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

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Background

We analyse the impacts on monthly metered electricity and reticulated gas use of the houses retrofitted with insulation or clean heat source under the New Zealand Insulation Fund (NZIF) programme, titled "Warm Up New Zealand: Heat Smart" (WUNZ:HS). Our study covers the period from the scheme's introduction in July 2009 to November 2010.

New Zealand's energy profile shows that electricity is the most prominent energy source used in residential houses, followed by solid fuels and gas. For residential space heating, specifically, the energy profile identifies that solid fuels are the most prominent energy source used, with electricity and reticulated gas following in importance. Our study directly measures impacts of WUNZ:HS on total household electricity and reticulated gas use (not just on space heating energy use). We provide a test of whether the impacts on metered energy use differ according to whether a house already uses a non-metered energy source for heating.

Previous research in this area has found that energy and electricity savings are made from retrofitting houses with insulation, but the effects from installing clean heating sources are dependent on a number of factors, such as the type of clean heating source being installed, the source of heating being replaced, temperature, and how households choose to receive any energy savings.

Methodology

Between July 2009 and May 2010, 46,655 houses had retrofitted insulation or had a clean heat source installed under WUNZ:HS. The Energy Efficiency and Conservation Authority (EECA) provided addresses of these houses. Quotable Value New Zealand Limited (QVNZ) successfully matched 37,163 (79.7%) of these houses to their property listing.

Up to 10 similar "control" houses were then matched by QVNZ to each of the "treated" houses that participated in WUNZ:HS. Control houses had to meet certain matching house characteristic criteria (including location, age, dwelling type and size) to be considered; 31,423 treated houses (67.4% of total treated houses) were able to be matched to at least one suitable control house.

Monthly household submission levels for metered electricity and reticulated gas were then matched to treated and control houses. These submission levels were measured in kWh.

While electricity was available to all households, reticulated gas is only available in parts of the North Island. Regional monthly average temperatures were also obtained for treated and control houses in the sample.

A 'difference-in-differences' approach was adopted to analyse the impacts of retrofitted insulation and heat pump installation on monthly household electricity and total metered energy use (defined to be the sum of metered electricity and reticulated gas use). This approach meant that the difference in monthly electricity and total metered energy use, between treated and control houses, was compared before and after insulation and/or a heat pump was installed. Heat pump installation comprised over 80% of all clean heat installations, and we focus on this type of clean heat installation in determining its direct effect on electricity and total metered energy use. The estimated model to determine the metered energy impacts of retrofitted insulation and clean heat installations controlled for house characteristics, time-varying characteristics (including changing prices over time) and regional characteristics.

Extensions to the main model were analysed. Extensions included: allowing impacts to differ between houses that received only retrofitted insulation or heat pump installation, relative to those with both retrofitted insulation and heat pump installation; allowing impacts to differ by household income level; analysing the effect of all clean heating installations; incorporating the effect of within-month temperature variation; testing the sensitivity of results to data cleaning criteria; allowing effects to differ between houses with and without reticulated gas; and accounting for effects of non-metered energy sources.

Results

Electricity savings and total metered energy savings were found for houses that had insulation retrofitted under WUNZ:HS. Magnitudes of the savings, while statistically significant, are quite small. Our preferred estimate (based on a cleaned dataset) finds that 0.96% of average annual household electricity use is saved as a result of having insulation retrofitted, while 0.66% of average annual total metered energy is saved. Some other estimates (based on broader samples) show greater savings, with up to 1.41% electricity savings and 1.03% total metered energy savings.

Figure ES1 (which reproduces Figure 13 in the main body of the report) summarises each of the electricity and total metered energy effects for houses that have insulation and heat pumps respectively installed through the WUNZ:HS scheme. Energy use is measured in kilowatt hours (kWh) per month. Changes in metered energy use for a treated house relative to its control house(s) are shown according to the average monthly temperature by region. A metered energy saving [increase] as a result of treatment is indicated where the respective line is below [above] zero. These results relate to our preferred estimate; other figures in the main body of the report summarise effects using different samples (and split samples) of houses.

Figure ES1: Treatment Effects by Temperature (Preferred Cubic Specification)

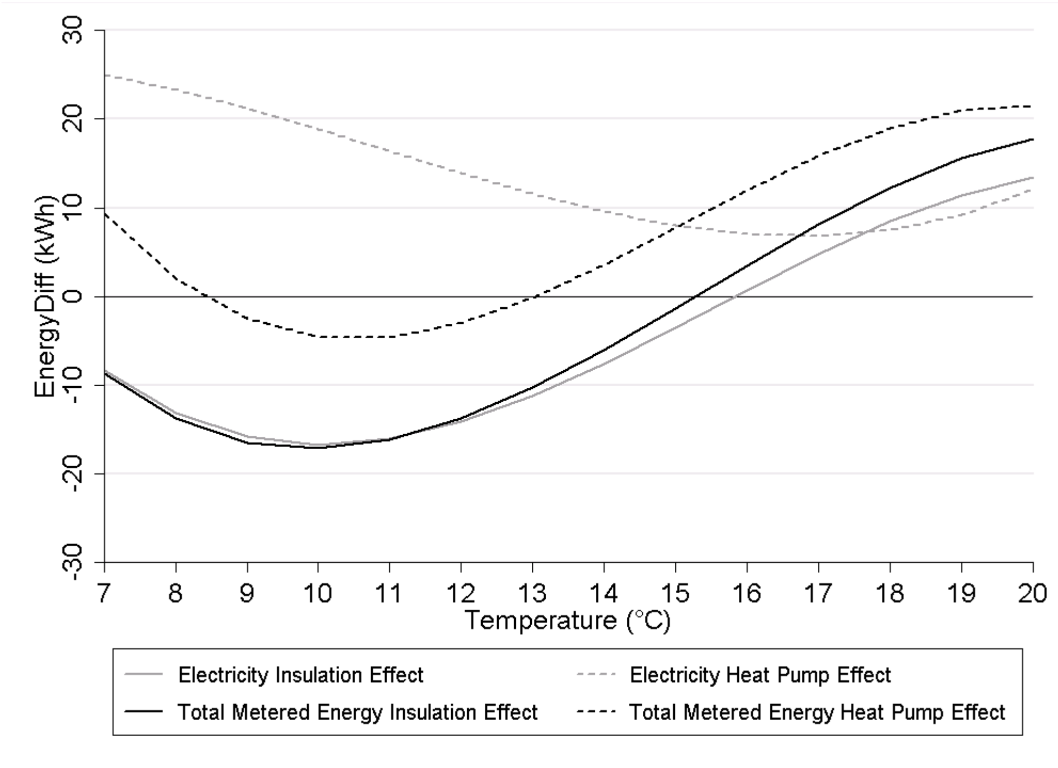

Figure ES1 shows that electricity and total metered energy savings are sensitive to external temperatures. At temperatures below 16˚C, houses that received retrofitted insulation save on electricity use, and below 15˚C, houses with retrofitted insulation save on total metered energy use. Above these temperatures, increased electricity and total metered energy use is found.

Houses that installed a heat pump under WUNZ:HS were found to increase their electricity use (1.92% increase in average annual metered electricity consumption). Total metered energy use of treated houses also increased as a result of heat pump installation (0.75% increase in average annual total metered energy consumption).

Following installation of a heat pump, electricity use of treated houses increased as external temperatures fell. In contrast, except at very cold temperatures (less that 8˚C), total metered energy use fell as temperatures decreased. Total metered energy savings were observed at temperatures between 9°C and 13°C following heat pump installation.

We found no difference in impacts of retrofitted insulation and heat pump installation on electricity and total metered energy use when we separated houses according to whether they had only retrofitted insulation or a heat pump installed, versus both types of installation. The inclusion of monthly variation of temperatures into the model also did not significantly impact metered energy savings behaviour.

Treated house income was not found to have a strongly significant effect on the impact on electricity and total metered energy use of either retrofitted insulation or heat pump installation. Two methods were used to divide treated houses into high and low income brackets: separation by census area unit (CAU) or "suburb" median income level, and separation by whether a treated house held a Community Services Card (CSC). The former approach did provide some weak evidence that lower income households may make greater energy savings than higher income households at low external temperatures after retrofitted insulation is installed.

The wider definition of clean heat installation (i.e. including sources other than heat pumps) indicated greater electricity and total metered energy savings for treated houses as temperatures fell below 12°C. This result implies that installation of solid fuel heaters leads to electricity and total metered energy savings; however, owing to data constraints, we cannot conclude whether total energy savings are made by these households.

Re-introduction of houses previously excluded as being outliers indicated that at the coldest temperatures, metered energy savings were greater than the savings found with a more tightly defined sample. This indicates that the findings from our tighter sample may represent a conservative estimate of energy savings from WUNZ:HS.

The separation of impacts into groups of houses that previously relied on non-metered fuel sources for heating and those that did not, showed some weak evidence that a house previously using non-metered fuel sources for heating saves more electricity than other houses after insulation was retrofitted (at the same time as a heat pump was installed). However there was no statistically significant indication of differences between the groups in terms of total metered energy use.

Houses that have access to both electricity and reticulated gas were found to make substantial total metered energy savings after a heat pump was installed. These savings increased as temperatures fell. In comparison, houses with only access to electricity were not impacted significantly as a result of having a heat pump installed. This result indicates that fitting a heat pump to a house previously using reticulated gas for heating results in energy efficiency savings.

Conclusions

The results indicated that retrofitted insulation did, on average, reduce metered energy usage (electricity and reticulated gas) of treated houses. A conservative estimate is that the annual reduction in household electricity use is in the order of 0.96% and the annual reduction in total metered energy usage (electricity plus reticulated gas) is around 0.66%. Since metered energy used for space heating represents only 16% of total metered household energy use (EEUD, 2007), the implied savings on metered energy used specifically for space heating are considerably higher at approximately 6% and 4% respectively.

The treatment effects vary according to outdoor temperatures. The greatest metered energy savings occur at moderately cold temperatures (monthly temperature average of 10ºC). Savings were also observed at colder temperatures, but the savings were not as great as at milder temperatures. At the coldest temperatures, we hypothesise that households took a greater part of the thermal benefits from insulation as warmer internal house temperatures (relative to temperatures in the absence of treatment) and a lesser proportion as metered energy savings. For temperatures that were well above the minimum, results suggested some evidence of a "take-back" effect, whereby houses used more energy than without treatment as householders became accustomed to warmer houses.

In contrast with the insulation treatment results, the impacts of heat pump treatment mostly showed increased annual electricity and total metered energy use for houses that had a heat pump installed across the whole range of external temperatures, with the greatest increase in electricity use occurring for houses in cold regions. An exception to this result is that houses that already used reticulated gas for heating made total metered energy savings at colder temperatures following heat pump installation.

Most extensions to the model gave results that were qualitatively unaffected by the extension. Where extensions had estimated treatment effects that differed from the main specification, they tended to indicate that the original model may underestimate the metered energy savings made by treated houses. The results from the main specification should therefore be treated as conservative estimates of energy savings.

This study could not directly account for energy savings made from non-metered energy heating sources (solid fuels, LPG gas, etc). It attempted to do so indirectly by comparing electricity and total metered energy treatment effects according to whether houses initially had a non-metered energy heating source. This information was available for a subset of houses that received clean heat treatment. No significant difference in total metered energy use was found between houses that already had these additional energy sources relative to houses that did not. However, the number of houses eligible for this test was small (at 418) and this may have contributed to the lack of statistical significance. To the extent that houses with non-metered energy heating sources reduce non-metered fuel use following treatment, our results will also provide a conservative indication of total energy savings.

Overall, we find that even our conservative estimates show that energy savings have resulted from WUNZ:HS. The results also imply that certain forms of scheme targeting could be investigated to further increase the average energy savings made. Firstly, retrofitted insulation results in larger household energy savings in cooler regions than in warmer regions. Secondly, while heat pump treatment generally results in higher total metered energy use, it results in total metered energy savings in households that already have access to reticulated gas for heating. Thirdly, two of our extensions indirectly imply that households equipped with solid fuel burners prefer to maintain use of these burners in place of heaters using metered energy sources. Thus if the intention is to reduce metered energy use, installation of solid fuel burners may be favoured.

1. Introduction

Programmes aimed at retrofitting houses with insulation are considered 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.

According to OECD standards, New Zealand homes are poorly constructed and heated (Howden-Chapman et al, 2009; Phillips and Scarpa, 2010). In 1978, the building code was updated to include mandatory insulation in newly built housing; prior to 1978, there were no requirements for new housing to be insulated (Phillips and Scarpa, 2010). Only one-third of New Zealand's current housing stock was built after 1978 when mandatory insulation was introduced (Howden-Chapman, 2009).

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.[1] Operating under the title "Warm Up New Zealand: Heat Smart" (WUNZ:HS), 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 that are insufficiently insulated (Energy Efficiency and Conservation Authority, 2011b). This study forms one part of a larger programme funded by the New Zealand Ministry of Economic Development analysing the impacts of WUNZ:HS on energy demand, health outcomes and employment. We analyse the effect on metered household energy demand of those houses that have had retrofitted insulation and efficient clean heating

[1] Households that hold a Community Services Card can access greater funding assistance (up to 60% of the cost of insulation).

installed under the programme. The purpose is to estimate whether there are significant changes in metered energy consumption behaviours resulting from the treatments.

The main findings are that there are significant, but quite small, effects on metered household energy consumption as a result of treatment received under WUNZ:HS. Houses that were insulated generally save on energy, while efficient heating (via heat pump installation) is found to increase metered energy use. Insulation treatment is most effective in saving metered energy in the presence of cool, but not very cold, temperatures, although energy savings are still seen with the coldest temperatures. Insulation is not effective in saving energy with warm temperatures, and we find evidence supporting a variant of the 'take-back' effect, whereby households become accustomed to a warmer internal temperature with subsequent increases in metered energy consumption to maintain this level. The results found relate to monthly energy demands. A variety of extensions indicate that these findings are qualitatively robust to changes in sample size and definitions. The Conclusions and Executive Summary note where material nuances occur and what these may mean for the potential for targeting of the scheme.

Section 2 of the paper provides a brief background review of prior studies of the impact of insulation and related treatments on outcomes for households, and presents the household optimisation problem. Section 3 outlines our methodology, section 4 describes the data used in the study and the main results are presented in section 5. Extensions to the analysis are found in section 6, with conclusions and discussion in section 7.

2. Background and Household Optimisation

Isaacs et al (2006) analysed residential energy use in New Zealand from 1995 to 2005, as part of the Household Energy End-use Project (HEEP). They found that New Zealand households' total energy use is predominantly reliant on electricity (69%), followed by solid fuels (20%) and gas (9%), meaning that metered energy makes up over 75% of total energy use in New Zealand. The picture for residential space heating energy use is very different: solid fuels (wood, coal, etc) are identified as the main source of space heating fuel (56% of total energy used for space heating), followed by electricity (24%) and reticulated gas (14%); total metered energy therefore comprises 38% of residential space heating energy. Solid fuel heating sources are used in 52% of New Zealand households, and the percentage is higher in cooler and rural areas. EEUD (2007) finds that 16% of metered household energy is used for space heating (13% of electricity use and 38% of reticulated gas use). Our study refers to total household metered energy use, not just to space heating energy use.

Houses that retrofit insulation or install efficient clean heating become more energy efficient and thus are hypothesised generally to conserve energy. Energy savings are associated with households retrofitting insulation (Phillips and Scarpa, 2010), and previous studies on the effects of retrofitting insulation have found that houses save energy (Chapman et al, 2009; Howden-Chapman et al, 2009; Orion, 2004). Chapman et al (2009) find that a typical household benefits from an approximate decrease of 5% in their metered energy consumption (electricity and gas) after they retrofit insulation. Retrofitted insulation is also found to significantly decrease average peak electricity consumption by 18% during winter months (Orion, 2004). However, Isaacs et al (2006) suggest that large energy savings from retrofitting insulation cannot be expected and while small total energy savings are possible, the majority of savings may come from non-electric sources.

As technological advances improve the energy efficiency of heating, less energy is needed to produce the same amount of heating (Berkhout et al, 2000). Given the largest proportion of New Zealand total household energy consumption comprises space heating (34%), energy savings may be observed once a house installs more efficient heating sources (Isaacs et al, 2006). Preval et al (2010) quantify energy savings as a result of having heating installed. Although their findings are not statistically significant, they conclude that houses subject to intervention save on average $25.53 per year on total energy, but on average spend $10.51 more from electricity use. A 2009 Orion Ltd study of the impact of Environment Canterbury's Clean Heat project, in which houses can install clean air approved heating appliances (along with any necessary insulation) at subsidised costs, found that, on average, electricity usage for homes participating in the project did not change after the first year and a 2% savings was experienced in the second year after installation. Electricity savings are dependent on the heating source being replaced (Orion, 2009). Replacing open fires results in electricity savings irrespective of the new heating source; however, woodburner replacement increases electricity use if replaced with a heat pump, but saves electricity if replaced with another solid fuel or gas heater (Orion, 2009).

Households can take 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). This phenomenon is known as the 'take-back' or 'rebound' effect; households effectively 'take-back' some of the potential savings resulting from increased energy efficiency via increased comfort levels.[2] As heating efficiency improves (i.e. as the effective marginal cost of heating falls), it is less costly to obtain the same amount of heat, enabling households to increase their overall heating without any additional cost and further improve comfort levels (Berkhout et al, 2000; Howden-Chapman et al, 2009). For example, a household, after heating efficiency improvement, may choose to make no energy cost savings, and increase their overall energy consumption by heating more rooms than it did previously to further improve the comfort level of the house. Therefore, actual levels of energy savings from improved energy efficiency are dependent on the magnitude of the take-back effect (Phillips and Scarpa, 2010).

In one randomised control trial, Howden-Chapman et al (2005) finds households were split evenly between taking energy savings as cash savings and increased temperatures (i.e. increased comfort levels). However, post-installation, the majority of houses that had retrofitted insulation 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. Households located in the warmer regions heat their houses for a shorter amount of time than in cooler regions (Isaacs et al, 2006). 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).

Targeting of these types of schemes can influence their effectiveness. Restricting funding to low or middle income households may not achieve the level of uptake policy makers desire. Opening up funding to all income levels may lift uptake rates, but may offer less assistance to those households most in need. Also, owner-occupied houses have more incentives to enter into such programs and improve the living standards of their properties, as they receive the subsequent benefits after bearing the costs. Landlords of rental properties do not have the same incentives, given that they bear the capital costs of installation, but benefit streams are received by tenants and may not be fully reflected in increased rents (Howden-Chapman et al, 2009).

The studies cited above 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

[2] The terms 'take-back' and 'rebound' are used interchangeably throughout the literature. To reduce confusion, we utilise the 'take-back' term to describe the phenomenon throughout this paper.

(such as Howden-Chapman et al, 2005) is that a randomised control trial (of households that meet the criteria for the trial) can be carried out, 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 owners 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 the age restriction of the house). However, the design of the programme was such that no randomisation of treatment was considered and so our methodology (outlined in Section 3) has to use quasi-experimental methods to assess the energy impacts of the scheme.

Before explaining our methodology, section 2.1 presents the theory behind the household optimisation problem with respect to insulation to frame our analysis. For readers that wish to skip the technical aspects of the theory (moving directly to section 3), its predictions can be summarised as follows: the model predicts that energy savings due to installation of insulation may be greatest where temperatures are cool, but the savings due to insulation may tail off both as temperatures become extremely cold and as temperatures become warm. It is possible, for both technological and preference reasons, for energy consumption to increase in some circumstances after insulation has been installed. Furthermore, the installation of heat-pumps may increase energy usage both at very cold temperatures and at very warm temperatures, when they can be used as air-conditioners to alleviate conditions that are too hot. The effect of heat-pumps on energy usage at moderate temperatures is ambiguous, although they are likely to cause at least a switch in energy usage towards electricity and away from other energy sources.

2.1. The Household Insulation Problem

To motivate the economic analysis of the impact of insulation on energy usage, consider the following household problem. The household's utility (*U*) is defined over both internal house warmth (*w*) and other consumption (*c*), with $u_c > 0$, $u_w > 0$, $u_{cc} < 0$, $u_{ww} < 0$, where a single (double) subscript indicates a first (second) partial derivative with respect to the subscripted variable. Prior to insulation being retrofitted, the household owns a certain number of heating appliances. We assume that the number of such appliances is held constant following insulation given that there is no need to increase heating appliances following insulation and there may be little or no market for used appliances. Even if a market for such appliances exists, households are unlikely to sell appliances immediately after insulation is retrofitted since they will wish to observe how effective the new insulation is prior to dispensing with some appliances. Consistent with this observation, and given that our study covers only the initial period of the scheme, the number of existing appliances is suppressed in the model.

Given the number of heating appliances, we hypothesise that internal house warmth (*w*) is a positive function of each of: external temperature (*temp*), energy usage for heating purposes (*e*), and whether or not the house is insulated (*insul* = 1 if insulated; = 0 otherwise). Energy usage for heating purposes, *e*, is constrained to be non-negative and is limited by an upper threshold (*h*) determined by the capacity of heating appliances within the household. Given previous assumptions, *h* does not change if a household switches from *insul* = 0 to *insul* = 1 (i.e. installs insulation).

Thus we have the following household problem:

Maximise: $$U = u(c, w) \tag{1}$$

subject to: $$p^c c + p^e e \leq Y \tag{2}$$

$$w = w(e, temp, insul) \tag{3}$$

$$0 \leq e \leq h \tag{4}$$

where Y is household income; p^c and p^e are the price of consumption goods (*c*) and energy usage (*e*), respectively; (2) represents the household's budget constraint; (3) represents the technology relating internal house warmth to energy and insulation, given outside temperatures; and (4) embodies the two inequality constraints on energy usage.

Given the inequality constraints on energy, and assuming (for simplicity) that all income is spent, this represents a standard non-linear programming problem that we express as:

Maximise$_{c,e}$ $$U = u(c, w(e, temp, insul)) + \lambda(Y - p^c c - p^e e) + \mu(e) + \nu(e - h) \tag{5}$$

with complementary slackness conditions:

$$e \geq 0 \tag{6}$$

$$\mu e = 0 \tag{7}$$

$$e - h \leq 0 \tag{8}$$

$$\nu(e - h) = 0 \tag{9}$$

The first order conditions yield:

$$u_w w_e - \frac{u_c p^e}{p^c} + \mu + \nu = 0 \tag{10}$$

When $0 < e < h$, i.e. the energy choice is not constrained, then $\mu = \nu = 0$, and hence the standard optimisation condition holds in which the household balances the marginal gains to utility from extra energy use relative to extra consumption against the relative price of energy to consumption:

$$\frac{u_w w_e}{u_c} = \frac{p^e}{p^c} \tag{11}$$

We assume that insulation makes a house warmer for any given energy input; thus, ceteris paribus, $u_w\big|_{insul=1} < u_w\big|_{insul=0}$. In these circumstances, to restore optimality, the household can reduce energy use and raise consumption so as to raise u_w; thus energy savings will be observed. However it is possible, depending on the shape of the $w(\cdot)$ function, that $w_e\big|_{insul=1} > w_e\big|_{insul=0}$, i.e. a marginal increment of energy has greater effect on warmth with insulation than without insulation (because of fewer heat leaks). If this were the case, the impact of installing insulation could be an increase in energy use due to the technological superiority of using energy for heating once a house is insulated relative to the situation prior to insulation. Thus the effect on energy use of installing insulation is ambiguous and will depend on the shape of the $w(\cdot)$ function as well as on the parameters of the utility function.

Prior to insulation, if $\nu > 0$, the household would ideally like to use extra energy for heating purposes at very cold temperatures but cannot do so owing to the upper limit on energy use that the available heating appliances can utilise. In this case, installation of insulation may have either of two effects. First, it may leave $e = h$ but result in a warmer house (since $w_e\big|_{insul=1} > w_e\big|_{insul=0}$). The constraint still binds after insulation in this case and so is most likely to be observed at the very coldest temperatures when all available heating appliances are being used. Second, insulation could relieve the binding nature of the constraint, resulting in $e < h$. This outcome is more likely to occur at cool (but not extremely cold) temperatures when households were previously using all available heating capacity but no longer have to use maximum heating capacity once insulation has been installed. Energy savings as a result of installed insulation are therefore likely to reach a peak at cool temperatures and to diminish both as temperatures rise (since less heating is then required) and as temperatures decline towards extremely cold conditions.

