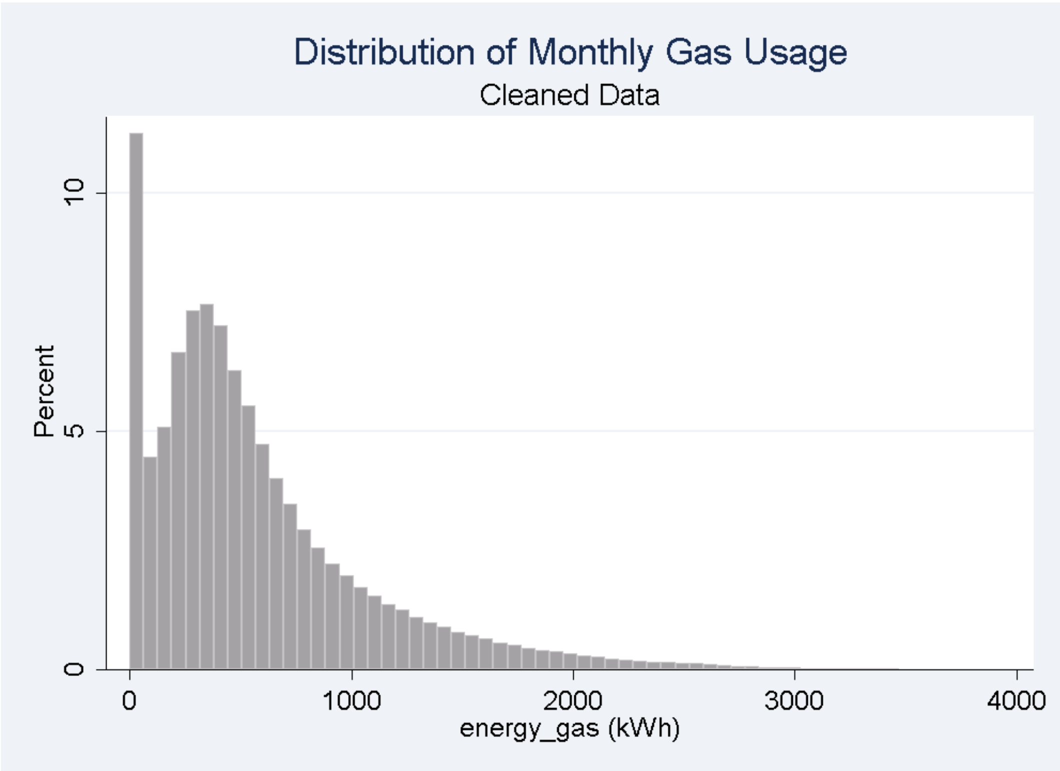

Figure 5: Distribution of Electricity Mean Monthly Temperature

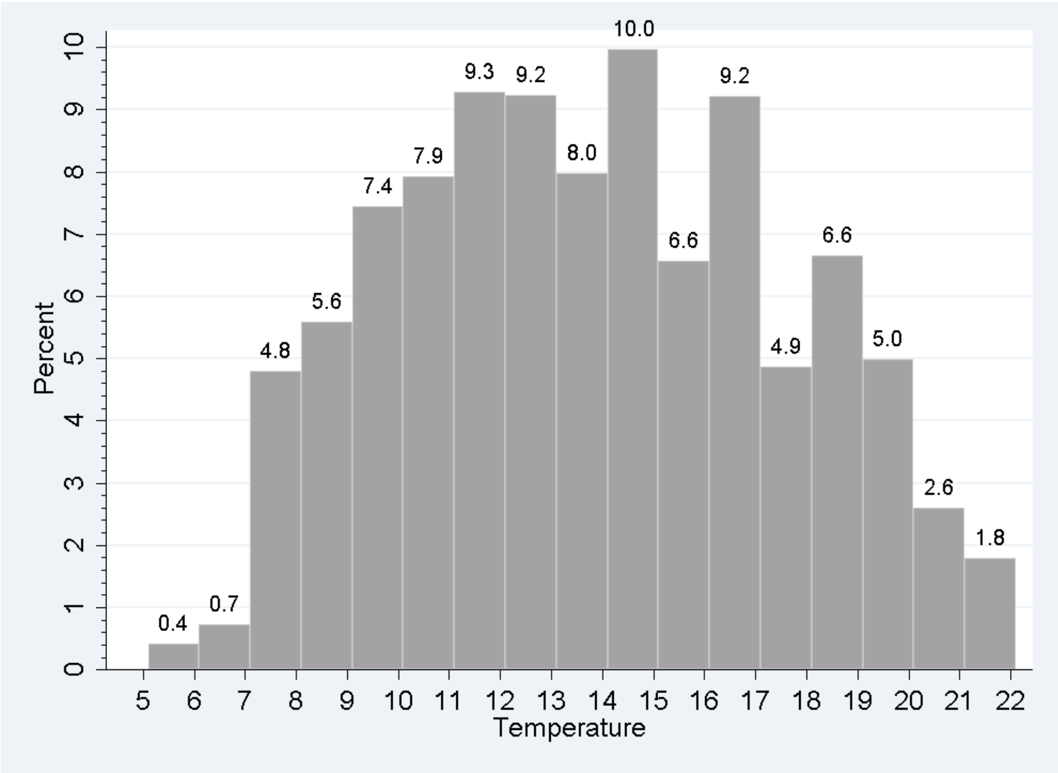

Figure 6: Electricity Treated Houses by House Type