When $\mu > 0$, energy is not used for heating prior to insulation being installed. However, as in the non-binding case, energy usage could potentially increase after insulation installation if $w_e\big|_{insul=1} > w_e\big|_{insul=0}$. Thus, at higher temperatures (when heating was not being used prior to insulation), it is possible to observe an increase in energy use after retrofitting owing to the technological superiority of heating after insulation is installed. Furthermore, with the addition of heat-pump installation to the household problem in (5), an extension of the above procedure indicates that extra energy may be used for heat-pumps acting as air conditioners to cool the house in these circumstances (i.e. to reduce warmth).

One further effect may be observed. The utility function depicted in (1) is assumed to be invariant to the treatment. If, instead, the utility function incorporates habit-persistence, so that the utility gained from each of warmth and consumption is expressed relative to some recent norm, the experience of living in a warmer house post-insulation could lead to a permanent increase in the desired warmth of a house. In this case, energy consumption would be higher, ceteris paribus, for any given vector of exogenous variables, (*temp,* p^e*,* p^c), after insulation than before, as households become accustomed to greater warmth. Thus energy savings could be diminished and/or energy usage could increase relative to pre-insulation conditions. This is one instance of the "take-back effect" whereby energy use can increase after insulation is installed. Another potential cause of the take-back effect, outlined above, is the increase in energy usage due to technological reasons that may arise where $w_e\big|_{insul=1} > w_e\big|_{insul=0}$.

Installation of extra heating devices provides another avenue whereby energy usage may rise. In this case, h rises and so the household is less likely to be constrained at the upper end (in very cold temperatures) by the constraint in (8). However, there is also an offsetting effect. Installation of more efficient energy devices will raise warmth for a given level of energy input, allowing the household to substitute towards consumption and away from energy use in the unconstrained case, while maintaining or still enhancing warmth. In addition, while not modelled here, a household may change from an old form of heating (e.g. unflued gas heater) to a more efficient heat-source (e.g. a heat-pump) so changing the nature of energy use (e.g. from gas or solid fuel fire to electricity use).

3. Methodology

The methodology we use to analyse the effect of treatment under WUNZ:HS on household energy use is limited by the fact that we can only observe metered energy sources, i.e. electricity and reticulated gas. We are able, however, to perform a test of whether treatment effects differ between houses that have solid fuel and other non-metered heating in place prior to treatment and those that do not. This test, which relates only to houses that have a clean heat device installed (with or without retrofitting of insulation), provides an indirect test of whether treatment has a significant impact on non-metered fuel use. If we were to find significantly less reduction in metered fuel use following treatment in houses with non-metered energy than for other houses, we could infer that those houses had instead (or also) reduced their use of non-metered fuel. Conversely, if metered fuel reductions are similar, we could infer that such houses maintained their non-metered fuel use levels broadly intact and instead reduced their use of metered energy.

To analyse the effect on metered energy use of being treated under WUNZ:HS , we adopt a "difference-in-difference" approach. We estimate the difference in metered energy use between treated house i and its control houses in month t ($EnergyDiff_{it}$) before and after treatment. For each specification we define metered energy use respectively as electricity use and alternatively as total metered energy use, defined as electricity plus reticulated gas. As discussed above, because total metered energy does not take into account solid fuels (wood, pellets, coal), oil or bottled gas, results may underestimate the overall energy effect. The electricity data are more complete than the gas data, so the former estimates may be more reliable but total metered use 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 metered energy use of a treated house from what it would have used had it remained untreated.

We run a series of model specifications which progressively disentangle the effects of treatment. We begin with the most parsimonious model, (12), in which the difference in metered 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 metered energy use of houses treated under WUNZ:HS (relative to the respective control houses) as a result of treatment.

$$EnergyDiff_{it} = \alpha_i + \mu_t + \gamma\, insulation_{it} + \delta\, heatpump_{it} + \varepsilon_{it} \qquad (12)$$

$EnergyDiff_{it}$ represents monthly difference in metered 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 metered 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 metered energy use[3,4]); $insulation_{it}$ is a dummy variable that is 1 if house i has received insulation treatment under WUNZ:HS 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 WUNZ:HS 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 month prior to the start of the scheme.

The simple specification in (12) provides a fairly crude inference on the effects of treatment since it hypothesizes the same metered energy saving in every month as a result of treatment. In (13), we extend (12) 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 metered energy consumption will vary with the time of the year. For example, houses which have been insulated under WUNZ:HS may save more metered energy in the middle of winter relative to non-treated houses, but there may be no significant difference during summer months (when heating is non-existent). Thus we estimate:

$$EnergyDiff_{it} = \alpha_i + \mu_t + \gamma_t insulation_{it} + \delta_t heatpump_{it} + \varepsilon_{it} \quad (13)$$

Generally, higher metered energy consumption occurs in colder periods, thus observed temperatures provide an alternative measure of the effect on the metered energy use behavior as a result of treatment. Equation (13) attempts to capture this effect through allowing coefficients to vary over time in order to analyse their magnitudes during different seasons (i.e. each month). However this specification imposes the same metered 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 regressing metered energy consumption on an interaction term between treatment and the monthly average temperature for the region in which the house

[3] 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).

[4] Using a difference-in-differences approach whilst controlling for time fixed effects also effectively accounts for any monthly changes in the price of electricity.

is located ($temp_{it}^{r}$). Equation (14) adopts this approach, whilst allowing for the effect of temperature on metered energy savings to vary non-linearly.

$$\begin{aligned} EnergyDiff_{it}^{r} = \alpha_i + \mu_t^r + \sum_{s=0}^{S} \gamma_s \left(insulation_{it} * \left[temp_{it}^{r} \right]^s \right) \\ + \sum_{s=0}^{S} \delta_s \left(heatpump_{it} * \left[temp_{it}^{r} \right]^s \right) + \varepsilon_{it} \end{aligned} \quad (14)$$

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 metered energy use difference, unlike μ_t in (12) and (13) 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 metered 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 metered 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 WUNZ:HS, and holds records on each treatment received under the programme. 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 WUNZ:HS during this period. Addresses of these treated houses were 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).

We extend the analysis 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 subsequently received treatment, invalidating them as a control. The updated dataset, after address matching by QVNZ, allowed us to identify and remove any initially suitable control houses that subsequently received treatment and update previously treated houses with additional treatments (if received) after May 2010.[5]

Treatment is classified into two broad categories; retrofitted 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 1: Treatment Category Uptake

Treatment Category	No. Houses Treated	Percentage of Total
Insulation Only	36,102	77.4%
Heating Only	3,611	7.7%
Both Insulation and Heating	6,942	14.9%
Total Houses	46,655	100%

Table 2: Treatment Uptake by Type

Treatment Type	No. Houses Treated	Percentage of Total*
Ceiling Insulation	36,606	78.5%
Draught-proofing	7,834	16.8%
Hot Water Cylinders	6,507	13.9%
Underfloor Insulation	30,723	65.9%
Other Insulation-related	1,400	3.0%
Flued Gas Heater	56	0.1%
Heat Pump	8,862	19.0%
Wood/Pellet Burner	1,636	3.5%

* Percentages sum to over 100% as houses are able to receive multiple treatment types.

[5] Though desirable, identifying and obtaining suitable controls for houses treated between May 2010 and November 2010 to generate a larger sample proved to be infeasible.

Treatments are not restricted to only one type, making it possible for properties to receive multiple treatments at different times. Table 3 provides a pair-wise breakdown of the number of houses that received multiple treatments and the type of treatments they received. For example, 7,096 houses that retrofitted ceiling insulation also received draught-proofing, while 685 houses that retrofitted underfloor insulation also received a wood/pellet burner. It is possible that a house had more than two treatments, i.e. received ceiling insulation, underfloor insulation and a heat pump heater.

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 to be available for use in subsequent work.

Table 3: House Counts of Pair-wise 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

4.2. QVNZ Data

Addresses of houses treated under WUNZ:HS 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 79.7% successful match ratio, i.e. 37,163 (of

46,655) treated houses were successfully matched and unmatched houses are subsequently removed from our sample. 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 WUNZ:HS over the entire study period.[6]

House characteristics used to determine suitable control houses are as follows: location (Census area unit, similar to a suburb), 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 the house was modernised, and dwelling quality (building and roof condition). Location, dwelling and house type, and number of levels are 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 37,163 matched treated houses, 31,423 houses possess at least one suitable control house, leaving 5,740 matched treated houses without a suitable control.

Table 4: Controls per Matched Treated House

No. of Controls per Treated House	No. of Treated Houses	Percentage of Total Treated Houses	No. Of Control Houses
1	1,067	3.40%	1,067
2	985	3.13%	1,970
3	1,043	3.32%	3,129
4	958	3.05%	3,832
5	973	3.10%	4,865
6	964	3.07%	5,784
7	1,003	3.19%	7,021
8	948	3.02%	7,584
9	962	3.06%	8,658
10	22,520	71.67%	225,200
Total	31,423	100%	296,110
Mean (Controls per Treated)	9		

[6] We cannot directly determine whether control houses have been insulated or had a heater installed independently or through other programmes, or whether they are insulated or have a heater at all. However, our modelling approach includes individual house fixed effects in our equations which account for all insulation and heating characteristics of control houses that do no change over the sample period. Installation of insulation in control houses before and during the study period will attenuate our estimates of the effectiveness of the programme, but our data rule out any such treatment attributed to WUNZ:HS.

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 metered energy use of all eligible control houses for a specific treated house. We use all eligible controls in order to reduce noise in our metered energy use data.

4.3. Metered Energy Data

To identify the metered energy impact of WUNZ:HS on treated houses, we require monthly metered energy use for the houses within our sample. In total, our sample contains 305,113 houses (treated and controls). There are two types of metered energy: electricity and reticulated gas. Unreticulated gas (gas bottles) and other non-metered energy sources (wood, coal, oil) are excluded from our analysis, since no suitable data on these sources are available.

New Zealand currently has five major suppliers of metered energy that collectively have over 90% of the electricity retail market share: Contact Energy (24.7% market share), Genesis Energy (23.9%), Mercury Energy (20.2%), Meridian Energy (12.5%), and Trustpower (11.5%).[7] 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.

Metered energy use data are recorded at the 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).

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[7] 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/).

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 with one address; however, addresses may have multiple ICP numbers.[8] 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 metered energy usage (across all ICP numbers for that address).

Combining the data from each energy company, we generate a comprehensive metered energy data file of raw ICP level submission volumes of metered energy use (divided between electricity and gas), along with energy company indicators, one for electricity and another for gas for each address.[9] Using the QVNZ address matching file, we are able to match data on metered energy use to 152,190 (49.88%) houses within our sample. Of the matched houses, 150,094 (98.62%) houses have observed electricity use, 20,693 (13.60%) houses have observed gas use; 18,597 (12.22%) houses have both electricity and gas use observed. Table 5 and Table 6 provide figures of house counts by energy company for houses matched to electricity and gas use data respectively.[10]

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

Energy Company	Treated Houses (% of total treated)		Control Houses (% of total controls)		Total	Ratio of Controls/Treated
Genesis	4,551	(25.15%)	37,483	(28.40%)	42,034	8.24
Mercury	4,269	(23.59%)	31,895	(24.16%)	36,164	7.47
Meridian	6,410	(35.42%)	40,911	(30.99%)	47,321	6.38
Trustpower	4,262	(23.55%)	31,411	(23.80%)	35,673	7.37
Total*	19,492	(107.71%)	141,700	(107.35%)	161,192	7.27

* These totals over-represent the true number of matched houses (see footnote 10 for more detail).

[8] 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 cases of multiple electricity meters also occur.

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

[10] These counts 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.

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

Energy Company	Treated Houses (% of total treated)		Control Houses (% of total controls)		Total	Ratio of Controls/Treated
Genesis	1,867	(80.34%)	15,066	(82.02%)	16,933	8.07
Mercury	478	(20.57%)	3,470	(18.89%)	3,948	7.26
Total*	2,345	(100.90%)	18,536	(100.91%)	20,881	7.90

* These totals over-represent the true number of matched houses (see footnote 10 for more detail).

We choose to analyse two samples of metered energy use data in this study; electricity use only and total metered energy use. Total metered energy use is defined to be the sum of electricity and reticulated gas use levels. We clean our raw metered energy use data to obtain datasets for analysis. 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 metered energy usage; therefore, any house containing a negative submission volume for electricity or gas use is removed. This affects 562 (0.37%) houses with observed electricity use, and 56 (0.27%) houses with observed gas use.[11] 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 supplier preference to the previous occupiers. A change in occupier may result in metered 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.[12] The result is a loss of 6,932 (4.64%) houses from the sample (889 (4.93%) treated houses, 6,043 (4.60%) controls). As a robustness check, we re-run our preferred equations for metered energy use with these houses added back into the sample.

Figure 1 (Figure 2) provides a histogram of raw monthly electricity (gas) energy use for all houses.[13] Both figures show a skewed distribution with a right-hand tail. Figure 2 also shows a

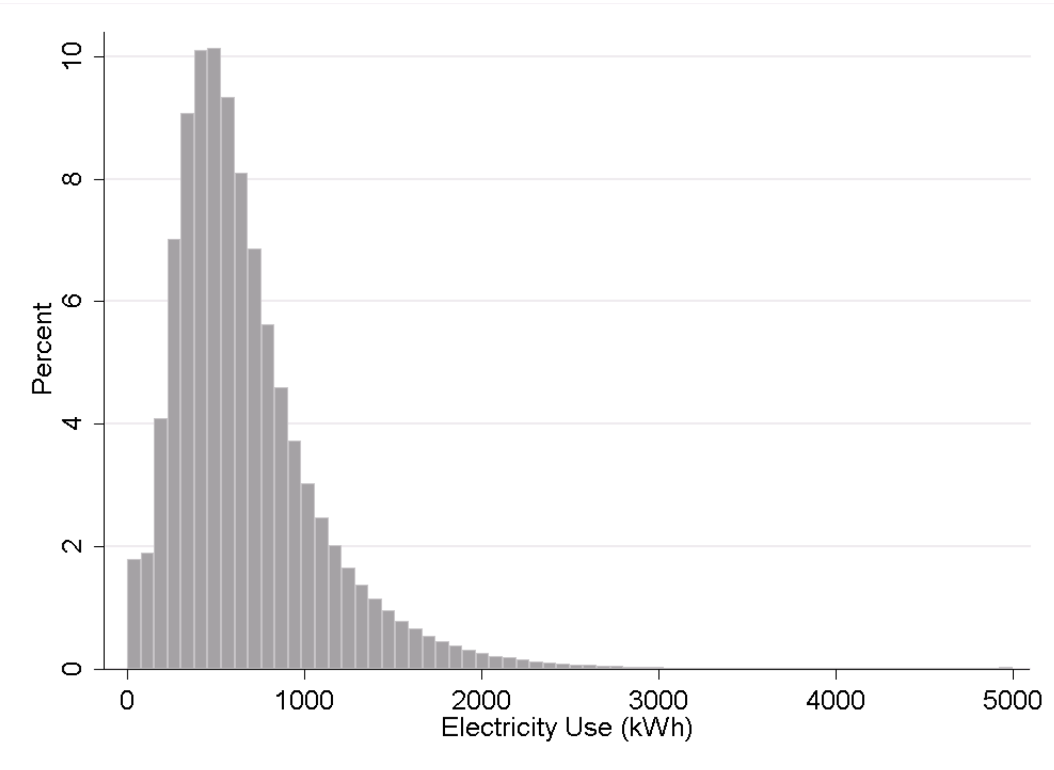
[11] To preserve consistency in our energy data series, any observation that is dropped results in all observations (electricity or gas) for that particular house being removed, since it is very likely that other submission volumes adjacent to that period will also be erroneous. We test the robustness of our results by reincorporating these observations (see section 6).

[12] Houses that switch gas supplier are retained, so that we do not lose observations on gas usage given the relatively few gas observation that we have available.

[13] 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.

spike around zero, which represents houses with very little gas use for certain months of the period (e.g. summer months). We proceed to clean the raw metered energy use data by removing houses with outlying observations. Table 7 provides summary statistics for the raw electricity and gas use. Average use between the two forms of metered 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). We define outliers for electricity to be observations outside the bottom and top 1%; i.e. observations below 30 kWh/month and above 2,235 kWh/month, and for gas, observations outside the top 1%, i.e. above 3,470 kWh/month[14].

Figure 1: Distribution of Raw Monthly Electricity Usage



[14] 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.

Figure 2: Distribution of Raw Monthly Gas Usage

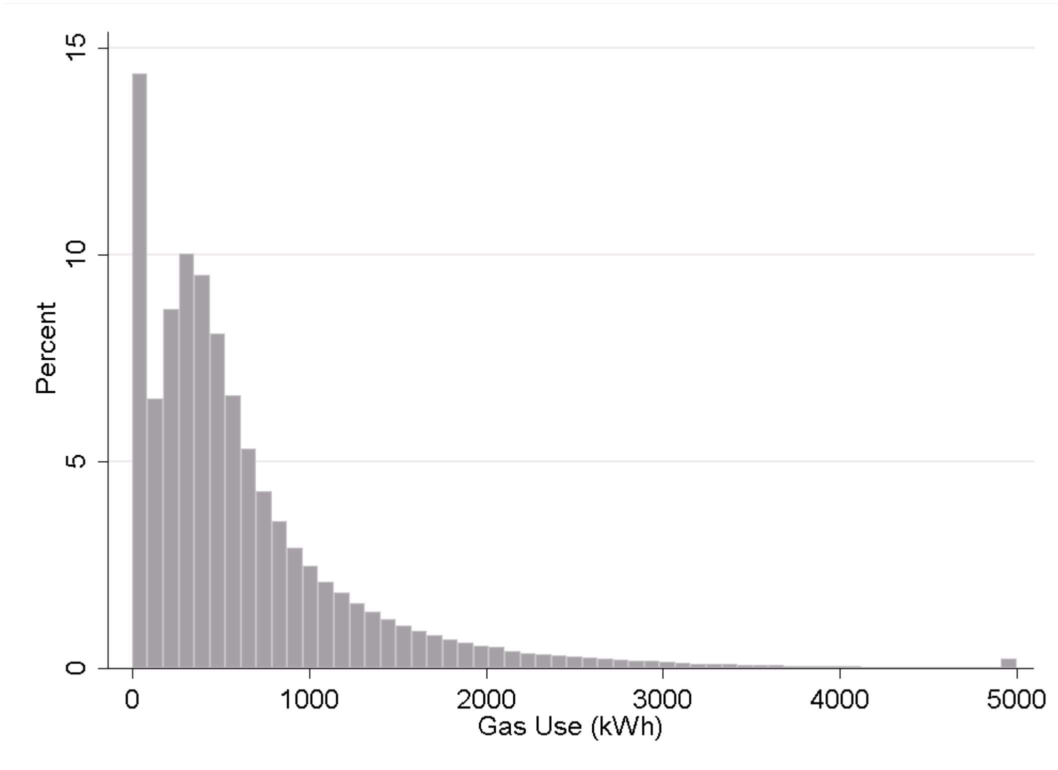


Table 7: Summary Statistics of Raw Monthly Energy Data

Summary Statistic	Electricity (kWh)	Gas (kWh)
Mean	677.82	656.31
Std. Dev.	515.44	786.15
Percentiles:		
1%	32.00	0.00
5%	182.11	3.00
10%	254.00	36.00
25%	386.77	221.00
50%	576.40	451.17
75%	847.00	833.76
90%	1211.61	1466.73
95%	1502.00	2015.00
99%	2236.68	3467.00
Monthly Observations	3,891,278	546,983

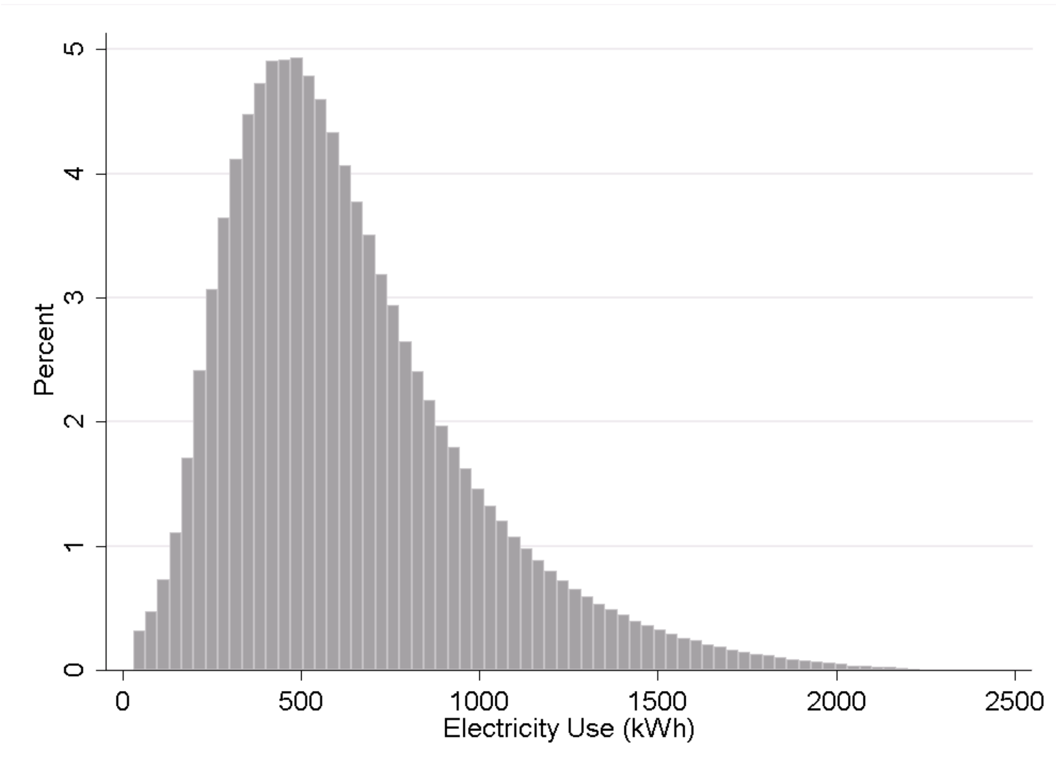
By removing houses with outlying electricity observations we reduce the sample by a total of 19,643 (13.77%) houses.[15] The distribution of the cleaned monthly levels of electricity

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

use is shown in Figure 3, using data on 14,970 treated houses and 107,897 controls. Removing houses with outlying gas observations, results in observations for 1,125 (6.44%) 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. Observations for 6,055 (36.55%) of houses with observed gas levels are removed. The cleaned distribution of monthly gas use is presented in Figure 4.

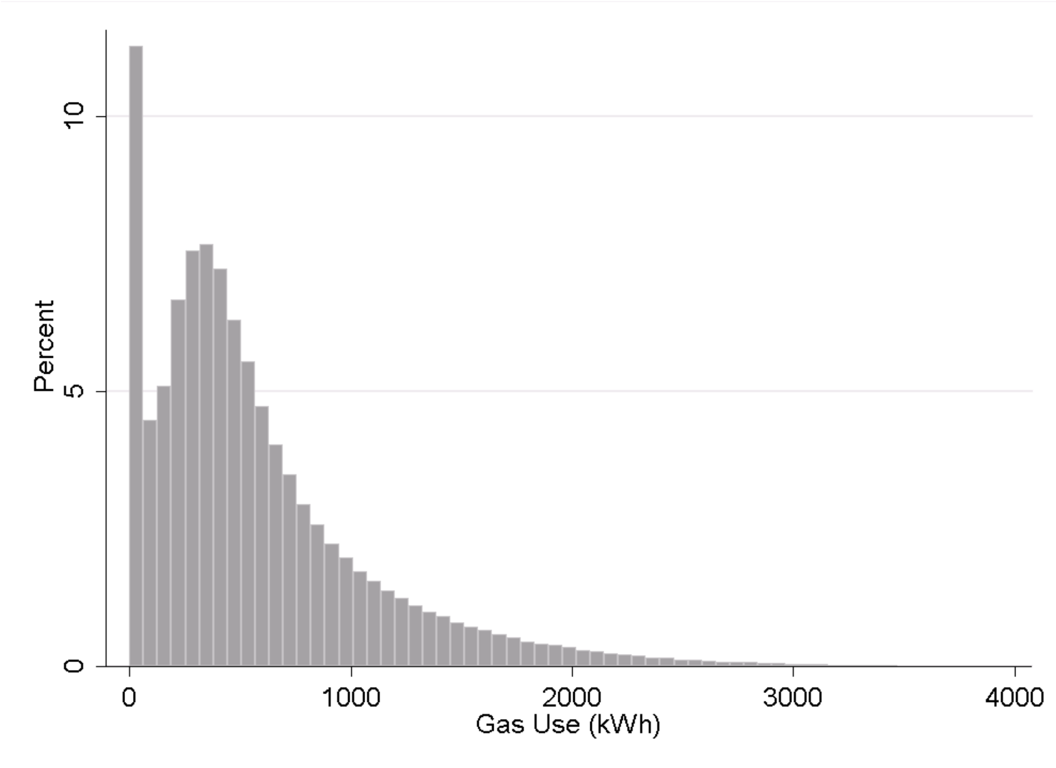
The resultant total metered energy sample has 123,982 houses. Of these, 113,472 (91.52%) houses only have observed electricity use, 1,025 (0.83%) houses have only observed gas use, and 9,485 (7.65%) houses have both observed gas and electricity use. The houses that have only observed gas use are removed from the sample.[16]

Figure 3: Distribution of Cleaned Monthly Electricity Usage



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

Figure 4: Distribution of Cleaned Monthly Gas Usage



We form the total metered energy variable by summing the electricity and reticulated gas use levels for each house. If a particular house is not observed to have reticulated gas use, then its monthly total metered energy use observations will be equivalent to its monthly electricity use observations. The final clean total metered energy sample contains data on 122,957 houses (14,970 treated houses and 107,987 control houses).

The data cleaning process, along with how our working data sets are formed, is presented in Figure 5.

4.4. Climate Data

Climatic conditions are hypothesised to influence 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.[17]

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 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.[18] The weather station located within the most densely populated CAU is selected as the representative station for that particular RC.[19]

For the purposes of this study, we obtain data on mean monthly air temperatures (˚C) and monthly standard deviation of daily temperatures (˚C) for each of the 16 regions in New Zealand. [20]

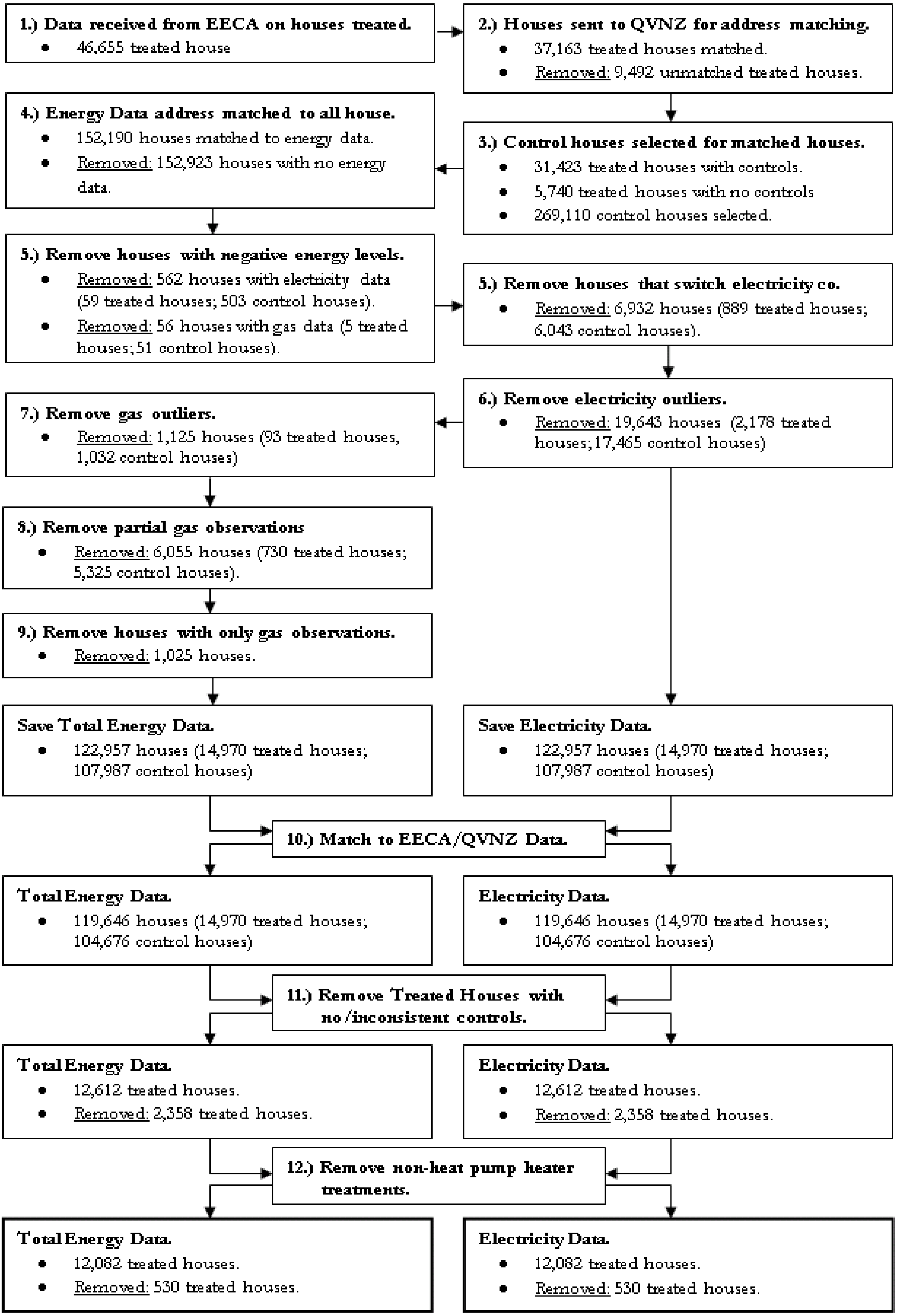
[17] cliflo.niwa.co.nz.

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

[19] 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, as are precise definitions for regional aggregation.

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

Figure 5: Data Cleaning Flow Diagram



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 metered energy use from heat pump treatment.[21] We test the robustness of results by subsequently including all houses that received any heating treatment and adopting a dummy variable for heating treatment, without distinguishing the nature of that treatment.[22] 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 metered energy sample, electricity and total metered energy, is matched to the comprehensive panel dataset to provide levels of electricity and total metered energy use for each property (treated and control). In the final sample, 119,646 houses (including 14,970 treated houses) have matching electricity and total metered energy use data.

4.5.1. The Dependent Variable

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

[21] 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.

[22] See section 0 for this robustness test.

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

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

Control houses must contain a data series of metered energy use that is consistent with that of their treated house. 2,262 (15.11%) treated houses in the electricity data and total metered energy data have no controls at all and are removed. Where a treated house, that has at least one control, does not have any controls with consistent data, the control house(s) with the longest series of data is used, provided there is 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 (being 96 (0.76%) treated houses for electricity use and total metered energy use).

4.5.2. Working Dataset Descriptive Statistics

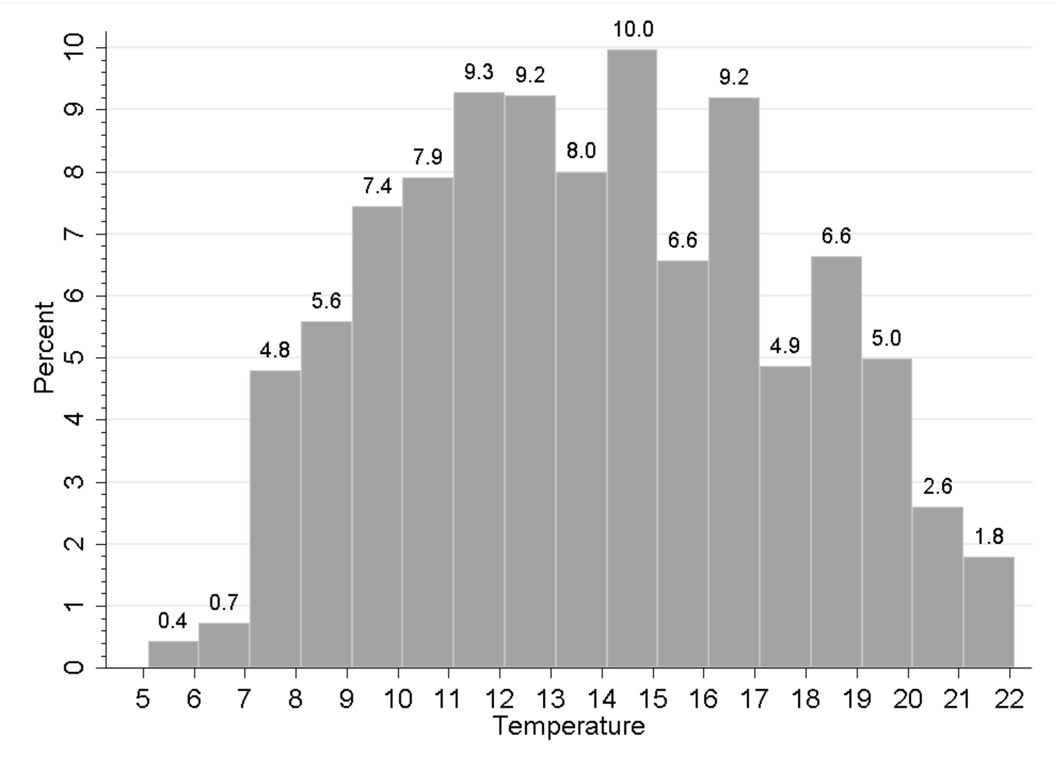
The resultant sample size for both the electricity and total metered energy datasets is 12,082 treated houses, with 325,439 (house-month) observations. Table 8 provides summary statistics for both working datasets.

Table 8: Summary Statistics for Working Datasets

	Electricity Sample			**Total Metered Sample**		
Variable	Observations	Mean	Std. Dev.	Observations	Mean	Std. Dev.
Build Decade	325,371	1955.10	22.39	325,371	1955.10	22.39
Floor Area	325,215	134.35	47.48	325,215	134.35	47.48
Number of Bedrooms	319,643	3.07	0.66	319,643	3.07	0.66
Main Roof Garages	301,133	0.50	0.77	301,133	0.50	0.77
Levels	325,439	1.87	0.33	325,439	1.87	0.33
Monthly Mean Temperature	325,439	13.74	3.71	325,439	13.74	3.71
Std. Dev. Daily Temperature	325,439	2.07	0.51	325,439	2.07	0.51
Energy Use (Treated House)	325,439	614.09	334.62	325,439	669.74	404.60
Energy Use (Control Houses)	325,439	638.25	266.40	325,439	702.64	331.55
EnergyDiff	325,439	-24. 16	343. 93	325,439	-32.90	408.30

The average treated houses (for both datasets) 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 6 displays the distributions of mean monthly air temperatures for electricity.[23] For both datasets, over 95% of monthly mean temperatures lie between 7˚C and 20˚C.

Figure 6: Distribution of Mean Monthly Temperatures



The average treated house uses 614 kWh of electricity per month, 24 kWh less per month than the mean of its control houses, and 670 kWh of total metered energy per month, approximately 33 kWh less per month than the mean of its controls. Summing the metered energy difference for the 12 months prior to WUNZ:HS, we find that treated houses used on average 187 kWh (270 kWh) electricity (total metered energy) less than their control houses. Table 9 presents t-tests to analyse whether these values are significantly different from zero. The results indicate that houses seeking treatment under WUNZ:HS used significantly less metered energy than control houses prior to treatment and so may already have been 'energy-conscious' households. However the mean difference is slight, being just 2.56% (electricity) and 3.36%

[23] For Figure 6 through to Figure 9 the corresponding total metered energy figures are almost identical and therefore are not presented.

(total metered energy) of the control house mean use for the 12 month pre-treatment period, implying that our matching approach appears successful in matching like houses.

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

	Electricity	Total Metered Energy
Mean	-187.1357	-269.7407
Standard Error	28.5241	33.5309
H_a: mean<0 (p-value)	<0.0001	<0.0001
H_a: mean≠0 (p-value)	<0.0001	<0.0001

Figure 7 shows that the majority of treated houses in our cleaned dataset 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.[24] The number of treated houses in each RC is presented in Figure 8 for our cleaned dataset. The Auckland region has the most treated houses, followed by Canterbury and Wellington. Figure 9 presents the number of houses in each RC within the cleaned dataset 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 0.7-1.6% of the total number of dwellings other than in three regions; Hawke's Bay, Tasman and Southland have smaller representation. In part, the regional variations are due to differing regional uptakes of WUNZ:HS that may be affected by region-specific factors. (For instance, in 2008, the Southland Warm Homes project, spearheaded by Electricity Invercargill and the Southland Electric Power Supply Consumer Trust, was established to offer Southland homeowners funding to make their homes warmer and more energy efficient (PowerNet, 2008) and the prior existence of this project may have affected uptake.) In part, the regional variation is also due to the cleaning process. When we include outlying observations in our estimates shown in section 6.5, the regional proportions change somewhat with more observations for houses in cold regions (Figure 23, section 6.5).

[24] "State-rental" houses are generally privately-owned houses that were formerly used as state rental houses.

Figure 7: Distribution of Treated Houses by House Type

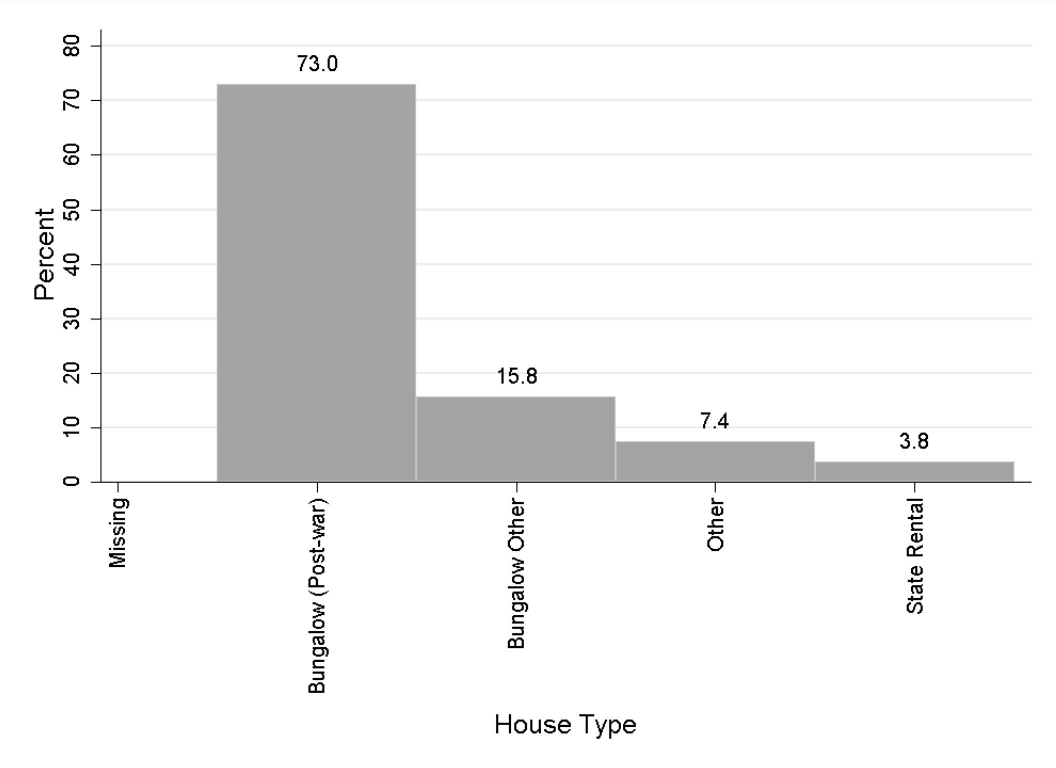


Figure 8: Frequency of Treated Houses by Regional Councils

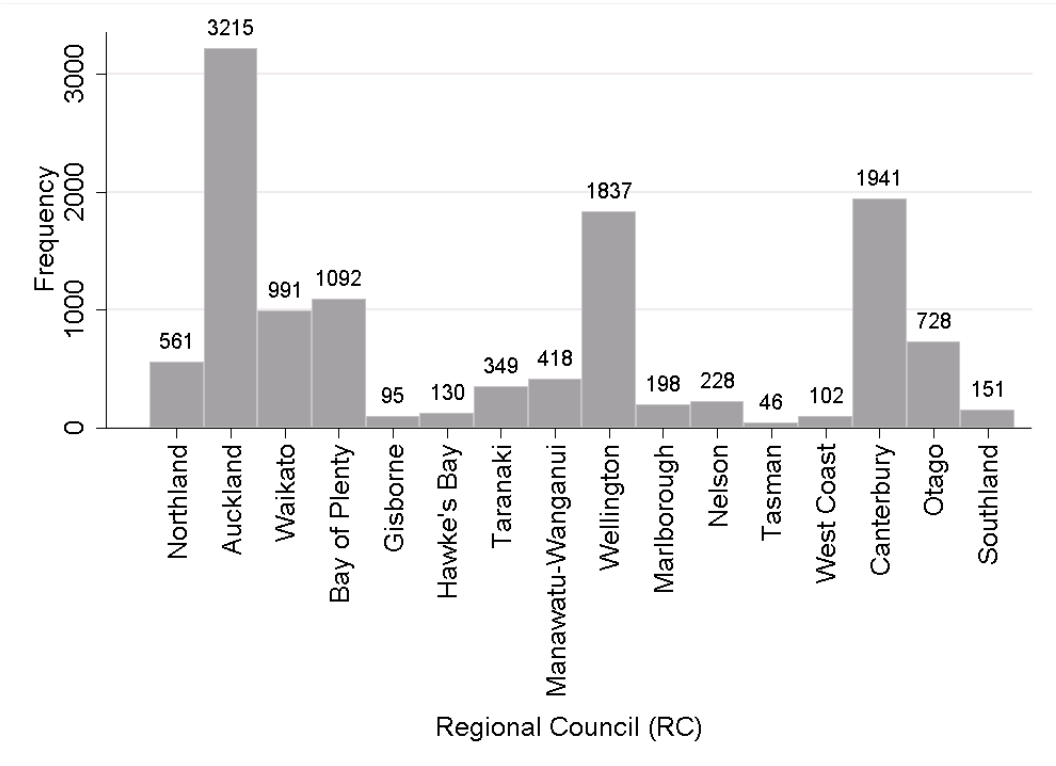
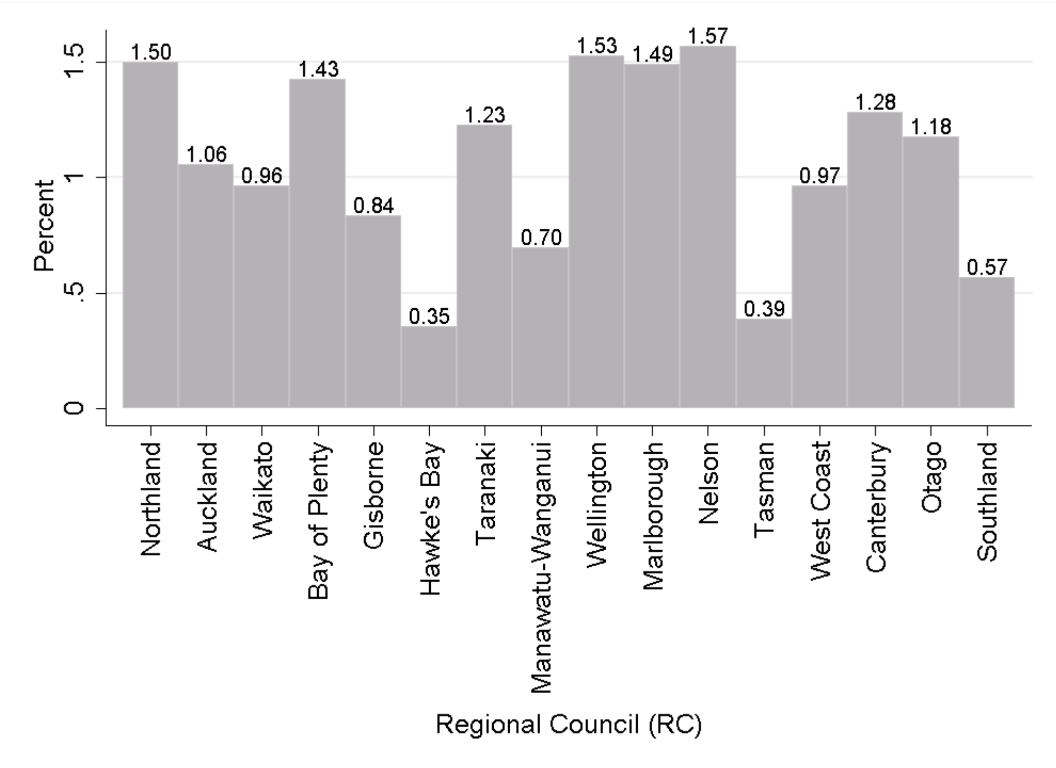


Figure 9: Percent of Treated Houses to Total Regional Dwellings



5. Regression Results

We estimate each of our specifications using a fixed-effects OLS estimator with standard errors clustered by house. Clustering standard errors by house relaxes the independence of observations assumption, allowing observations over time to be correlated within a house, but remain independent across houses. Fixed effects are included for each house in all specifications, and time (month) fixed-effects are included. For the equations that interact temperature with treatment variables, we replace time fixed-effects with region*time fixed-effects (in addition to the house fixed-effects). Estimates of the fixed-effects are not reported separately.

Estimation results for equation (12), our simplest specification, are shown in Table 10. Insulation treatment is estimated to have a small negative effect on $EnergyDiff_{it}$ (i.e. metered energy savings occur) for both electricity and total metered energy use; however, the latter effect is not significant. Heat pump installation has a positive impact on $EnergyDiff_{it}$ for both electricity and total metered energy, with coefficients of 12.89 kWh and 4.80 kWh respectively. Only the effect for electricity use is significant. Over the study period, monthly electricity and total metered energy use for treated houses is on average 614 kWh and 670 kWh respectively, meaning these increases are roughly in the vicinity of 1-2% of average use. Heat pumps are electricity-reliant for operation, so a larger effect on electricity use than on total metered energy use, as estimated, is expected. In particular, if houses treated with heat pumps replace the use of less efficient gas heaters, one should expect a smaller total metered energy treatment effect than for electricity only.

Table 10: Estimation Results for Equation (12)

	Electricity	**(Std. Error)**	**Total Metered Energy**	**(Std. Error)**
insulation	-4.4351*	(2.5064)	-2.0957	(2.9138)
heatpump	12.8870***	(4.1095)	4.8049	(4.5414)
Observations	325,439		325,439	
Number of houses	12,082		12,082	
R-Squared (within)	0.00156		0.00117	

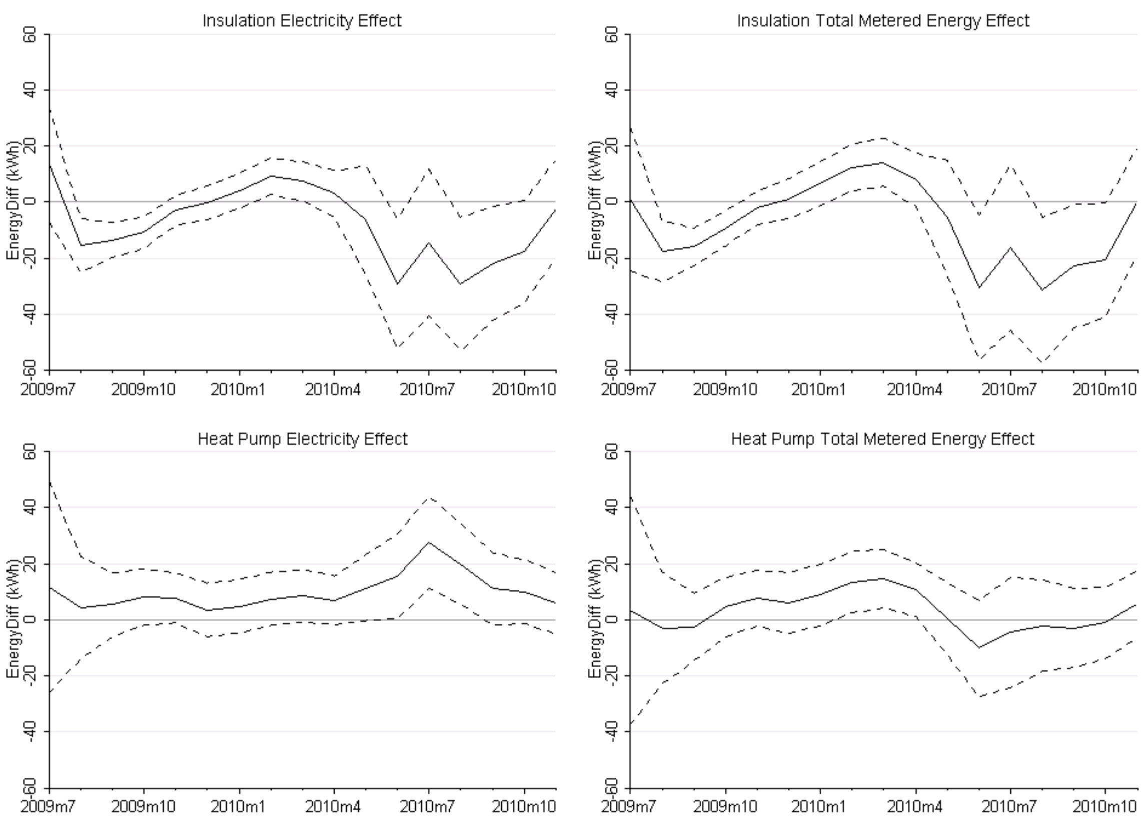
Note: Individual house fixed-effects and time (month) fixed-effects are included. Clustered Standard Errors are given in parentheses. R-squared (within) measures the R-squared from the mean-deviating regression (i.e. the usual R-squared achieved from running OLS on the data). *** p<0.01, ** p<0.05, * p<0.1

A comment is useful here on the explanatory power of this and succeeding equations. We have chosen our control houses to match as closely as possible with their respective treated houses. Prior to treatment, a perfect match would see only random variation (noise) in metered energy use between the matched houses, thus not being capable of any explanation ($R^2 = 0$). Following treatment, even where that treatment has a significant impact on metered energy use of the treated house, we would still expect that this 'signal' will be dominated by random noise where houses have been well matched. This is indeed what we find in all our estimates, supporting our matching algorithm. Nevertheless, significant treatment effects are still found despite the dominance of the noise component in our regressions.