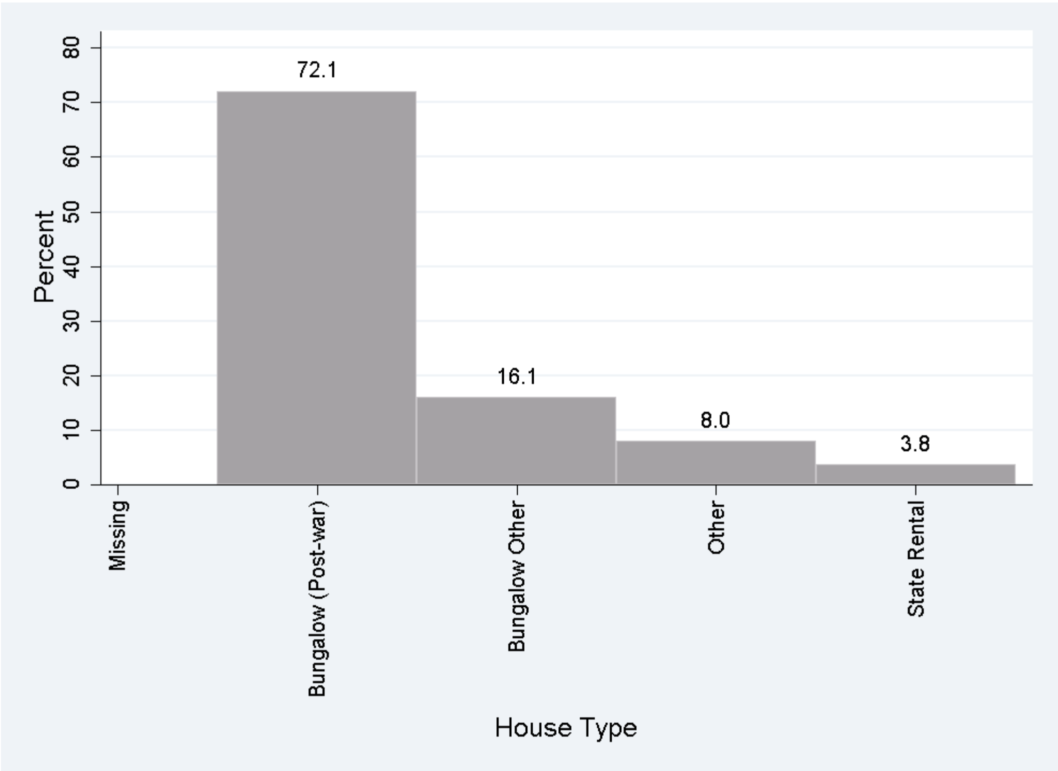

Figure 7: Frequency of Electricity Treated Houses by Regional Councils

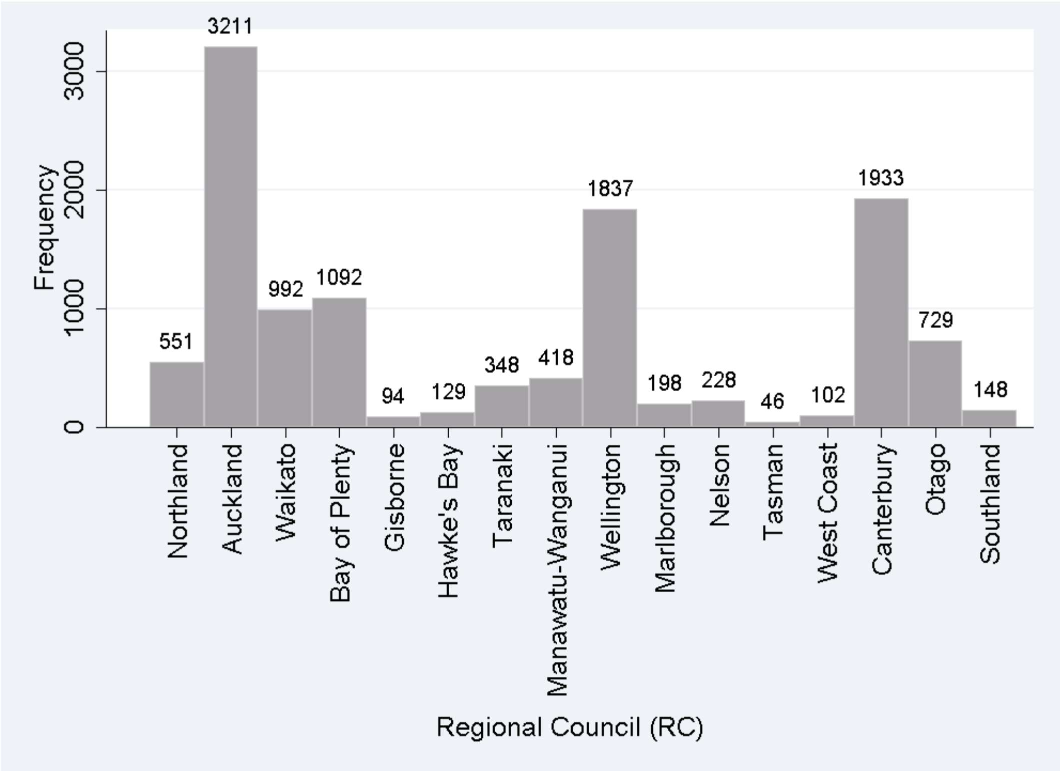

Figure 8: Percent of Electricity Treated Houses to Total Regional Dwellings