Specification (12) restricts the impact of insulation and heating to be identical across months (and hence seasons), whereas we hypothesise that the effects will differ according to season. Allowing the effect to differ by month in (13) achieves the estimation results in Table 11, also presented as Figure 10. Insulation treatment leads to metered energy saving behaviour between May and November, coinciding with the winter/spring months. Electricity savings for treated houses are significant during the months of August, September and October 2009, and June, August and September 2010; total metered energy savings are significant in August, September and October 2009, and June, August, September, and October 2010. Between January and April 2010 (summer/autumn period) positive coefficients are consistently observed, indicating increased metered energy consumption in treated relative to untreated houses.

February and March have significantly positive coefficients for both electricity and total metered energy use. A variant of the "take-back" effect, whereby households substitute metered energy savings for increased comfort, may be present during the warmer summer months. Households treated with insulation may get accustomed to a warmer indoor temperature than they were used to prior to treatment, and therefore increase metered energy use to maintain this temperature.

Figure 10: Specification (13) Estimated Effects over Time



Note: Dashed lines represent the 90% confidence intervals.

Houses receiving heat pump installation consistently increase their electricity use in all periods (Table 11 and Figure 10). Between June and August 2010, significant increases in $EnergyDiff_{it}$ are observed for electricity use, but total metered energy use decreases (albeit not significantly) for most of this period. The inconsistency in the effects between electricity and total metered energy use supports the hypothesis that installed heat pumps are used to replace gas heaters. Although more electricity is consumed during the winter as a result of heat pump installation, less gas is used thus offsetting the increase in electricity consumption. Total metered

Table 11: Estimation Results for Equation (13)

Coefficient	Electricity	(Std. Error)	Total Metered Energy	(Std. Error)
insulation#jul2009	13.4409	(12.5568)	1.1908	(15.5484)
insulation#aug2009	-15.4847***	(5.8703)	-17.6931***	(6.6524)
insulation#sep2009	-13. 6024***	(3.7824)	-15.9098***	(4.0481)
insulation#oct2009	-10.7739***	(3.4730)	-9.4253**	(3.7845)
insulation#nov2009	-2.9275	(3.2792)	-2.0511	(3.7235)
insulation#dec2009	-0.3196	(3.6167)	1.2053	(4.3357)
insulation#jan2010	3.9694	(3.8455)	6.5308	(4.7782)
insulation#feb2010	9.1412**	(3.9958)	12.3603**	(5.1031)
insulation#mar2010	7.3865*	(4.1968)	14.149***	(5.210)
insulation#apr2010	2.9822	(5.0430)	7.9457	(5.7967)
insulation#may2010	-6.5027	(11.6733)	-5.4703	(12.3220)
insulation#jun2010	-29.1774**	(14.0695)	-30.4222*	(15.7172)
insulation#jul2010	-14.5056	(15.8924)	-16.2993	(17.8721)
insulation#aug2010	-29.1155**	(14.4287)	-31.4601**	(15.8929)
insulation#sep2010	-21.9887*	(12.3252)	-22.9592*	(13.4151)
insulation#oct2010	-17.7647	(11.1527)	-20.5918*	(12.3037)
insulation#nov2010	-2.4637	(10.6463)	-0.0751	(11.7011)
heatpump#jul2009	11.7497	(22.9748)	3.3771	(24.7645)
heatpump#aug2009	4.2998	(11.1166)	-2.9101	(12.1368)
heatpump#sep2009	5.4066	(6.8556)	-2.5781	(7.3956)
heatpump#oct2009	8.2080	(6.1075)	4.5581	(6.4776)
heatpump#nov2009	7.8637	(5.4375)	7.7054	(6.0054)
heatpump#dec2009	3.6310	(5.7996)	6.0231	(6.5718)
heatpump#jan2010	4.9313	(5.7787)	8.9628	(6.6955)
heatpump#feb2010	7.5481	(5.7634)	13.4885**	(6.6510)
heatpump#mar2010	8.6192	(5.6703)	14.6892**	(6.3369)
heatpump#apr2010	7.0662	(5.2922)	10.8006*	(5.8097)
heatpump#may2010	11.4409	(7.1227)	0.4577	(7.7676)
heatpump#jun2010	15.5587*	(9.1721)	-10.1270	(10.4879)
heatpump#jul2010	27.7669***	(9.9437)	-4.5091	(11.9270)
heatpump#aug2010	19.8994**	(8.7958)	-1.9831	(9.8688)
heatpump#sep2010	11.0362	(7.8543)	-2.8436	(8.6036)
heatpump#oct2010	10.1002	(6.9541)	-1.0765	(7.6712)
heatpump#nov2010	5.9221	(6.6881)	5.5801	(7.2129)
Observations	325,439		325,439	
Number of houses	12,082		12,082	
R-Squared(within)	0.00185		0.00135	

Note: Individual house fixed-effects and time (month) fixed-effects are included. Clustered Standard Errors are given in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

energy use increases significantly between February and April 2010, the warmer months of the year, while electricity usage also increases at this time (albeit not quite significant at the 10% level in any month). Heat pumps are able to be used as air conditioners and it is possible that the increased metered energy usage during these months in houses fitted with heat pumps reflects their use to cool, rather than to heat, houses in warmer months.

The estimates from (13) indicate that impacts of WUNZ:HS treatments on metered energy usage differ across seasons. Estimation of (14) clarifies the seasonality pattern by explicitly estimating the effect of external temperature on the treatment effects. Results are presented in Table 12. When S=0, (14) is identical to (12) except that we allow for region-specific time effects, so coefficients in Table 12 are of similar magnitude and significance to those found from estimating (12).

Setting S=1, we allow *temp* to interact with *insulation* and *heatpump* linearly. The linear effect of temperature on the treatment effect for insulation is significant, with a negative intercept and positive slope, implying that metered energy savings increase as temperature decreases. The impacts of insulation treatment are broadly consistent across electricity and total metered energy. The effects of heat pump installation on $EnergyDiff_{it}$ as temperature changes differ between electricity and total metered energy usage in the linear case. The impact on electricity use has a positive intercept and a negative slope, suggesting, with a linear specification, that heat pump installation boosts electricity use mostly when temperatures are cold. On the other hand, the effect from total metered energy use has a negative intercept and positive slope. A Wald test indicates that the insulation coefficients are jointly significant at the 1% level for both electricity and total metered energy use in this case (Table 12). Heat pump coefficients are also jointly significant for both electricity and total metered energy use, at the 1% and 10% level of significance, respectively.

A quadratic functional form (S=2) results in estimated coefficients that are consistent in sign and have roughly similar magnitudes for both insulation and heat pump treatments across both electricity and total metered energy. The Wald tests (Table 12) show that for the quadratic case, we observe strong joint significance of the insulation coefficients (for both electricity and total metered energy); the heat pump coefficients for electricity and total metered energy are each significant at the 5% level.

Coefficient signs are comparable across the cubic and quartic cases (S=3 and S=4). The Wald tests for these functional forms provide similar results as for the quadratic case; however the quartic significance tests are marginally weaker than for the cubic indicating that the

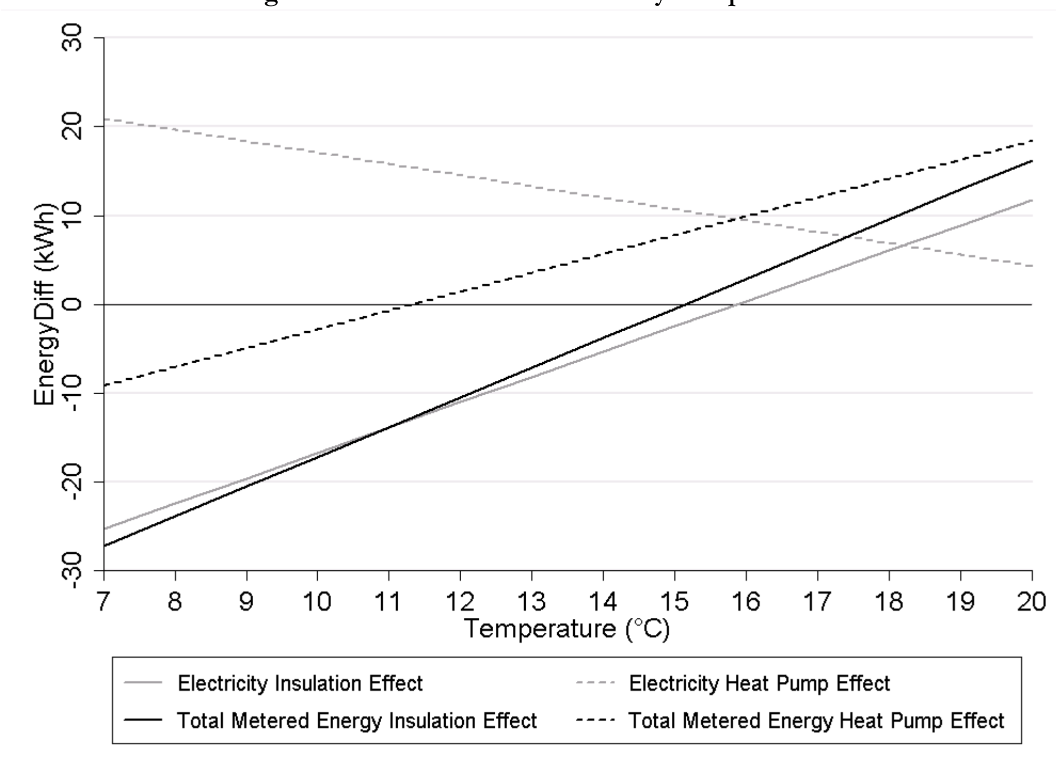
Table 12: Estimation Results for Equation (14)

	S=0		S=1		S=2		S=3		S=4	
	Electricity	**Total**	**Electricity**	**Total**	**Electricity**	**Total**	**Electricity**	**Total**	**Electricity**	**Total**
insulation#temp^{0}	-4.4179*	-2.2314	-45.2353***	-50.6169***	-13.8023	-22.3994	108.5349	118.5217	212.8986	111.5724
	(2.5147)	(2.9285)	(10.5570)	(12.1890)	(35.7079)	(38.8410)	(108.3472)	(113.8498)	(332.2138)	(337.9265)
insulation#temp^{1}			2.8503***	3.3427***	-1.7354	-0.7638	-29.6769	-32.5997	-62.8339	-30.3421
			(0.6896)	(0.8273)	(4.7567)	(5.1973)	(22.4726)	(23.8537)	(97.0605)	(98.9763)
insulation#temp^{2}					0.1584	0.1415	2.1840	2.4281	5.9606	2.1661
					(0.1550)	(0.1705)	(1.5152)	(1.6265)	(10.3321)	(10.5626)
insulation#temp^{3}							-0.0469	-0.0525	-0.2303	-0.0396
							(0.0332)	(0.0360)	(0.4747)	(0.4866)
insulation#temp^{4}									0.0032	-0.0002
									(0.0080)	(0.0082)
heatpump#temp^{0}	13.9052***	5.0046	29.8728**	-23.9874	63.3577*	15.9876	12.3674	173.4879*	25.3851	272.5105
	(4.0834)	(4.5313)	(13.6956)	(16.1652)	(37.3825)	(40.3825)	(98.2376)	(103.9248)	(309.7866)	(317.4846)
heatpump#temp^{1}			-1.2771	2.1193*	-6.4641	-4.1008	6.1972	-41.2287*	2.1727	-73.5442
			(0.9049)	(1.0960)	(5.1875)	(5.6626)	(21.2749)	(23.0278)	(94.3354)	(96.9872)
heatpump#temp^{2}					0.1896	0.2282	-0.7986	3.0034*	-0.3515	6.7821
					(0.1772)	(0.1975)	(1.4964)	(1.6483)	(10.4213)	(10.7324)
heatpump#temp^{3}							0.0244	-0.0661*	0.0032	-0.2544
							(0.0341)	(0.0380)	(0.4949)	(0.5103)
heatpump#temp^{4}									-0.0004	0.0034
									(0.0085)	(0.0088)
Observations	325,439	325,439	325,439	325,439	325,439	325,439	325,439	325,439	325,439	325,439
Number of Houses	12,082	12,082	12,082	12,082	12,082	12,082	12,082	12,082	12,082	12,082
R-Squared (within)	0.00345	0.00388	0.00363	0.00404	0.00365	0.00405	0.00366	0.00407	0.00366	0.00407
R-Squared (adjusted)	0.00177	0.00220	0.00195	0.00236	0.00196	0.00236	0.00197	0.00237	0.00197	0.00237
Wald Tests insulation (p-value)	0.0790	0.4461	0.0001	0.0002	0.0000	0.0001	0.0000	0.0001	0.0000	0.0003
heatpump (p-value)	0.0007	0.2694	0.0053	0.0589	0.0112	0.0480	0.0102	0.0552	0.0175	0.0991

Note: Individual house fixed-effects and region*time fixed effects are included. Clustered Standard Errors are given in parentheses. *** p<0.01, ** p<0.05, * p<0 relationship may be over-fitted in that case. The adjusted R-squared values indicate that the higher functional forms (cubic and quartic) have greater explanatory power than the constant, linear and quadratic forms. The quartic functional form does not provide any additional information to the cubic, and is punished for having extra terms (marginally lower adjusted R-squared); thus we adopt the cubic functional form as being the most appropriate.

We use the estimated coefficients in Table 12 to graph the predicted treatment effects on $EnergyDiff_{it}$ for both electricity and total metered energy, across a range of temperatures, for the linear, quadratic, cubic and quartic cases (Figure 11, Figure 12, Figure 13, and Figure 14 respectively).[25] Increasing the flexibility of the functional form changes the shapes of the curves; however, similar conclusions are drawn from each. We concentrate on the cubic results (Figure 13).

Figure 11: Linear Treatment Effect by Temperature



[25] Over 95% of observed temperatures over our study period fall between 7°C and 20°C, so we present the impacts of treatment over that range of temperatures.

Figure 12: Quadratic Treatment Effect by Temperature

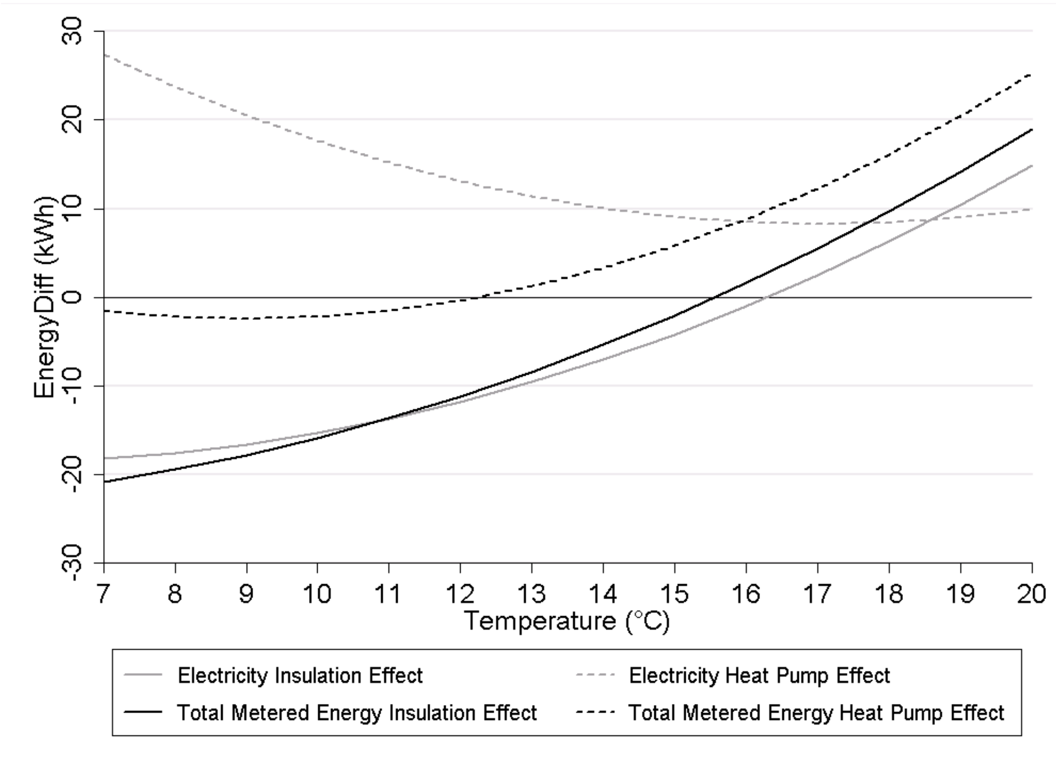


Figure 13: Cubic Treatment Effects by Temperature

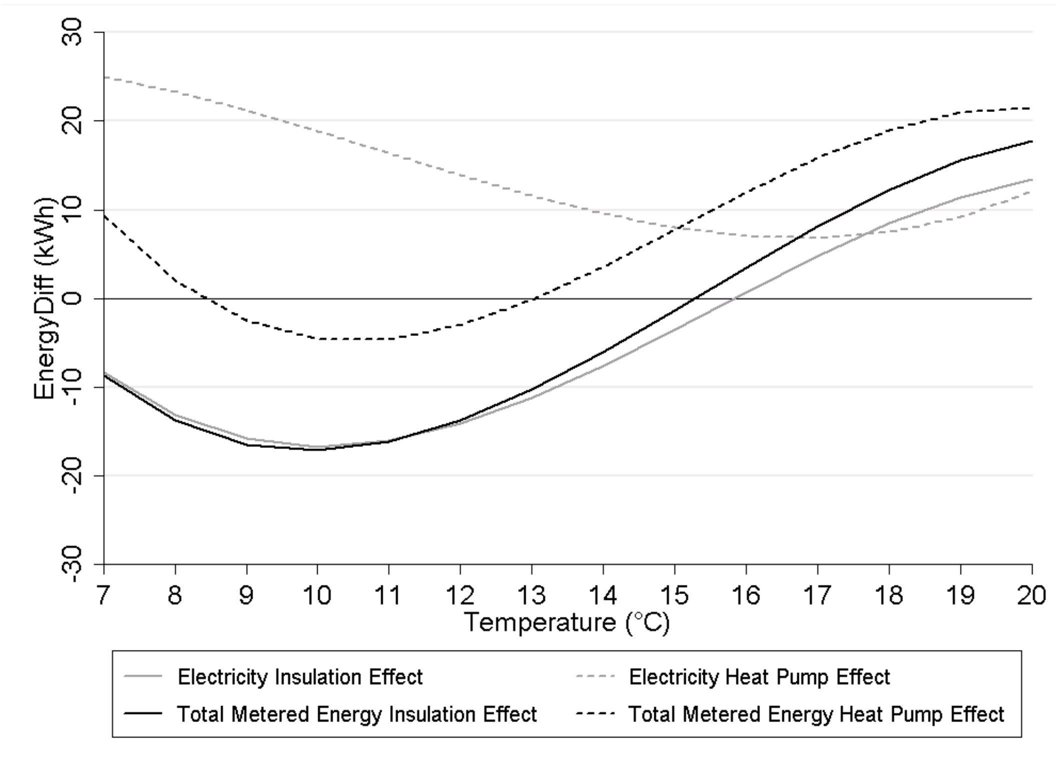
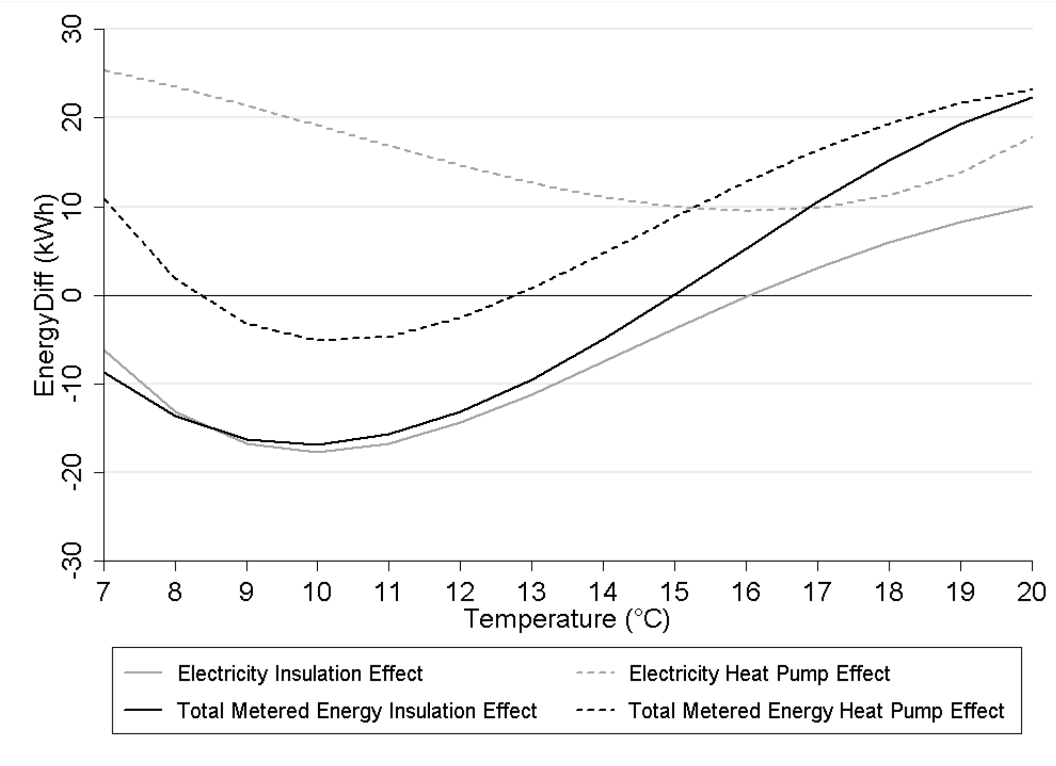


Figure 14: Quartic Treatment Effects by Temperature



We find that there are generally metered energy savings from insulation treatment occurring for temperatures below 15˚C (total metered energy) or 16˚C (electricity), and increased metered energy consumption above these temperatures. This is consistent with the findings from (13), where winter months show metered energy savings and summer months show the opposite. Figure 13 further supports a "take-back" effect, with warmer months showing higher metered energy use than prior to treatment. Houses that receive heat pump installations are generally less energy conservative after receiving the treatment, although the effect differs depending on whether we consider electricity or total metered energy use. At very low temperatures, we observe higher metered energy (and especially electricity) usage from heat pump installation. As temperature rises, extra metered energy use falls to a minimum and then begins to rise again. For total metered energy, we observe slight savings between 9˚C and 13˚C. Higher metered energy use at warmer temperatures is consistent with heat pumps being used as air conditioners.

In each of Figures 11-14, the addition to metered energy use at high temperatures slightly exceeds the addition to electricity use at those temperatures following heat pump installation. This result is also found in the monthly regressions reported in Table 11 for February and March 2010. This outcome may indicate some difference in behaviours between those households with reticulated gas relative to those without. One of the robustness tests (reported in section 6.6.2) splits the sample according to availability of reticulated gas to the household and confirms that, following heat pump treatment, households with reticulated gas make slightly greater additions to metered energy use than do households without gas in months with high average temperatures. Households with reticulated gas are limited to the North Island, and so this result may imply that the 'air conditioner' effect is more pronounced in (generally warmer) North Island areas than in the South Island.

We calculate the average annual electricity and total metered energy savings a treated house makes due to each treatment type, across each of the models estimated. For national results, regional monthly mean temperatures for the first twelve months of WUNZ:HS are weighted by the number of treated houses within each region to generate a national monthly temperature. These national monthly temperatures are substituted in to obtain predicted annual electricity and total metered energy savings. The top portion of Table 13 presents these savings as a percentage of the mean annual electricity or total metered energy use of the control houses across the nation.[26] Electricity and total metered energy savings are observed as a result of insulation treatment for a typical treated house, while electricity and total metered energy use increases for those houses treated with a heat pump. The magnitudes of the overall effects (in the preferred cubic case) are 0.96% electricity saving from insulation, and a 1.92% rise in electricity use for heat pump installation. Total metered energy changes are lower in absolute value at approximately 0.66% savings from insulation and 0.75% increase from heat pump installation.

Table 13 also presents mean percentage metered energy savings figures broken down by regional councils.[27] These values represent the predicted annual savings for a treated house within each region as a percentage of the mean annual use of control houses within the regional council. The percentages indicate that warmer regions save less electricity and total metered energy from insulation treatment, but as regions get colder, savings tend to increase. The West Coast has the maximum savings for treated houses at 2.24% (electricity) and 2.11% (total metered energy). The very coldest regions do not save quite as much metered energy, however, owing to the lesser savings achieved at very cold temperatures (see Figure 13). Heat pump installation in all regions increases electricity and total metered energy use. Interestingly,

[26] Only control houses that have electricity or total metered energy use observed in each of the 12 months following the implementation of WUNZ:HS are used in calculating the mean annual electricity and total metered energy use.

[27] These estimates are based on the estimated coefficients across the whole country applied to region-specific average monthly temperatures. Table A1 in Appendix A presents regional predicted monthly energy savings levels in kWh per house.

contrasting patterns emerge when we consider electricity and total metered energy use. Warmer regions have smaller electricity dissavings following heat pump installation than cooler regions, which is consistent with cooler regions using heaters more intensely, but the opposite pattern is found for total metered energy, with warmer regions having higher total metered energy dissavings from heat pump installation. In the latter case, households in warmer regions may be using their heat pumps more for air conditioning purposes as opposed to heating purposes.

Table 13: Predicted Annual Percentage Savings from Treatment

	Insulation		**Heat Pump**	
	Electricity (%)	Total Metered Energy (%)	Electricity (%)	Total Metered Energy (%)
National:				
Uniform	0.70	0.32	-2.19	-0.72
Linear	0.95	0.66	-1.94	-0.74
Quadratic	0.96	0.67	-1.93	-0.73
Cubic	0.96	0.66	-1.92	-0.75
Quartic	1.12	0.47	3.82	-0.81
Regional Council (cubic):				
Northland	0.04	-0.41	-1.80	-1.82
Auckland	0.19	-0.16	-1.77	-1.30
Waikato	0.99	0.58	-2.17	-0.73
Bay of Plenty	1.31	1.05	-2.51	-0.80
Gisborne	0.57	0.23	-1.89	-1.02
Hawke's Bay	1.24	1.02	-2.23	-0.76
Taranaki	1.71	1.15	-2.56	-0.39
Manawatu-Wanganui	1.39	1.05	-2.40	-0.63
Wellington	1.02	0.63	-1.79	-0.56
Marlborough	1.01	0.80	-2.34	-1.04
Nelson	0.87	0.63	-2.16	-1.03
Tasman	1.09	0.90	-2.06	-0.75
West Coast	2.24	2.11	-3.21	-0.38
Canterbury	1.26	1.13	-1.98	-0.46
Otago	1.44	1.36	-2.31	-0.47
Southland	1.16	1.12	-2.28	-0.67

6. Robustness Tests

We subject our preferred cubic specification to a range of robustness tests. First, we include interaction terms between insulation and heat pump treatment to test whether there are differing effects on houses that received both treatments as opposed to only one of the treatments. Second, we split our sample by two measures of income to analyse whether insulation and heat pump installation has differing effects according to a treated household's affluence. Third, we widen our definition of heater treatment to account for all forms of heater installation, instead of restricting attention only to heat pump installation. Fourth, we expand the temperature definition to include monthly temperature variation. Fifth, we relax the sample exclusion criteria to test whether our sample definitions affect the results. Sixth, we account for differences in the nature of heating sources already within a house at the time of treatment, testing whether use of reticulated gas or a non-metered energy source leads to significant differences in metered energy effects.

6.1. Including Insulation-Heat Pump Interaction Terms

For the first of our robustness checks, we include additional terms accounting for the interaction between insulation and heat pump installation. These additional terms allow us to investigate whether there is any differing behaviour from those houses that receive both insulation installation and heat pump installation, compared with those that only receive one type of treatment. There are 1,609 (13.32%) treated houses that received both insulation and heat pump installation within our sample.

We take our preferred cubic specification from equation (14) and include four three-way interaction terms that interact the insulation and heat pump variables together, and then with each temperature term. Estimation produces the results presented in Table 14. The three-way interaction terms are not individually significant for either electricity use or total metered energy use. In addition, the Wald tests produce no evidence that the additional interaction terms are jointly significant. For electricity and total metered energy use, the insulation effects remain jointly significant overall. Heat pump effects for electricity use also remain jointly significant; however, following the inclusion of the insulation-heat pump interaction terms, heat pump installation effects for total metered energy are no longer jointly significant (other than at the 20% level).

While there are marginal improvements to the R-squared values from our preferred cubic specification, there is no evidence of any significant difference in metered energy consumption behaviour from those households that installed both insulation and heat pumps, as opposed to either just insulation or heat pumps. Therefore, we retain our original cubic specification as these additional terms do not offer significant improvements to the preferred specification.

Table 14: Insulation-Heatpump Interaction Estimation Results

		Electricity	(Std. Error)	Total Metered Energy	(Std. Error)
insulation#temp^0		161.9845	(125.5740)	113.3959	(134.3374)
insulation#temp^1		-39.5951	(25.9678)	-30.6806	(27.9638)
insulation#temp^2		2.8007	(1.7402)	2.2963	(1.8899)
insulation#temp^3		-0.0594	(0.0379)	-0.05	(0.0414)
heatpump#temp^0		98.3828	(178.3069)	157.5391	(187.1506)
heatpump#temp^1		-9.0734	(38.2003)	-36.1817	(40.6521)
heatpump#temp^2		0.1427	(2.6553)	2.7201	(2.8639)
heatpump#temp^3		0.0058	(0.0598)	-0.0619	(0.0652)
insulation#heatpump#temp^0		-110.1965	(209.7609)	26.6004	(221.6486)
insulation#heatpump#temp^1		19.2706	(45.1092)	-7.8508	(48.4588)
insulation#heatpump#temp^2		-1.1768	(3.1509)	0.4336	(3.4321)
insulation#heatpump#temp^3		0.0228	(0.0713)	-0.0064	(0.0785)
Observations		325,439		325,439	
Number of Houses		12,082		12,082	
R-Squared (within)		0.00369		0.00409	
R-Squared (adjusted)		0.00198		0.00239	
Wald Tests	insulation (p-value)	0.0001		0.0018	
	heatpump (p-value)	0.0253		0.1979	
	insulation#heatpump (p-value)	0.7043		0.6009	

6.2. Sub-sampling by Income

Previous insulation and clean heating funding programmes discriminated by household income levels, only offering assistance to low and middle income households. By contrast, WUNZ:HS makes funding available to all households, regardless of income level. We investigate how WUNZ:HS affects metered energy use for households of different income brackets. Two methods for dividing households between income categories are used: firstly, we divide households into high and low income categories determined by the median household income level of the census area unit (CAU), or "suburb", that they are located within, and, secondly, we divide treated households into those that hold a Community Services Card (CSC) and those that do not.

6.2.1. CAU Household Median Income

We separate our samples into high and low income areas to investigate if there are any differences in electricity and/or total metered energy use attributable to household income.

Using median household income at CAU level from the 2006 Census, we define high income treated houses to be located within CAUs with a median household income of $50,800 or higher, and low income to be those houses located in CAUs with a median income less than $50,800.[28] To allow us to distinguish between the two groups, we generate a dummy variable equal to 1 if a house is classed as high income, and 0 otherwise. As found with the full sample, high and low income households that eventually receive treatment, are already 'energy-conscious'; metered energy differences (electricity and total metered energy) are small but significantly negative over the 12 month period prior to the implementation of WUNZ:HS (Table 15).

Table 15: High/Low Income t-test Results for 12 Month Pre-NZIF EnergyDiff

	Low Income Households		**High Income Households**	
	Electricity	Total Metered Energy	Electricity	Total Metered Energy
Mean	-190.5789	-243.7218	-183.6810	-295.8458
Standard Error	37.4678	41.6966	43.0395	52.5567
H_a: mean<0 (p-value)	<0.0001	<0.0001	<0.0001	<0.0001
H_a: mean≠0	<0.0001	<0.0001	<0.0001	<0.0001

To estimate the different income brackets, we interact the terms in our model with the income dummy variable, using the preferred cubic specification of equation (14). Results are presented in Table 16. A Wald test on the joint significance of the high income household coefficients show that there is no difference (at conventional significance levels) between metered energy use behaviour of high and low income households, for electricity or total metered energy as a result of either insulation or heat pump treatment (Table 16). However two of the tests (insulation treatment effect for electricity use and heat pump treatment effect for total metered energy use) are significant at the 20% level and so provide some weak indication of differences in treatment effects between households in high and low income areas.

Figure 15 and Figure 16 provide the graphical interpretation of the predicted treatment effects for each income group. Except for very cold temperatures, low income households are affected by treatment in a similar manner to what is found for the full sample. For low income households, however, at very low temperatures we observe no reduction in electricity and total metered energy savings from being insulated relative to savings at cool temperatures. After having heat pump installation, low income households consume more metered energy regardless of temperature. High consumption is observed at low temperatures; this initially falls as

[28] $50,800 is the mid-point of the CAU median household values, and therefore provides similar numbers of treated houses within the high and low income brackets.

temperature increases, but begins to rise again once temperatures reach 13˚C (total metered energy) or 18˚C (electricity).

Table 16: High/Low Household Income Estimation Results

		Electricity	(Std. Error)	Total Metered Energy	(Std. Error)
insulation#temp^0		-27.9907	(140.2505)	-46.5860	(144.6247)
high_income#(insulation#temp^0)		304.8571	(214.9124)	369.3006	(226.4463)
insulation#temp^1		0.7584	(29.5966)	3.8819	(30.6316)
high_income#(insulation#temp^1)		-67.6013	(44.4353)	-80.2123*	(47.2331)
insulation#temp^2		0.1155	(2.0394)	-0.1236	(2.1159)
high_income#(insulation#temp^2)		4.5825	(2.9931)	5.5145*	(3.2134)
insulation#temp^3		-0.0025	(0.0455)	0.0049	(0.0476)
high_income#(insulation#temp^3)		-0.0981	(0.0656)	-0.1219*	(0.0710)
heatpump#temp^0		52.7815	(130.3614)	131.1125	(134.4048)
high_income#(heatpump#temp^0)		-149.1210	(196.0743)	-31.5604	(207.9469)
heatpump#temp^1		-1.6896	(28.7732)	-25.3986	(30.1021)
high_income#(heatpump#temp^1)		29.1249	(42.3091)	-9.4866	(45.8943)
heatpump#temp^2		-0.2259	(2.0686)	1.6641	(2.1895)
high_income#(heatpump#temp^2)		-1.9934	(2.9709)	1.2957	(3.2774)
heatpump#temp^3		0.0105	(0.0482)	-0.0336	(0.0515)
high_income#(heatpump#temp^3)		0.0452	(0.0677)	-0.0369	(0.0754)
Observations		325,439		325,439	
Number of Houses		12,082		12,082	
High Income Houses		6,031		6,031	
Low Income Houses		6,051		6,051	
R-Squared (within)		0.00615		0.00609	
R-Squared (adjusted)		0.00282		0.00276	
Wald Test of High Income Effects	insulation (p-value)	0.1701		0.4395	
	heatpump (p-value)	0.7561		0.1866	

Note: Individual house fixed-effects and time (month) fixed-effects are included. Clustered Standard Errors are given in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

High income households are affected in a different manner. We concentrate on the two treatment effects (insulation treatment for electricity use and heat pump treatment for total metered energy use) where there is some weak evidence that behaviour by high income households differs from low income households. At extremely low temperatures, high income households that are treated with insulation use approximately the same electricity as their controls. As temperatures increase, from about 8˚C to about 16˚C, high income households save electricity following insulation treatment. Above 16˚C, we see evidence of the "take-back" effect. The effect of heat pump installation shows the most decisive difference in behaviour for high income relative to low income households. Unlike low income households, high income households are estimated to save on total metered energy at lower temperatures from having a heat pump installed. As temperature increases, total metered energy savings decrease; at 14°C, high income households begin consuming more total metered energy than prior to treatment. By contrast, the effects of heat pump installation on electricity consumption are positive and relatively constant over temperature.

These results (if treated as statistically significant) imply that some high income households treated with a heat pump replace gas heating with more efficient electricity heating following treatment, thus saving on total metered energy use at colder temperatures, while increasing their electricity use. By contrast, low income households appear not to have the same substitution opportunities, possibly because they were previously not using substantial gas heating in their house, or had been using other sources of heating (wood or unreticulated gas). These results are opposite to Milne and Boardman (2000), who found low income households to take energy savings as comfort improvements at low temperatures.

While these differences in behaviour are plausible, the difference in results must be treated with caution given the weak statistical evidence that the effects differ by income.

Figure 15: Low Income Treatment Effects by Temperature

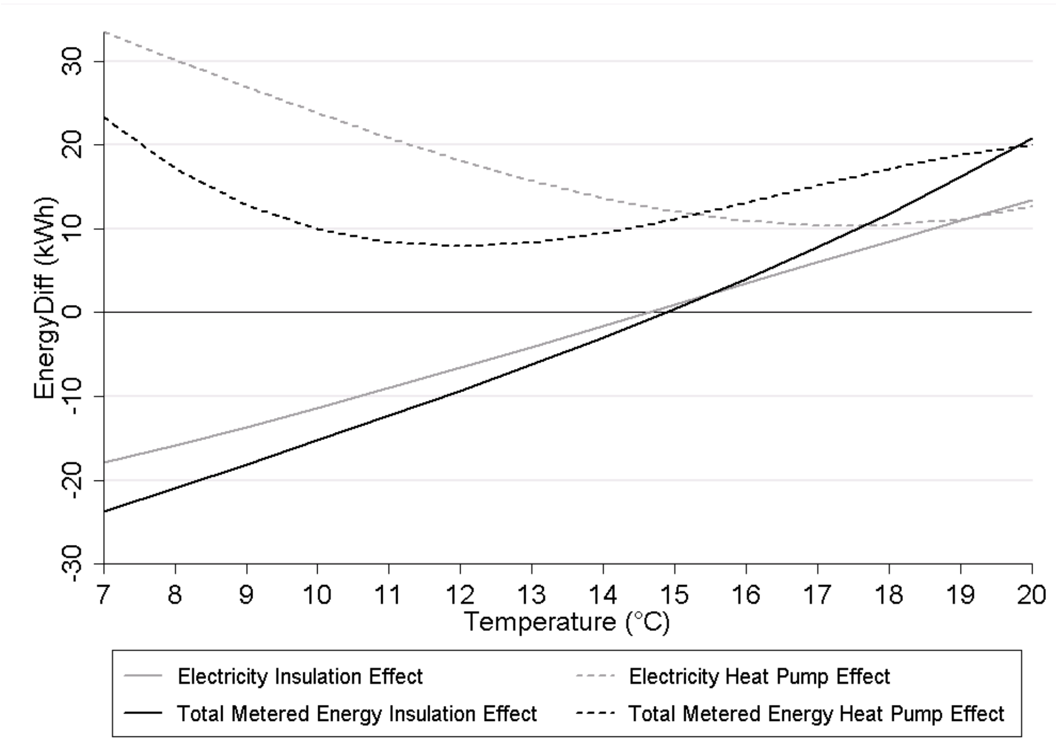
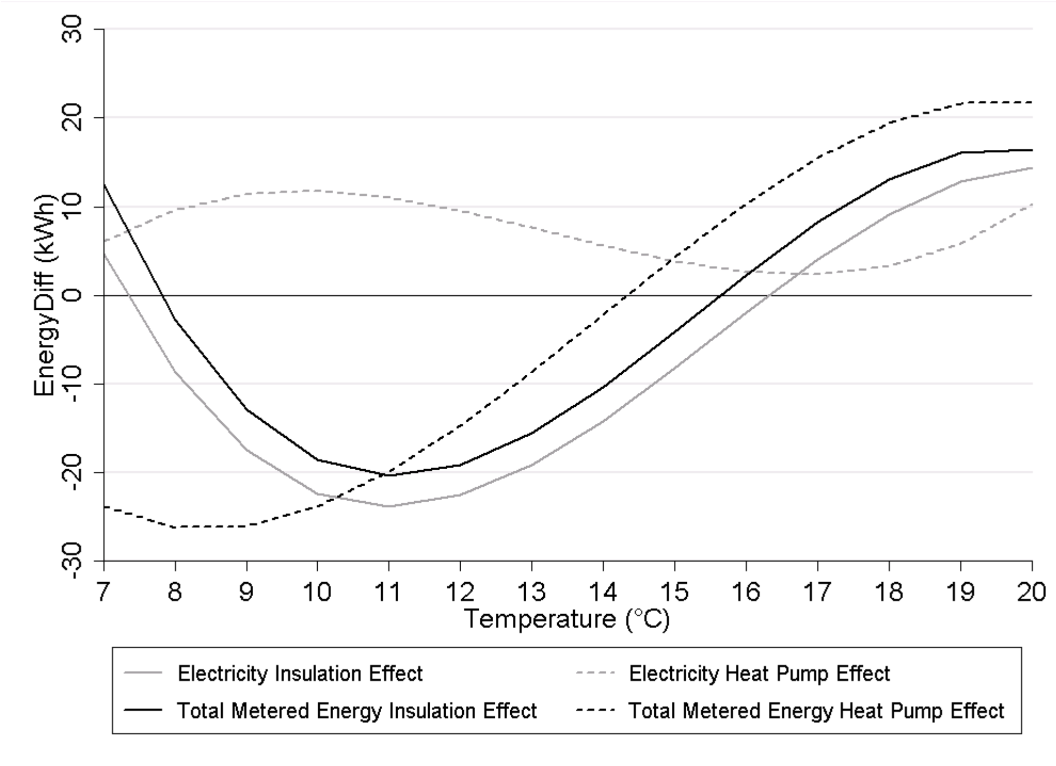


Figure 16: High Income Treatment Effects by Temperature



6.2.2. Community Services Card Holders

Secondly, we divide our sample into treated houses with and without a Community Services Card (CSC). CSCs are available to people aged 18 years and older, on a low to middle income level, and who are a New Zealand citizen or permanent resident. Those receiving social benefits are automatically issued with a card. CSCs allow holders access to lower costs of health care, through subsidised health services and prescriptions.

Of the treated houses in our sample, 6,460 (53.47%) treated houses hold a CSC, while 5,622 (46.53%) treated houses do not hold a CSC. We create a dummy variable *CSC*=1 if a treated house holds a CSC, and zero otherwise. Following a similar approach as in 6.2.1, we estimate the effect of insulation and heat pump installation on houses with and without a CSC to assess whether households holding a CSC react differently in terms of metered energy use post-treatment. Results are presented in Table 17. Individual coefficients on the CSC interaction terms, together with the joint-significance Wald test results, indicate that there is very little evidence of any difference in treatment effects between CSC houses and other houses for either electricity or total metered energy use.[29]

Given the lack of statistically significant evidence from either method of income sub-sampling, we retain our (simpler) cubic specification as our preferred model.

Table 17: CSC Estimation Results

		Electricity	(Std. Error)	Total Metered Energy	(Std. Error)
$insulation\#temp^0$		22.4304	(175.4440)	26.9157	(183.4201)
$CSC\#(insulation\#temp^0)$		138.8866	(224.1075)	144.4312	(234.9614)
$insulation\#temp^1$		-13.4192	(36.0569)	-17.4622	(38.1506)
$CSC\#(insulation\#temp^1)$		-25.8597	(46.3664)	-22.9413	(49.1112)
$insulation\#temp^2$		1.1296	(2.4090)	1.6209	(2.5819)
$CSC\#(insulation\#temp^2)$		1.6696	(3.1183)	1.1637	(3.3396)
$insulation\#temp^3$		-0.0240	(0.0523)	-0.0386	(0.0567)
$CSC\#(insulation\#temp^3)$		-0.03659	(0.0681)	-0.0191	(0.0737)
$heatpump\#temp^0$		6.8469	(154.2294)	160.9856	(163.4997)
$CSC\#(heatpump\#temp^0)$		-19.2761	(201.0211)	-8.9066	(212.5215)
$heatpump\#temp^1$		5.7481	(32.7760)	-40.2925	(35.7641)
$CSC\#(heatpump\#temp^1)$		8.0576	(43.2184)	6.1722	(46.8269)
$heatpump\#temp^2$		-0.6870	(2.2708)	3.0521	(2.5356)
$CSC\#(heatpump\#temp^2)$		-0.7396	(3.0231)	-0.6733	(3.3384)
$heatpump\#temp^3$		0.0213	(0.0511)	-0.0694	(0.0581)
$CSC\#(heatpump\#temp^3)$		0.0181	(0.0686)	0.0193	(0.0767)
Observations		325,439		325,439	
Number of Houses		12,082		12,082	
CSC Houses		6,460		6,460	
No CSC Houses		5,622		5,622	
R-Squared (within)		0.00574		0.00590	
R-Squared (adjusted)		0.00237		0.00253	
Wald Test of CSC Treatment Effects	insulation (p-value)	0.7638		0.7923	
	heatpump (p-value)	0.9275		0.9887	

6.3. Widening the Definition of Heater Installation

The next extension we undertake is to widen our definition of heater installation to include houses that had heaters other than an electric heat pump installed. From Table 2, approximately 84.0% of heater installations were heat pumps, 15.5% are wood/pellet burners,

[29] Given the lack of evidence for any difference between CSC and no CSC houses, figures of treatment effects by temperature are not presented.

and 0.5% were flued gas heaters. By including these additional heater installations, we increase our sample size by 530 treated houses.

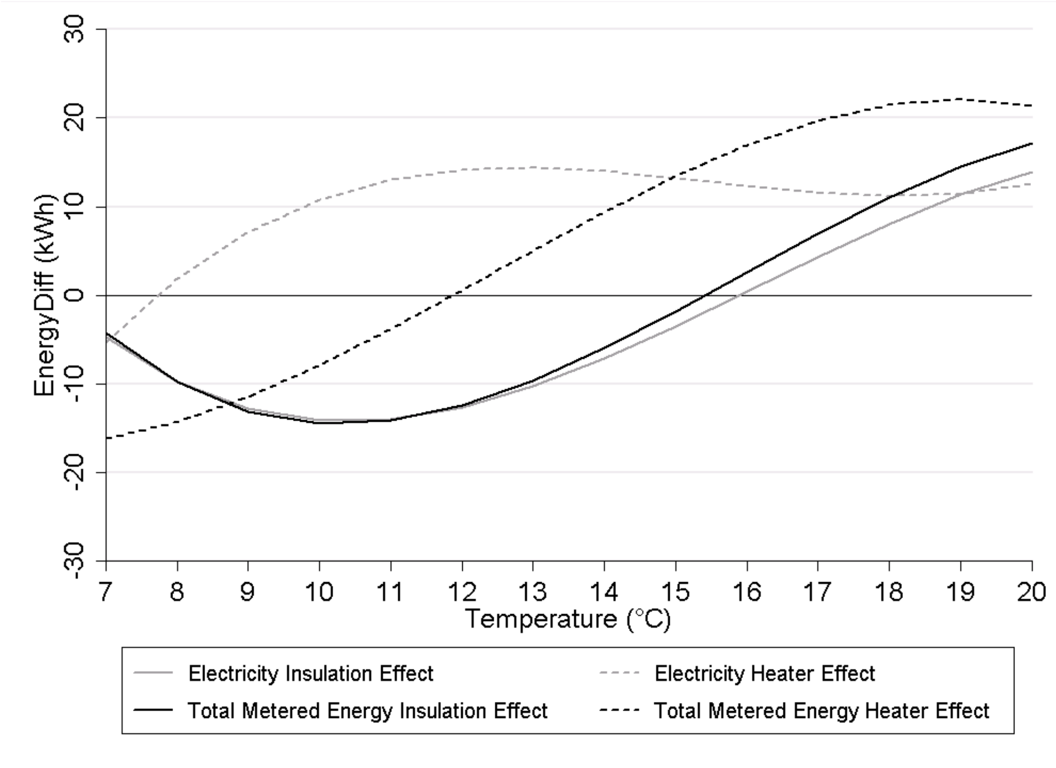
Estimating the cubic specification of equation 13, we obtain the results presented in Table 18 and Figure 17. The effect of insulation is not sensitive to how the heater effect is defined. Coefficients are of the same sign and similar magnitude across the two regressions, for both electricity and total metered energy, and the insulation effects by temperature are very similar for electricity and total metered energy in Figure 13 and Figure 17. Where we do see a marked difference between the two sets of results is when we consider the heater effects.

At temperatures above 13˚C, heater effects are similar regardless of the definition of heater installation (Figure 13 and Figure 17). However, below 13˚C, there are differences in the effect of heater installation on metered energy saving between the two heater definitions. When we defined heater installation as solely heat pump installation, we observed electricity use increase as temperatures dropped, while total metered energy savings are made until we reach the coldest temperatures. Once we change the definition of heater to include all heater installations, we see that, below 13˚C, electricity use is still higher for treated houses, except at the coldest temperatures, while below 12˚C total metered energy savings occur.

Table 18: Insulation and Heater Estimation Results

		Electricity	(Std. Error)	Total Metered Energy	(Std. Error)
insulation#temp^0		105.0895	(101.3111)	120.4600	(106.1711)
insulation#temp^1		-27.3052	(21.0682)	-31.2132	(22.3432)
insulation#temp^2		1.9393	(1.4248)	2.2424	(1.5301)
insulation#temp^3		-0.0401	(0.0313)	-0.0470	(0.0340)
heater#temp^0		-129.7745	(91.1918)	14.3229	(96.3715)
heater#temp^1		-29.4111	(19.8446)	-11.7996	(21.4499)
heater#temp^2		-1.9567	(1.4021)	1.3077	(1.5412)
heater#temp^3		0.04212	(0.03211)	-0.0350	(0.0357)
Observations		339,057		339,057	
Number of Houses		12,612		12,612	
R-Squared (within)		0.00355		0.00412	
R-Squared (adjusted)		0.00192		0.00250	
Wald Test of Treatment Effects	insulation (p-value)	0.0001		0.0004	
	heatpump (p-value)	0.0082		0.0035	

Figure 17: Insulation and Heater Treatment Effects by Temperature



The majority of the non-heat pump heater installations are wood/pellet burners that rely on solid fuels (rather than electricity or reticulated gas). Use of these heaters more intensely during cold periods will not be accounted for in our measures of energy use, as we are unable to incorporate the amount of solid fuel burnt in these heaters. Since solid fuel is not incorporated into our measures of energy, at the coldest temperatures, houses with wood/pellet burners will be saving on electricity and gas use as they are able to burn solid fuels.

However, given that we are unable to measure the amounts of solid fuel being burnt, we cannot deduce with this wider definition of heater installation whether treated houses are actually making total energy savings. Therefore, we retain our initial definition of heater installation (heat pumps only) in order to accurately tease out actual metered energy savings resulting from heat pump installation.

6.4. Extension to include Monthly Temperature Variation

We extend our analysis to investigate whether the variability of temperatures within a month affects the total metered energy saved as a result of having insulation or a heat pump installed, and whether this effect varies as temperatures rise. We have two hypotheses: firstly, metered energy savings will be greater when monthly temperatures are more variable, and secondly, metered energy savings in response to temperature variability will be more marked at lower temperatures (for the same reason). Temperature quintiles are formed using the monthly mean temperatures; quintiles are defined as: 5˚C ≤ ***temp_1*** <8˚C; 8˚C ≤ ***temp_2*** < 11˚C; 11˚C ≤ ***temp_3*** < 14˚C; 14˚C ≤ ***temp_4*** < 17˚C; and 17˚C ≤ ***temp_5***. These quintiles are then interacted with the interaction between *insulation* and *var_temp* (the monthly variance of daily temperature). The three-way interaction terms are then added to the cubic version of equation (14) to give:

$$\begin{aligned} EnergyDiff_{it}^{r} = \alpha_i + \mu_t^r + \sum_{s=0}^{3}\gamma_s\left(insulation_{it} * \left[temp_{it}^{r}\right]^s\right) \\ + \sum_{s=0}^{3}\delta_s\left(heatpump_{it} * \left[temp_{it}^{r}\right]^s\right) \\ + \sum_{q=1}^{5}\lambda_q\left(temp\_q * insulation_{it} * var\_temp_{it}^{r}\right) \\ + \sum_{q=1}^{5}\theta_q\left(temp\_q * heatpump_{it} * var\_temp_{it}^{r}\right) + \varepsilon_{it} \end{aligned} \tag{15}$$

Estimation of (15) provides the results presented in Table 19. The previous effects found from estimating (14) are preserved for both electricity and total metered energy. Coefficients have the same sign and are of similar magnitudes as those in Table 12. Wald tests indicate that coefficients remain jointly significant for both insulation and heat pump effects. Looking at the coefficients λ_q, we find that, for electricity and total metered energy use, the insulation impact is not significantly affected by the monthly variation of temperatures for any temperature quintile. A Wald test on the *var_temp* interaction terms shows that they are not jointly significant. In other words, more variable monthly temperatures do not affect the estimated impact of insulation on metered energy use, regardless of the underlying monthly temperature. However, we find that temperature variability does affect the impact of heat pump installation on metered energy use, especially for electricity consumption. All coefficients θ_q (except θ_1) are statistically significant and negative for electricity use, indicating that months with more variation in the temperature will induce greater metered energy savings in houses with heat pumps installed under WUNZ:HS. In addition, as temperatures increase, the additional effect of temperature variation reduces (except for the warmest quintile, where it increases again), implying that, as temperatures get cooler, metered energy savings become larger for more varied temperatures. However, caution should be taken with respect to these results as the temperature variation terms for heat pump installation are not jointly significant.

As temperatures decrease, we conjecture that houses that have had heat pumps installed will intensify their heat pump use and subsequently increase their electricity use. If monthly temperature variation is higher, houses experience more periods within the month of warmer temperatures, as well as more periods of cooler temperatures. Warmer periods will require less heating, and hence, require less use of heat pumps meaning greater additional metered energy savings. This effect will diminish as the underlying temperature increases since households' demand for heating falls as temperatures rise. During cold periods, households will operate their heat pumps more intensively, possibly reaching the appliance's capacity. This constraint limits the amount of additional electricity use during colder periods and means that increased electricity use due to more frequent colder periods may be more than offset by the savings from reduction in use in warmer periods.

Table 19: Estimation Results for Equation (15)

		Electricity	(Std. Error)	Total Metered Energy	(Std. Error)
insulation#temp^0		65.4813	(178.7426)	137.3006	(197.3862)
insulation#temp^1		-24.0012	(36.4156)	-41.9352	(40.4223)
insulation#temp^2		1.9594	(2.3991)	3.3202	(2.6768)
insulation#temp^3		-0.0446	(0.0510)	-0.0758	(0.0571)
tempband1#(insulation#var_temp)		5.3493	(6.6393)	2.2796	(8.1223)
tempband2#(insulation#var_temp)		1.3690	(1.7638)	2.1420	(1.9702)
tempband3#(insulation#var_temp)		0.9843	(1.3710)	0.7092	(1.5265)
tempband4#(insulation#var_temp)		-0.1072	(1.1618)	-0.4988	(1.2102)
tempband5#(insulation#var_temp)		0.6134	(1.6536)	-0.7078	(1.8753)
heatpump#temp^0		19.7065	(150.1345)	191.2552	(161.7523)
heatpump#temp^1		7.9721	(31.8556)	-50.5895	(35.0403)
heatpump#temp^2		-0.8656	(2.1817)	3.9606	(2.4359)
heatpump#temp^3		0.0239	(0.0481)	-0.0910*	(0.0542)
tempband1#(heatpump#var_temp)		-6.299	(5.6451)	4.3201	(6.5318)
tempband2#(heatpump#var_temp)		-4.3870*	(2.2963)	0.7040	(2.6777)
tempband3#(heatpump#var_temp)		-4.1575**	(1.8043)	0.1239	(2.0713)
tempband4#(heatpump#var_temp)		-2.9935**	(1.4362)	-1.9372	(1.5163)
tempband5#(heatpump#var_temp)		-4.4275**	(2.1261)	-5.1319**	(2.3595)
Observations		325,439		325,439	
Number of Houses		12,082		12,082	
R-Squared (within)		0.00372		0.00409	
R-Squared (adjusted)		0.00200		0.00237	
Wald Test of Treatment Effects	insulation (p-value)	0.0346		0.0201	
	heatpump (p-value)	0.0023		0.0241	
Wald Test of Temperature Variation Effects	insulation (p-value)	0.7583		0.8466	
	heatpump (p-value)	0.1830		0.2074	

Note: Individual house fixed-effects and time (month) fixed-effects are included. Clustered Standard Errors are given in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

The additional heat pump installation effect on total metered energy use from monthly temperature variation is weaker than the effect on electricity use. The coefficient on the warmest temperature quintile (θ_5) is significant and negative, but the lower temperature quintiles have no significant effects. The limited additional heat pump effect on total metered energy use from monthly temperature variation may be caused by households exhibiting similar metered energy consumption behaviours when monthly temperatures fluctuate, regardless of whether the house has a reticulated gas heater or a heat pump. However, given that only heat pumps have the dual function of an air conditioning unit we see a significant effect from θ_5.

The extension to include monthly temperature variation marginally adds to the explanatory power of the impacts of insulation and heat pump treatment on houses (the adjusted R-squares on the electricity use sample slightly improves from the cubic specification without the temperature variation terms; no change in adjusted R-squared is observed for total metered energy). Given that the addition in explanatory power is slight, and that the Wald tests indicate that the temperature variation terms are not jointly significant for both insulation and heat pump treatment, we retain the previous simpler cubic specification (without the monthly temperature variation terms) as our preferred specification.

6.5. Relaxing Exclusion Criteria in Defining Sample

We relax the exclusion criteria used in defining our sample to analyse whether there are significant changes in the results. Given that none of the previous robustness tests uncovered material significant additions to our original preferred cubic specification, we continue to test the robustness of our sample on this specification.

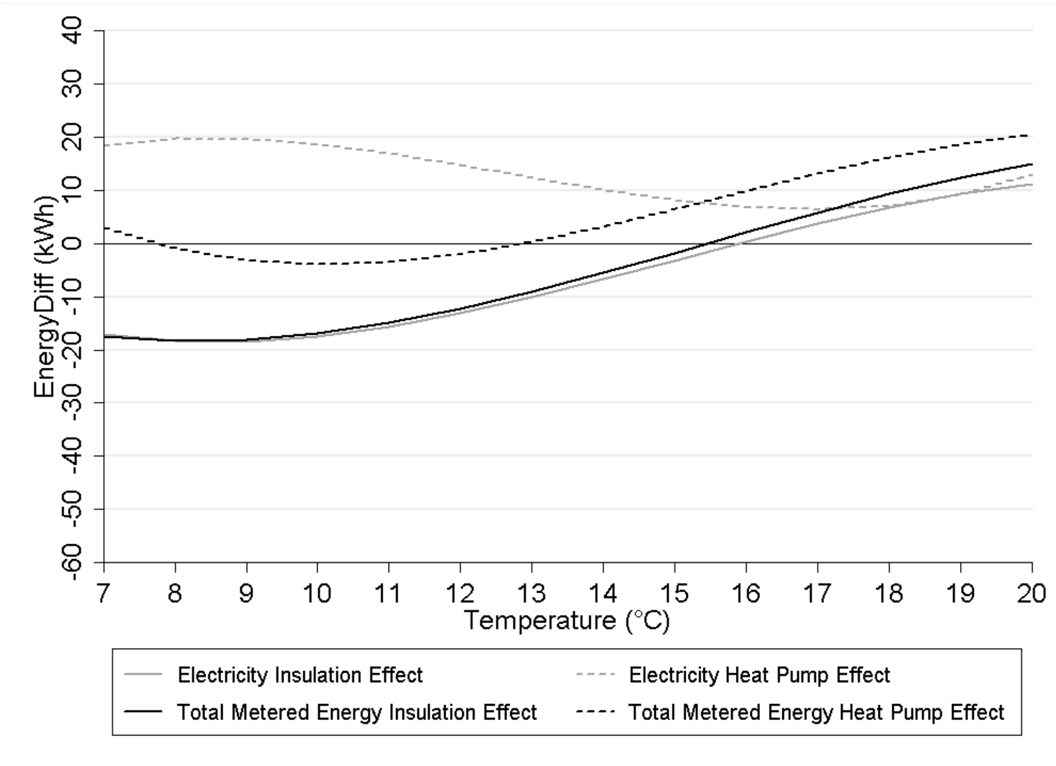
We test the robustness of our results by incrementally relaxing the exclusion criteria to observe whether the impacts of treatment are affected by how the sample is defined. Exclusion criteria which are preserved throughout all the stages are: zero electricity use observations are removed, any house with only a partial series of gas use is removed, and any house with only gas use observed is removed.

6.5.1. Include Houses that Switched Electricity Company.

First, we take our initial sample, but re-introduce those houses previously removed because they had switched electricity company at some time during the sample period. These houses were originally removed as we considered that they may be atypical houses, potentially being houses with changing occupiers, or houses with very price-sensitive occupants. By including houses that have switched electricity company, we increase our original sample to 12,736 treated houses from 12,082, with an increase to 345,556 house-month observations.

The treatment effects estimated from this sample is presented in Figure 18. The treatment effects are similar between this sample and our original; the only noticeable changes are the magnitudes of effects at the lowest temperatures. At the lowest temperatures, the sample that includes houses that switched electricity company indicates that slightly more metered energy is being saved from insulation treatment, and a slightly smaller amount of metered energy is being spent from heat pump treatment.

Figure 18: Treatment Effects by Temperature from Including Houses that Switched Electricity Company

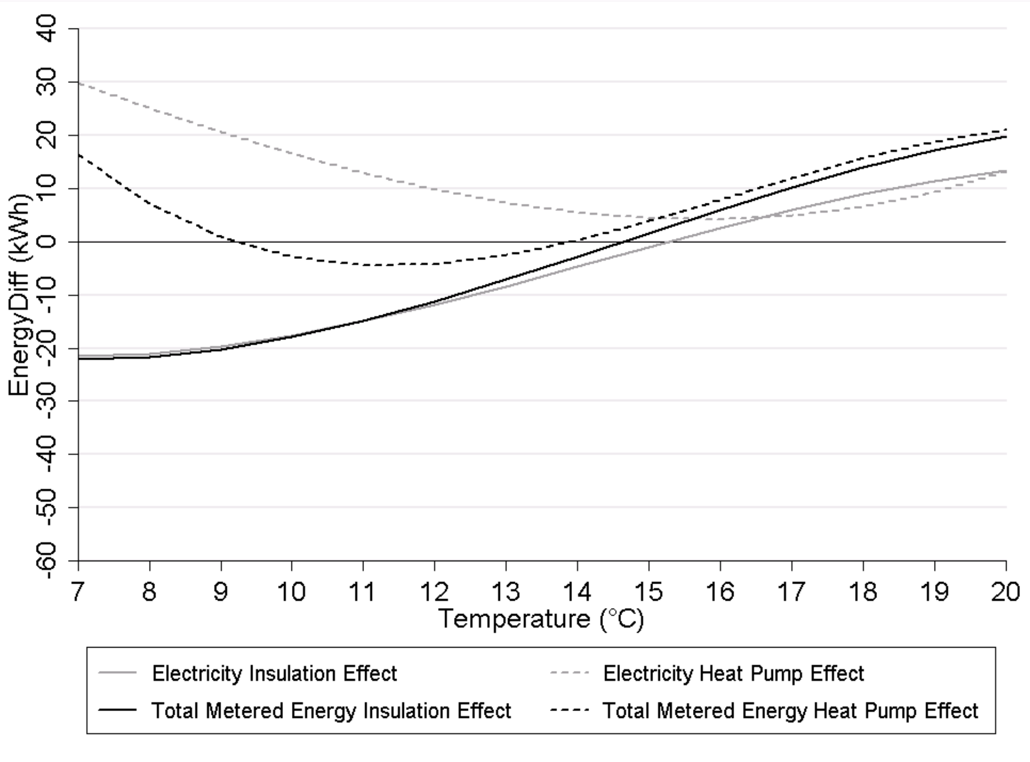


6.5.2. Relaxing the Outliers Constraint.

Next, we take our initial sample and re-include all non-outlying electricity use observations for houses that previously had all their electricity use observations removed due to their having had at least one outlying observation. The electricity outliers themselves (defined as being in the top and bottom 1% of all electricity use levels) are still removed. The sample here contains 13,958 treated houses with 367,495 house-month observations, an increase of 1,876 treated houses and 42,056 house-month observations.

The effects of treatment found from estimating our cubic specification on this less restrictive sample are presented in Figure 19. Much the same treatment effects are observed between this sample and our initial sample (Figure 13). We do see a change in behaviour at the very coldest temperatures, where results indicate continued metered energy savings from insulation whereas previously we found less savings as temperatures reached their coldest.

Figure 19: Treatment Effects by Temperature from Relaxing the Outliers Constraint

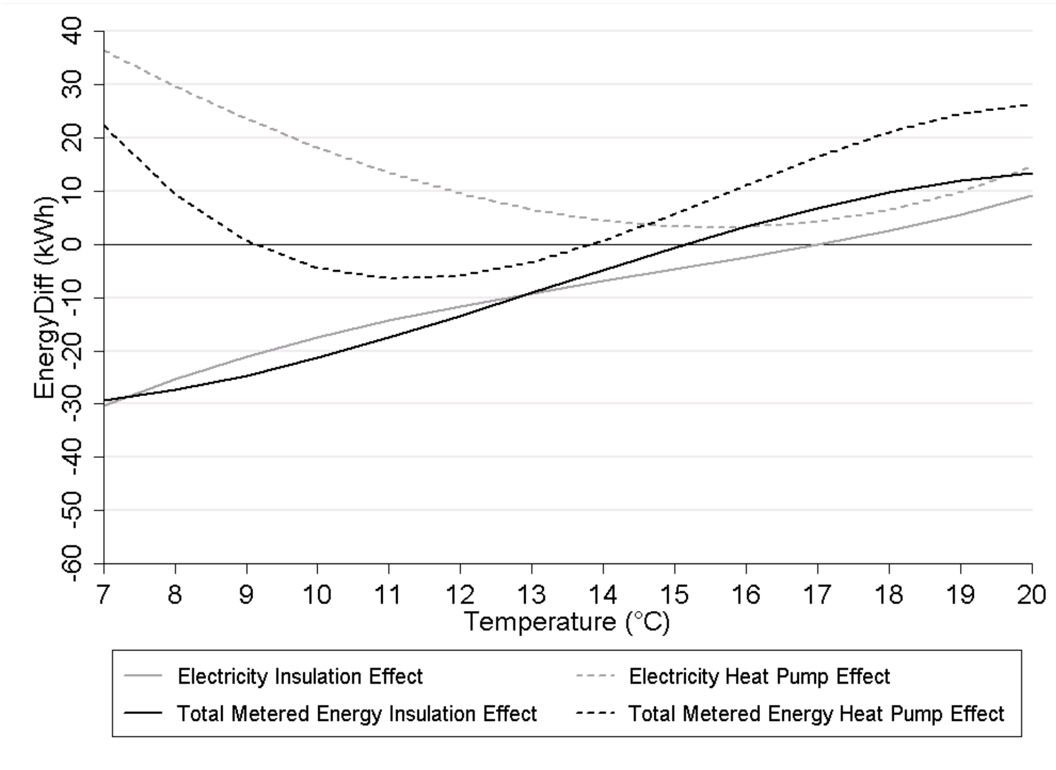


6.5.3. Not Removing Outliers.

We now take the same sample as in 6.5.2, except we do not remove outlying observations. This boosts the number of treated houses to 13,988, with 373,160 house-month observations.

Estimation of this sample provides the results depicted in Figure 20. The change between Figure 19 and Figure 20 is marginal; however, the insulation effect on electricity and total metered energy use as temperatures reach the coldest temperatures shows increased savings.

Figure 20: Treatment Effects by Temperature from Not Removing Outliers

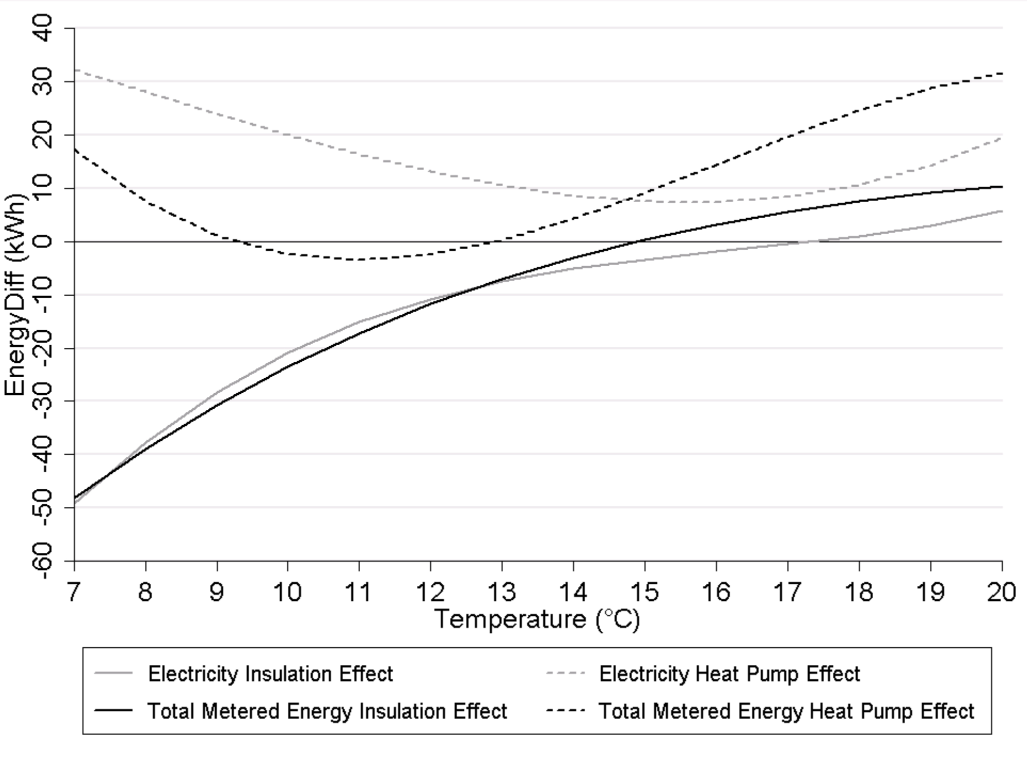


6.5.4. Including Outliers and Houses that Switched Electricity Company.

This next sample extension includes observations from all outlying houses, along with those houses that have switched electricity company. The number of treated houses included in this sample is 14,793, with 397,864 house-month observations.

The estimated treatment effects from this less restrictive sample are presented in Figure 21. With this sample, we see a marked difference in the effect of insulation from our original sample as we approach the coldest temperatures. Both electricity and total metered energy experience increased savings as temperatures reach their coldest.

Figure 21: Treatment Effects by Temperature from Including Outliers and Switched Houses

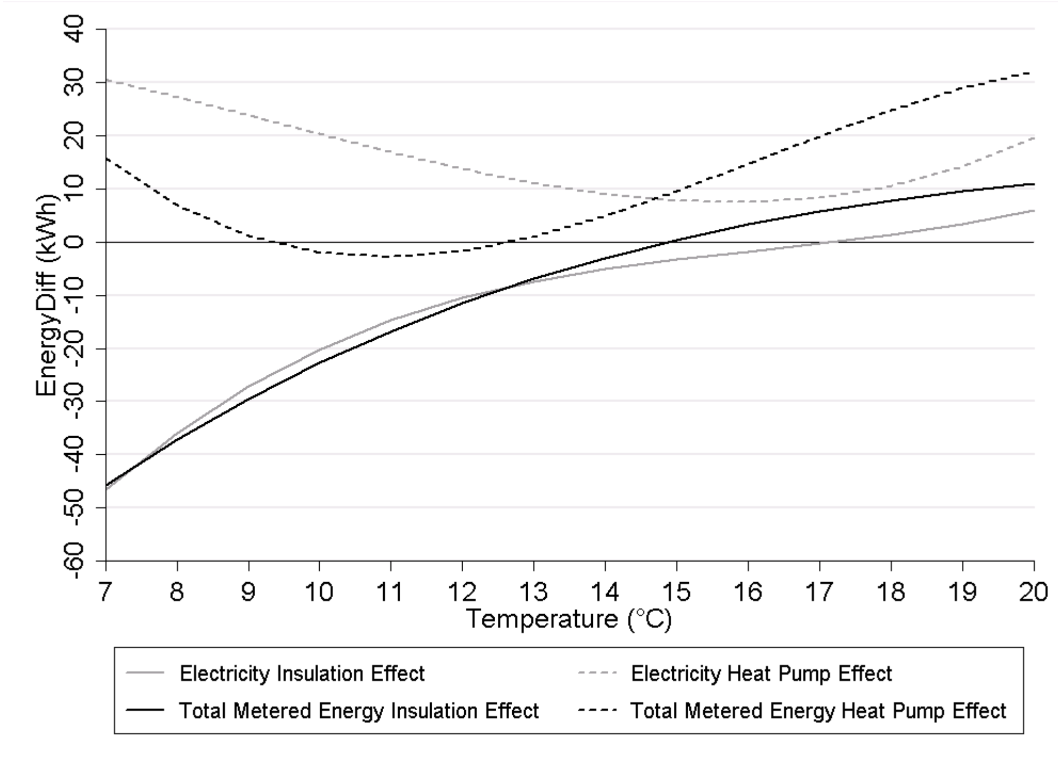


6.5.5. All Exclusion Criteria Relaxed

Initially, we excluded all metered energy observations for houses with at least one negative electricity or gas submission level, as we deemed all observations to be potentially contaminated by this error. We now only remove the specific negative observation, rather than all observations. Houses that switched electricity supply company are included, as are outliers. This least restrictive sample contains 14,846 treated houses, with 399,129 house-month observations.

Estimating the cubic specification of equation 14 with this least restrictive sample provides the regression results presented in Figure 22. The addition of metered energy data for houses with negative observations does little to affect the treatment effects on top of what was observed in Figure 21.

Figure 22: Treatment Effects by Temperature from Relaxing All Exclusion Criteria



6.5.6. Summary of Relaxing Exclusion Criteria

The results from progressively relaxing the exclusion criteria suggest that, for the most part, our results are robust to changes in sample definition. Above the coldest temperatures (greater than 10˚C), the insulation effect and the heat pump effect change very little across the differing samples. However, at the coldest temperatures we observe marked changes in insulation effects. Previously, we found reduced electricity and metered energy savings were observed from insulation installation at the coldest temperatures, but with the extended samples, we find that there is generally increasing electricity and total metered energy savings as temperatures drop. This is especially true for the least restrictive samples (Figure 20 to Figure 22). The criterion that the results seem to be most sensitive to is outliers. Even when removing just outlying observations, the results at the coldest temperatures are affected. In our original specification, at the coldest temperature (7˚C), electricity savings represented approximately 1.25% of mean control electricity use, while total metered energy savings represented around 1.28% of mean control total metered energy use. For the least restrictive sample, the same respective figures are approximately 6.79% and 5.96%. Although these numbers indicate a relatively large increase, there are few houses that experience monthly average temperatures of 7°C or lower, so the impact on estimates of overall energy savings are not great.

The majority of households in the South Island rely on non-metered energy sources (solid fuels and non-metered gas) for space heating. These households are likely to have below average metered energy use and may therefore show up as low outliers, i.e. outliers identified as being in the bottom 1% (using less than 30 kWh per month) of metered electricity use. Figure 23 indicates that three southern regions (Canterbury, Otago and Southland) have the highest percentage of their treated houses with observed metered energy identified as outliers. The extended samples therefore include relatively more houses from these regions compared with the cleaned sample, and this may be one reason that results differ across samples.

Figure 23: Outlier Treated Houses as a Percent of Regional Treated Houses

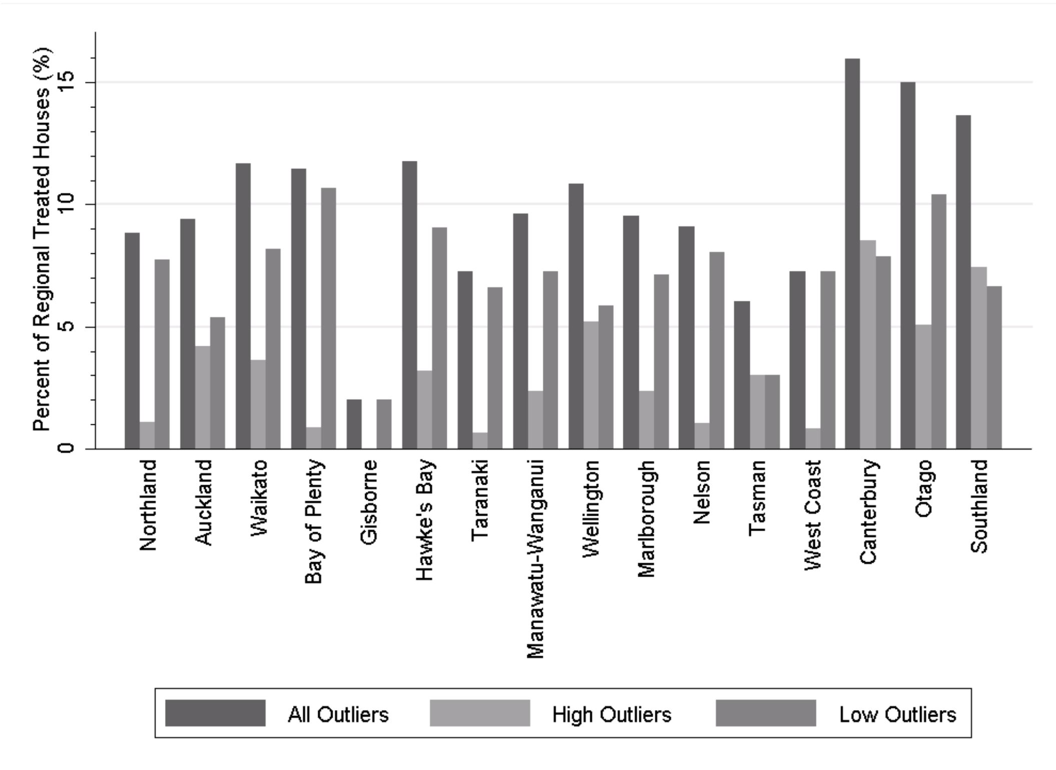


Table 20 provides national estimates of energy savings for the cleaned sample (as per the cubic specification in Table 13), and for each of the non-split extended samples (i.e. those corresponding to section 6.3 and sections 6.5.1-6.5.5). Most, but not all, of the extended samples indicate moderately higher metered energy savings due to retrofitted insulation. The highest estimates are for an annual electricity saving of 1.41% and a total metered energy saving of 1.03% following insulation treatment. The impacts of heat pump installation show that the estimates of extra metered energy use from the extended samples are broadly balanced around the estimates from the cleaned sample. Overall, therefore, our calculations of energy savings based on the cleaned sample are shown to be conservative estimates of metered energy impacts of the WUNZ:HS scheme, although none of the alternative estimates are notably greater.

Table 20: Predicted Annual Percentage Savings from Treatment (Alternative Samples)

	Insulation		Heat Pump	
	Electricity (%)	Total Metered Energy (%)	Electricity (%)	Total Metered Energy (%)
Preferred (Cleaned) Specification	0.96	0.66	-1.92	-0.75
Heater Extension (6.3)	0.81	0.57	-1.90	-0.99
Sample Extension 1 (6.5.1)	1.03	0.75	-1.93	-0.65
Sample Extension 2 (6.5.2)	0.83	0.46	-1.53	-0.53
Sample Extension 3 (6.5.3)	1.24	0.91	-1.54	-0.70
Sample Extension 4 (6.5.4)	1.41	1.03	-2.08	-1.13
Sample Extension 5 (6.5.5)	1.35	0.97	-2.11	-1.19

6.6. Accounting for Non-Metered Energy

Energy data used in our analysis measures only metered energy, i.e. electricity and reticulated gas. Non-metered energy sources, such as solid fuels (wood, coal, etc), oil and bottled gas (LPG), are also popular choices used for heating purposes; however, data that measure households' consumption of non-metered energy sources are unavailable. Therefore we are unable to measure directly the full effects of WUNZ:HS on household total energy consumption.

Our current model predicts overall metered energy savings, but given that we are unable to account for all energy sources, these metered energy savings may understate the full impact of the scheme. We analyse two separate sub-samples of our treated houses to gain insight into additional effects that may give a more complete picture of energy savings from being insulated and having a heat pump installed.

6.6.1. Sub-Sampling by Houses that use Non-Metered Fuel for Heating

Our raw data provides a variable that indicates the prior heating source of a household, if known. This variable is included where a house received a clean heat treatment (whether or not it also received insulation treatment under the scheme), although it is missing in many instances. We utilise this variable to generate a dummy variable equal to one if a household is known to have used non-metered fuel (e.g. solid fuel or LPG) to heat their homes prior to WUNZ:HS treatment, and zero otherwise. Interacting this dummy variable with our preferred specification, we observe whether metered energy use behaviour is affected differently for those households that formerly used non-metered fuels to heat their home. Our hypothesis is that following insulation and/or heat pump treatment, houses previously using non-metered fuels for heating will reduce their consumption of these fuels and will therefore see a smaller reduction in metered energy use in comparison to other households.

A comparison of the effect of insulation installation on these two sub-sets of households is presented in Figure 24. Households that used non-metered fuel heaters prior to treatment save more metered energy (electricity and total) than other households once they have insulation installed. While this response is in the *opposite* direction of what was hypothesised, the differences are not statistically significant at the 5% level for either total metered energy or electricity (Table 21), although the electricity effect is significant at the 10% level and the total metered energy effect is significant at the 15% level.

The sample of houses with pre-existing non-metered energy heating appliances is small (N=418), while the differences between the outcomes for houses with and without non-metered heating sources in Figure 24 are material. It may be reasonable, therefore, tentatively to conclude that houses with non-metered energy heating appliances save more metered energy once insulation is installed. This could occur if households that have solid fuel (and other) burners keep using these appliances for heating in cold conditions either because of the ambience of a fire or because the fuel is obtained from free sources. These houses may therefore reduce their metered energy heating by more than houses without solid fuel appliances. In turn, this would imply that their savings in non-metered fuels may not be material, but we have no direct evidence on this.

The effect of heat pump installation for these two household sub-sets is presented in Figure 25. Increased electricity and total metered energy use is observed for households that replace (or complement) non-metered fuel heaters with heat pump heaters. This result is expected; heat pumps require electricity to operate and since these houses move from using non-metered sources of energy to metered electricity, installing a heat pump should increase these households' metered energy consumption. However, these differences in energy use behaviour are not statistically significant at even the 20% level (Table 21) and so we do not ascribe any differences in metered energy use between these two sub-sets of households in response to heat pump treatment.

The metered energy effects from insulation treatment for both sub-sets of houses is already captured in our original specification and, given the lack of statistical precision, the sub-sampling adds little to our preferred equation. In addition, the fact that our sub-sample of houses with pre-existing non-metered energy heating sources is limited to houses that received clean heating treatment may limit the inferences we can draw from this split sample. (We do not have explicit observations on non-metered energy heating sources for houses that received only insulation treatment.) Thus, while we find no evidence to imply that non-metered energy use declines following insulation or heat pump treatment, we cannot rule this possibility out from the data that are available.

Figure 24: Insulation Effects from Sub-Sampling by Solid Fuel Houses

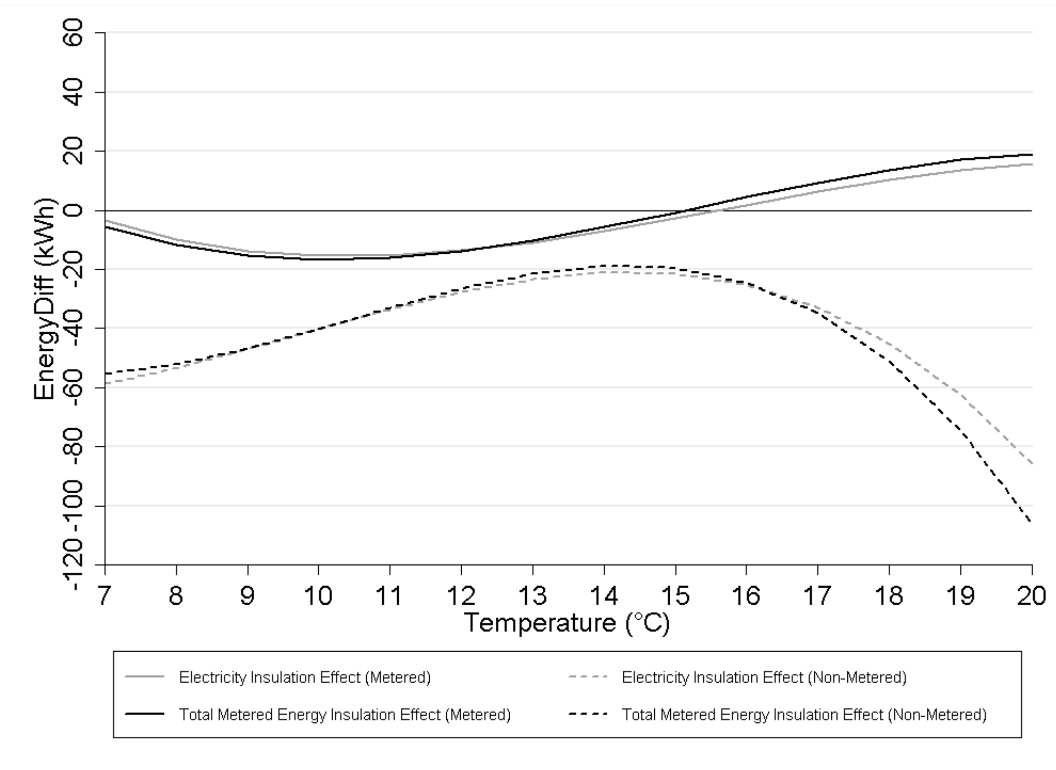


Figure 25: Heat Pump Effects from Sub-Sampling by Solid Fuel Homes

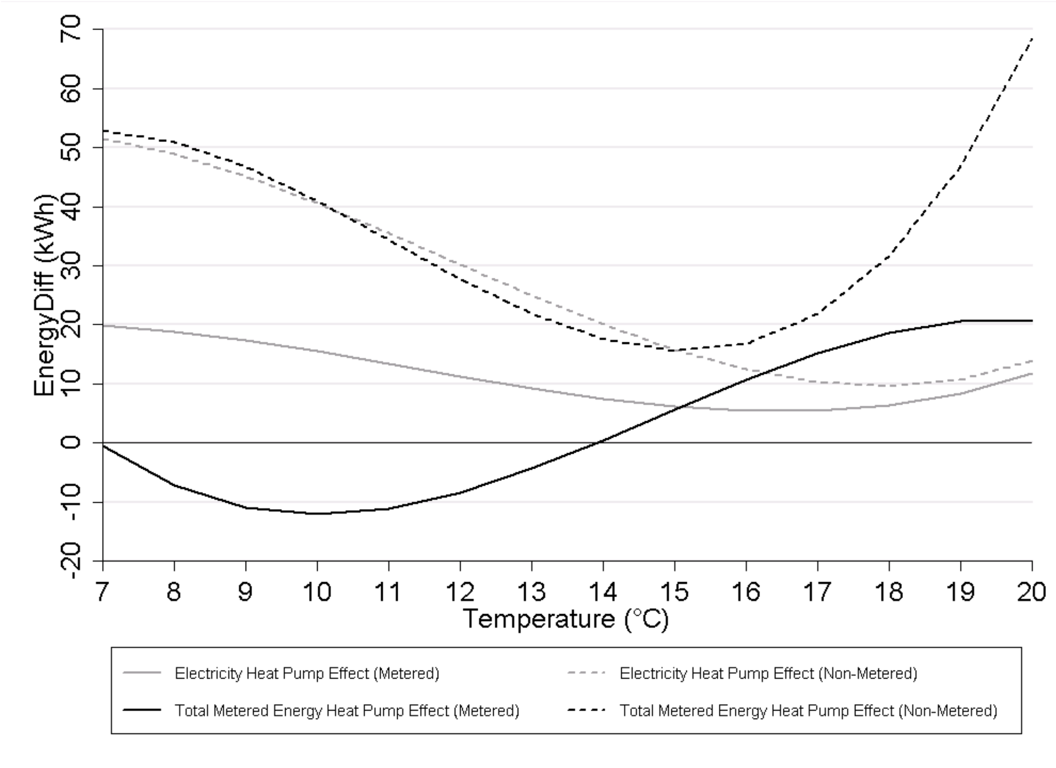


Table 21: Estimation Results from Non-Metered Energy Sub-Sampling

		Electricity	(Std. Error)	Total Metered Energy	(Std. Error)
insulation#temp^0		139.2024	(113.3361)	146.4038	(119.5706)
non-metered#(insulation#temp^0)		-154.0098	(438.9903)	-82.0603	(451.8076)
insulation#temp^1		-35.6161	(23.4858)	-38.5018	(25.0024)
non-metered #(insulation#temp^1)		13.3310	(98.2989)	-4.9515	(102.5700)
insulation#temp^2		2.5579	(1.5808)	2.8307	(1.7006)
non-metered #(insulation#temp^2)		0.4551	(7.1743)	2.0243	(7.6249)
insulation#temp^3		-0.0543	(0.0346)	-0.0612	(0.0375)
non-metered #(insulation#temp^3)		-0.0495	(0.1703)	-0.0942	(0.1855)
heatpump#temp^0		-2.0138	(105.8247)	170.9174	(112.4270)
non-metered #(heatpump#temp^0)		17.0872	(570.5710)	-238.1816	(579.4070)
heatpump#temp^1		8.2212	(22.8618)	-44.1593	(24.8774)
non-metered #(heatpump#temp^1)		6.5441	(124.6486)	85.2498	(127.7251)
heatpump#temp^2		-0.9168	(1.6035)	3.3387	(1.7780)
non-metered #(heatpump#temp^2)		-0.7843	(8.8664)	-7.6762	(9.1943)
heatpump#temp^3		0.0270	(0.0364)	-0.0753	(0.0409)
non-metered #(heatpump#temp^3)		0.0210	(0.2057)	0.2064	(0.2169)
Observations		325,439		325,439	
Number of houses		12,082		12,082	
Metered Energy Houses		11,664		11,664	
Non-metered Energy Houses		418		418	
R-Squared (within)		0.00506		0.00521	
R-Squared (adjusted)		0.00199		0.00214	
Wald Test of Non-metered Treatment Effects	insulation (p-value)	0.0940		0.1465	
	heatpump (p-value)	0.8827		0.2633	

6.6.2. Sub-sampling by Reticulated Gas Houses.

Our second sub-sample divides those houses that have access only to electricity from those houses that have access to both electricity and reticulated gas. This division enables us to observe whether having access to reticulated gas has differing effects on energy savings due to treatment. We estimate our preferred cubic specification but include additional terms interacting treatment effects with a dummy variable equal to one if a house accesses reticulated gas, and zero otherwise. Results are presented in Table 22 and in Figure 26 and Figure 27.

Table 22: Estimation Results from Sub-sampling by Gas-accessible Houses

		Electricity	(Std. Error)	Total Metered Energy	(Std. Error)
insulation#temp^0		125.6278	(114.2045)	129.6121	(115.7050)
gas#(insulation#temp^0)		-245.9105	(270.0244)	-498.1289	(564.9976)
insulation#temp^1		-33.1022	(23.7831)	-36.2066	(24.1612)
gas #(insulation#temp^1)		49.5363	(54.6216)	106.0096	(113.2008)
insulation#temp^2		2.3998	(1.6088)	2.7660	(1.6397)
gas #(insulation#temp^2)		-3.1613	(3.6398)	-7.5343	(7.4597)
insulation#temp^3		-0.0511	(0.0353)	-0.0624	(0.0361)
gas #(insulation#temp^3)		0.0641	(0.0795)	0.1794	(0.1613)
heatpump#temp^0		34.4417	(101.7985)	34.3416	(104.3085)
gas #(heatpump#temp^0)		12.8669	(264.5957)	-413.9206	(493.3322)
heatpump#temp^1		-0.7020	(22.0857)	1.0967	(22.9111)
gas #(heatpump#temp^1)		16.9533	(57.4480)	-19.6604	(104.6771)
heatpump#temp^2		-0.2177	(1.5565)	-0.4410	(1.6293)
gas #(heatpump#temp^2)		-2.1683	(4.0844)	5.9368	(7.3424)
heatpump#temp^3		0.0096	(0.0355)	0.0163	(0.0374)
gas #(heatpump#temp^3)		0.0684	(0.0939)	-0.1888	(0.1678)
Observations		325,439		325,439	
Number of Houses		12,082		12,082	
Electricity Only Houses		10,476		10,476	
Electricity and Gas Houses		1,606		1,606	
R-Squared (within)		0.00611		0.02811	
R-Squared (adjusted)		0.00355		0.02560	
Wald Test of Gas	insulation (p-value)	0.8731		0.3646	
Treatment Effects	heatpump (p-value)	0.2239		0.0000	

Figure 26: Insulation Effects from Sub-sampling by Gas-accessible Houses

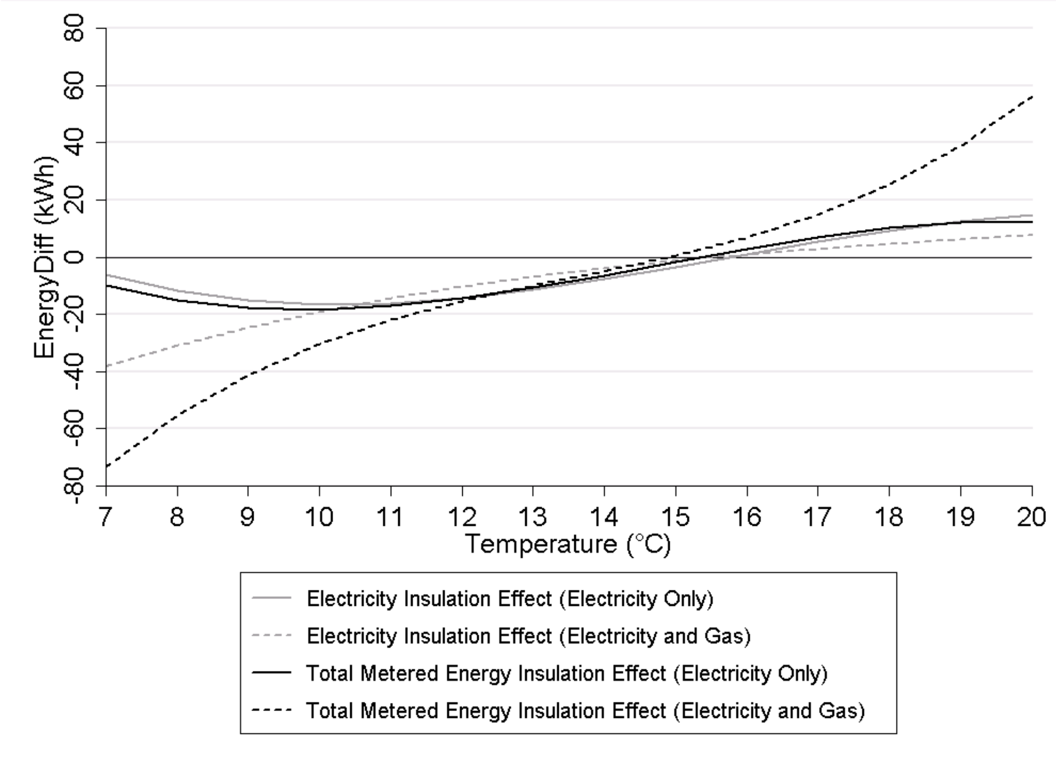


Figure 27: Heat Pump Effects from Sub-sampling by Gas-accessible Houses

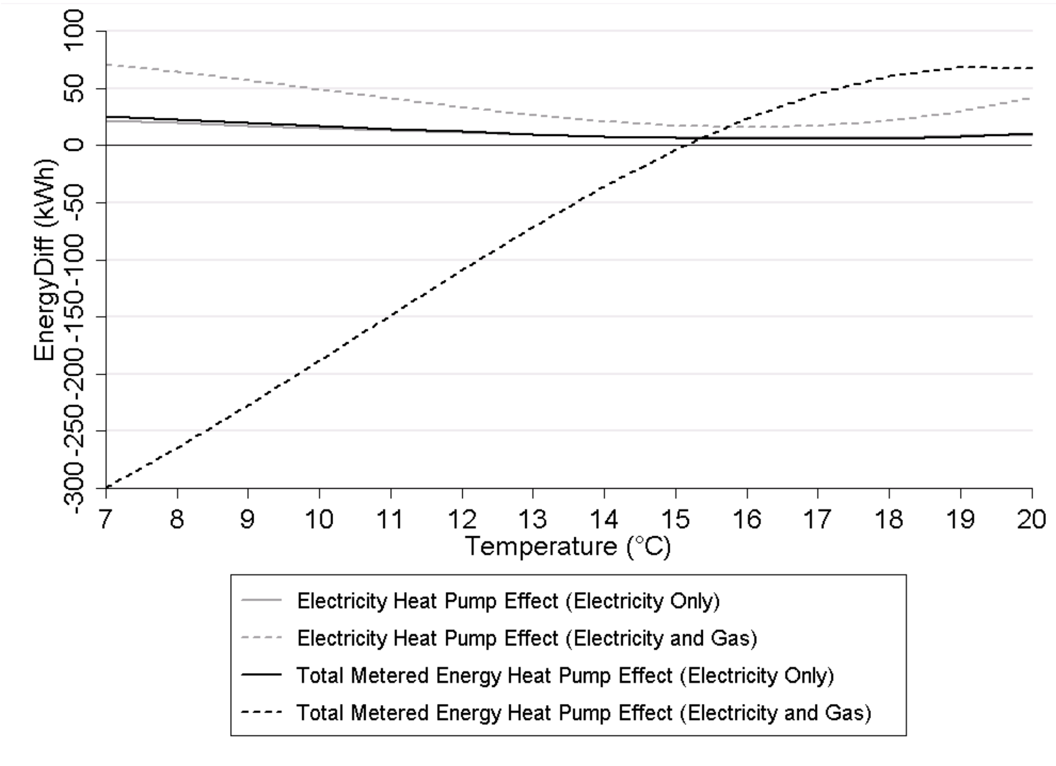


Figure 26 indicates that houses with access to reticulated gas may have greater savings through insulation treatment at colder temperatures than houses that can only access electricity. However the results in Table 22 indicate that houses with access to reticulated gas do not have a significantly different response to electricity-only houses after having insulation installed; neither the electricity nor the total metered energy Wald test is significant at even the 20% level. We therefore do not infer differential responses between the two sub-samples with respect to insulation treatment.

The effect of heat pump installation on electricity use also shows no significant difference (at the 20% level) across the two sub-samples. However the Wald test on the effect of heat pump installation on total metered energy use shows that houses that have access to both electricity and gas have a very different response to that of houses that can only access electricity, with a p-value (to four decimal places) of 0.0000. Figure 27 demonstrates that houses with reticulated gas that receive heat pump treatment make a substantial total metered energy saving that increases as temperature falls. It appears that these houses replace their current gas heating with heating from the installed electric heat pump, resulting in significant total metered energy savings. This finding is consistent with the purpose of the scheme to promote efficient heating using electrical appliances in place of other less efficient heating sources. Again, this effect is allowed for in our preferred total metered energy specification and so is not additional to the effects detected there.

The result that installation of a heat pump reduces total metered energy use for houses that also use reticulated gas contrasts with the results in 6.6.1 that implied that heat pump installation in houses with non-metered energy heat sources either increased or had no change in metered energy use relative to houses without such heat sources. The split according to reticulated gas status may be interpreted as implying that the results from 6.6.1 could be due to data inadequacies, with an implication that non-metered energy use does decline with heat pump treatment for such houses. Another interpretation is that houses fitted with a heat pump switch heating from alternative 'quick' heating sources (including reticulated gas) but they make little or no adjustment to their use of solid fuel burners that cannot be switched on and off quickly. The available data cannot readily distinguish between these alternative explanations. With respect to insulation treatment, the lack of difference in response between houses with and without reticulated gas is supportive of the implication from section 6.6.1 that there are no material non-metered energy savings following insulation treatment for houses with non-metered energy heating options.

7. Conclusions

The Warm Up New Zealand: Heat Smart (WUNZ:HS) 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. We have evaluated the impacts of these treatments on metered energy usage for houses treated under the programme.

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.

If a household chooses not to be at either extreme it 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" effect whereby households become accustomed to a warmer house in winter and then 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 may increase energy use for treated homes as they have access to improved (i.e. lower cost) heating technology. Standard demand theory indicates that greater heat will be consumed as a result of the reduction in the effective cost of heating; offsetting this effect is the technological superiority of delivering heat via a heat pump relative to prior heating methods. It is therefore an empirical issue as to which of these effects dominates in terms of the change in energy use following heat pump treatment. A separate consideration relates to the potential to use heat pumps as air-conditioning units, which may increase energy use in summer months, particularly in the hotter parts of the country.

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 WUNZ:HS programme. This paper sets out to measure these treatment effects but is limited to the analysis of metered energy use, only a subset of all energy sources available to households. The results apply to total household metered energy use, and are not restricted just to energy use for space heating.

We find that insulation treatment does, on average, reduce metered energy usage by treated houses. Our preferred model indicates that retrofitted insulation treatment leads to an annual reduction in electricity use for typical energy users in the order of 1.0% and an annual reduction in total metered energy usage (electricity plus reticulated gas) of around 0.7%. Other estimates, based on alternative samples, indicate that the electricity and total metered energy benefits may be up to 1.4% and 1.0% respectively.

These modest reductions relate to monthly metered energy demands and do not account for the time of day, and hence, whether savings are achieved in peak or off-peak electricity demand times. Savings in peak demand periods have greater benefits in terms of saving on thermal generation than those in off-peak demand periods, and prior studies have found considerable reduction in peak electricity demand loads from insulation programmes. This aspect will need to be accounted for when incorporating our results into a cost-benefit analysis of the programme.

Our estimated treatment effects vary according to outdoor temperature. Greatest metered energy savings from insulation occur at moderately cold temperatures (monthly temperature average of 10ºC). Savings are also observed at colder temperatures but the savings are not as great. In these latter circumstances, we hypothesise that households take a greater part of the thermal benefits as warmer house temperatures (relative to temperatures in the absence of treatment) and a lesser proportion through metered energy savings. For temperatures well above the minimum, our results suggest some evidence of a "take-back" effect whereby houses use more metered energy than without treatment as householders become accustomed to warmer houses.

A result of these estimated effects is that insulation treatment has variable impacts on metered energy use across regions. Greatest metered energy reductions due to insulation treatment occur in moderately cold regions such as West Coast and Taranaki. Houses in the coldest regions (e.g. Southland) experience metered energy savings but these are not as great as for slightly warmer regions owing to households taking a greater part of the thermal benefits as warmer housing temperatures given the very cold conditions outside. Houses in warm regions (e.g. Northland and Auckland) appear to make little or no metered energy savings as a result of insulation treatment. For atypical houses, including those with extremely high energy usage, savings appear to be greater at very cold temperatures (7˚C to 10˚C) than for more typical houses. These 'outliers' include houses in the coldest regions, e.g. Southland; inclusion of houses in very cold areas may explain the greater savings found in the estimates based on extended samples.

In contrast with the insulation treatment results, the impacts of heat pump treatment mostly showed increased annual electricity and total metered energy use for houses that had a heat pump installed. This increase occurred across the whole range of external temperatures, with the greatest increase in electricity use occurring for houses in cold regions. An exception to this result is that houses which already had access to reticulated gas for heating made total metered energy savings at colder temperatures following heat pump installation.

Our results are obtained from a sample of over 12,000 treated houses covering the first 17 months of WUNZ:HS. 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 metered 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 metered 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 data for non-metered energy use means that we are unable to confidently extrapolate our results to total (metered plus non-metered) energy use impacts. Our test that splits the sample according to whether a house had a prior non-metered energy heating source indicates that such houses have treatment impacts for metered energy that are not significantly different from houses without such heating sources. By contrast, houses that have access to reticulated gas for heating make a significant total metered energy saving (both absolutely and relative to non-gas houses) at temperatures below 15˚C following heat pump treatment. One possible implication of these two sets of results is that (efficient) heat pumps are used as a quick source of heating in preference to reticulated gas, but there is little or no switching between these quick sources of heat and heating sourced from solid fuel burners that cannot be switched on and off quickly. Further investigation of the non-metered energy impacts of both insulation and heat pump treatment for houses with non-metered energy heat sources is warranted if data can be sourced that enables rigorous analysis of switching behaviour amongst this broader set of fuel sources.

Statistically, we find little evidence that the treatment impacts of insulation or heat pump installation differ between households with different income levels. To the extent that effects do differ, the main difference appears to be that low income households make greater metered energy savings at very low temperatures than do high income households. In other words, at very low temperatures, households in low income areas reap the thermal benefits through metered energy savings whereas households in high income areas reap the benefits through warmer houses.

This study forms just one component of a broader evaluation of the WUNZ:HS programme; other components examine the health impacts of the programme and the employment and output effects of the programme. Together, these components will be used to assess the costs and benefits of the scheme as a whole. As the energy study is only one part of the evaluation it is not appropriate to draw normative conclusions on the outcomes of the programme in this report. Objectively, however, we conclude that insulation treatment, on average, has a significant, albeit modest, impact in reducing metered energy use of treated houses. Heat pump treatment has the effect of increasing metered energy use for most houses; an exception is for houses that already access reticulated gas for heating where heat pump installation reduces total metered energy use.

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Appendix A

Table A1: Predicted Monthly Energy Savings (kWh/house)

		Insulation		Heat Pump	
Region	Year/Month	Electricity (kWh/house)	Total Metered Energy (kWh/house)	Electricity (kWh/house)	Total Metered Energy (kWh/house)
NZ	2009m7	14.9008	15.5594	-22.1917	0.8431
NZ	2009m8	15.6411	15.6009	-15.6734	4.2909
NZ	2009m9	15.0527	14.8673	-14.8915	3.8101
NZ	2009m10	15.2166	15.0700	-15.0942	3.9490
NZ	2009m11	6.1189	4.3466	-8.9231	-5.0646
NZ	2009m12	-2.1773	-5.1556	-6.8523	-13.3840
NZ	2010m1	-7.1494	-10.7903	-7.1087	-17.9185
NZ	2010m2	-11.5249	-15.7012	-9.2844	-21.0485
NZ	2010m3	-5.0898	-8.4617	-6.8200	-16.1116
NZ	2010m4	2.5005	0.1853	-7.6989	-8.7544
NZ	2010m5	13.1267	12.5383	-12.9906	2.0304
NZ	2010m6	16.7355	17.1554	-18.7805	4.5973
NZ	2010m7	15.2506	15.9034	-21.8862	1.4351
NZ	2010m8	16.5661	16.8327	-17.5909	4.8077
NZ	2010m9	13.8901	13.4528	-13.6638	2.7590
NZ	2010m10	12.7672	12.1102	-12.6989	1.6806
NZ	2010m11	2.1621	-0.2025	-7.6092	-9.0962
Northland	2009m7	14.1351	13.7483	-13.8986	2.9877
Northland	2009m8	8.7201	7.3601	-10.1208	-2.3964
Northland	2009m9	7.9589	6.4759	-9.7401	-3.1765
Northland	2009m10	8.7201	7.3601	-10.1208	-2.3964
Northland	2009m11	0.1346	-2.5209	-7.1619	-11.1242
Northland	2009m12	-7.4077	-11.0817	-7.1681	-18.1352
Northland	2010m1	-11.4107	-15.5740	-9.1792	-20.9901
Northland	2010m2	-14.1231	-18.5176	-16.2944	-20.0325
Northland	2010m3	-11.1536	-15.2873	-8.9575	-20.8511
Northland	2010m4	-6.3144	-9.8472	-6.9543	-17.2015
Northland	2010m5	2.6664	0.3754	-7.7444	-8.5867
Northland	2010m6	10.5285	9.4705	-11.1416	-0.5536
Northland	2010m7	14.8327	14.5969	-14.6336	3.6191
Northland	2010m8	10.5285	9.4705	-11.1416	-0.5536
Northland	2010m9	7.5713	6.0265	-9.5562	-3.5741
Northland	2010m10	7.9589	6.4759	-9.7401	-3.1765
Northland	2010m11	-1.5414	-4.4319	-6.9147	-12.7693
Auckland	2009m7	16.6395	16.9472	-17.8884	4.7963
Auckland	2009m8	11.5374	10.6555	-11.7955	0.4627
Auckland	2009m9	9.8228	8.6451	-10.7222	-1.2703
Auckland	2009m10	9.8228	8.6451	-10.7222	-1.2703
Auckland	2009m11	-0.7061	-3.4801	-7.0234	-11.9535
Auckland	2009m12	-9.4213	-13.3480	-7.8681	-19.7183
Auckland	2010m1	-13.2503	-17.6081	-11.7247	-21.5056
Auckland	2010m2	-13.8370	-18.1435	-19.5279	-18.0786
Auckland	2010m3	-11.6580	-15.8494	-9.4127	-21.1138
Auckland	2010m4	-4.3902	-7.6689	-6.7861	-15.4719
Auckland	2010m5	6.3839	4.6527	-9.0323	-4.7927
Auckland	2010m6	13.8824	13.4435	-13.6566	2.7518
Auckland	2010m7	16.5047	16.7421	-17.3878	4.8005
Auckland	2010m8	13.0675	12.4677	-12.9416	1.9730
Auckland	2010m9	9.0932	7.7943	-10.3174	-2.0148
Auckland	2010m10	6.7835	5.1146	-9.2022	-4.3826
Auckland	2010m11	-3.9926	-7.2180	-6.7793	-15.1035

Waikato	2009m7	13.8227	14.4772	-22.9400	-0.9158
Waikato	2009m8	15.9299	15.9694	-16.1310	4.5022
Waikato	2009m9	15.0441	14.8567	-14.8812	3.8027
Waikato	2009m10	13.6200	13.1283	-13.4163	2.5037
Waikato	2009m11	6.3839	4.6527	-9.0323	-4.7927
Waikato	2009m12	-2.7794	-5.8403	-6.8102	-13.9605
Waikato	2010m1	-9.4213	-13.3480	-7.8681	-19.7183
Waikato	2010m2	-13.7599	-18.1586	-13.1919	-21.2617
Waikato	2010m3	-3.9926	-7.2180	-6.7793	-15.1035
Waikato	2010m4	3.9239	1.8187	-8.1224	-7.3097
Waikato	2010m5	14.3779	14.0423	-14.1422	3.2112
Waikato	2010m6	16.5800	17.1104	-19.8491	3.9953
Waikato	2010m7	14.1444	14.8028	-22.7402	-0.3988
Waikato	2010m8	16.7168	17.0891	-18.3860	4.7170
Waikato	2010m9	14.1351	13.7483	-13.8986	2.9877
Waikato	2010m10	11.8593	11.0350	-12.0194	0.7842
Waikato	2010m11	0.5563	-2.0394	-7.2419	-10.7054
Bay of Plenty	2009m7	8.8617	9.3260	-24.8431	-8.5076
Bay of Plenty	2009m8	16.6893	17.1732	-19.3675	4.3196
Bay of Plenty	2009m9	16.4163	16.6167	-17.1368	4.7753
Bay of Plenty	2009m10	16.3144	16.4764	-16.8854	4.7324
Bay of Plenty	2009m11	7.9589	6.4759	-9.7401	-3.1765
Bay of Plenty	2009m12	-0.7061	-3.4801	-7.0234	-11.9535
Bay of Plenty	2010m1	-5.5586	-8.9924	-6.8595	-16.5337
Bay of Plenty	2010m2	-11.8952	-16.1131	-9.6582	-21.2218
Bay of Plenty	2010m3	-0.7061	-3.4801	-7.0234	-11.9535
Bay of Plenty	2010m4	8.7201	7.3601	-10.1208	-2.3964
Bay of Plenty	2010m5	16.0709	16.1524	-16.3824	4.5955
Bay of Plenty	2010m6	15.2310	15.8842	-21.9045	1.4015
Bay of Plenty	2010m7	9.9660	10.4861	-24.5416	-6.8556
Bay of Plenty	2010m8	16.1593	16.7623	-20.7881	3.0796
Bay of Plenty	2010m9	16.5047	16.7421	-17.3878	4.8005
Bay of Plenty	2010m10	15.4335	15.3401	-15.3791	4.1275
Bay of Plenty	2010m11	4.7539	2.7732	-8.4039	-6.4625
Gisborne	2009m7	16.4041	16.9742	-20.3230	3.5831
Gisborne	2009m8	15.2445	15.1046	-15.1297	3.9723
Gisborne	2009m9	12.7779	12.1230	-12.7074	1.6912
Gisborne	2009m10	12.4798	11.7691	-12.4756	1.3988
Gisborne	2009m11	-1.9564	-4.9043	-6.8720	-13.1711
Gisborne	2009m12	-9.4213	-13.3480	-7.8681	-19.7183
Gisborne	2010m1	-11.1536	-15.2873	-8.9575	-20.8511
Gisborne	2010m2	-13.3969	-17.7677	-12.0714	-21.4739
Gisborne	2010m3	-8.4459	-12.2515	-7.4714	-18.9777
Gisborne	2010m4	1.4008	-1.0739	-7.4229	-9.8618
Gisborne	2010m5	12.1735	11.4063	-12.2462	1.0963
Gisborne	2010m6	16.6855	17.0262	-18.1376	4.7663
Gisborne	2010m7	16.6893	17.1732	-19.3675	4.3196
Gisborne	2010m8	15.0441	14.8567	-14.8812	3.8027
Gisborne	2010m9	8.3419	6.9206	-9.9283	-2.7838
Gisborne	2010m10	11.5374	10.6555	-11.7955	0.4627
Gisborne	2010m11	3.0869	0.8576	-7.8643	-8.1607
Hawke's Bay	2009m7	13.1171	13.7575	-23.3274	-2.0327
Hawke's Bay	2009m8	16.7331	17.1356	-18.6333	4.6480
Hawke's Bay	2009m9	16.3144	16.4764	-16.8854	4.7324
Hawke's Bay	2009m10	15.4335	15.3401	-15.3791	4.1275
Hawke's Bay	2009m11	5.1656	3.2473	-8.5531	-6.0414
Hawke's Bay	2009m12	-0.7061	-3.4801	-7.0234	-11.9535
Hawke's Bay	2010m1	-5.5586	-8.9924	-6.8595	-16.5337
Hawke's Bay	2010m2	-10.0330	-14.0342	-8.1864	-20.1502
Hawke's Bay	2010m3	-3.1869	-6.3034	-6.7915	-14.3474
Hawke's Bay	2010m4	8.3419	6.9206	-9.9283	-2.7838
Hawke's Bay	2010m5	14.3779	14.0423	-14.1422	3.2112

Hawke's Bay	2010m6	16.5005	17.0516	-20.0871	3.8004
Hawke's Bay	2010m7	14.7272	15.3871	-22.3294	0.5541
Hawke's Bay	2010m8	16.5047	16.7421	-17.3878	4.8005
Hawke's Bay	2010m9	11.8593	11.0350	-12.0194	0.7842
Hawke's Bay	2010m10	13.3483	12.8029	-13.1779	2.2440
Hawke's Bay	2010m11	5.1656	3.2473	-8.5531	-6.0414
Taranaki	2009m7	10.9778	11.5439	-24.2189	-5.3280
Taranaki	2009m8	16.6395	16.9472	-17.8884	4.7963
Taranaki	2009m9	16.7341	17.1653	-18.8794	4.5591
Taranaki	2009m10	16.5047	16.7421	-17.3878	4.8005
Taranaki	2009m11	10.8717	9.8729	-11.3564	-0.2066
Taranaki	2009m12	3.5061	1.3388	-7.9904	-7.7349
Taranaki	2010m1	-0.7061	-3.4801	-7.0234	-11.9535
Taranaki	2010m2	-5.9390	-9.4228	-6.9023	-16.8719
Taranaki	2010m3	0.9784	-1.5570	-7.3290	-10.2845
Taranaki	2010m4	7.9589	6.4759	-9.7401	-3.1765
Taranaki	2010m5	15.4335	15.3401	-15.3791	4.1275
Taranaki	2010m6	16.5800	17.1104	-19.8491	3.9953
Taranaki	2010m7	12.3268	12.9443	-23.6978	-3.2630
Taranaki	2010m8	16.5800	17.1104	-19.8491	3.9953
Taranaki	2010m9	15.4335	15.3401	-15.3791	4.1275
Taranaki	2010m10	15.4335	15.3401	-15.3791	4.1275
Taranaki	2010m11	10.1788	9.0611	-10.9301	-0.9083
Manawatu-Wanganui	2009m7	13.8227	14.4772	-22.9400	-0.9158
Manawatu-Wanganui	2009m8	16.4163	16.6167	-17.1368	4.7753
Manawatu-Wanganui	2009m9	16.5792	16.8524	-17.6384	4.8076
Manawatu-Wanganui	2009m10	16.0709	16.1524	-16.3824	4.5955
Manawatu-Wanganui	2009m11	9.4608	8.2227	-10.5179	-1.6393
Manawatu-Wanganui	2009m12	-0.2863	-3.0013	-7.0890	-11.5403
Manawatu-Wanganui	2010m1	-6.6845	-10.2654	-7.0159	-17.5222
Manawatu-Wanganui	2010m2	-11.1536	-15.2873	-8.9575	-20.8511
Manawatu-Wanganui	2010m3	-1.5414	-4.4319	-6.9147	-12.7693
Manawatu-Wanganui	2010m4	7.9589	6.4759	-9.7401	-3.1765
Manawatu-Wanganui	2010m5	15.0441	14.8567	-14.8812	3.8027
Manawatu-Wanganui	2010m6	16.5005	17.0516	-20.0871	3.8004
Manawatu-Wanganui	2010m7	13.1171	13.7575	-23.3274	-2.0327
Manawatu-Wanganui	2010m8	16.6395	16.9472	-17.8884	4.7963
Manawatu-Wanganui	2010m9	14.8327	14.5969	-14.6336	3.6191
Manawatu-Wanganui	2010m10	13.0675	12.4677	-12.9416	1.9730
Manawatu-Wanganui	2010m11	4.3399	2.2969	-8.2603	-6.8854
Wellington	2009m7	15.4539	16.1009	-21.6871	1.7867
Wellington	2009m8	15.2445	15.1046	-15.1297	3.9723
Wellington	2009m9	15.2445	15.1046	-15.1297	3.9723
Wellington	2009m10	15.6110	15.5629	-15.6292	4.2678
Wellington	2009m11	7.1794	5.5726	-9.3768	-3.9763
Wellington	2009m12	-0.7061	-3.4801	-7.0234	-11.9535
Wellington	2010m1	-3.9926	-7.2180	-6.7793	-15.1035
Wellington	2010m2	-8.1064	-11.8693	-7.3601	-18.7077
Wellington	2010m3	-4.3902	-7.6689	-6.7861	-15.4719
Wellington	2010m4	0.5563	-2.0394	-7.2419	-10.7054
Wellington	2010m5	12.1735	11.4063	-12.2462	1.0963
Wellington	2010m6	16.6855	17.0262	-18.1376	4.7663
Wellington	2010m7	14.4458	15.1060	-22.5366	0.0910
Wellington	2010m8	16.3144	16.4764	-16.8854	4.7324
Wellington	2010m9	13.0675	12.4677	-12.9416	1.9730
Wellington	2010m10	13.8824	13.4435	-13.6566	2.7518
Wellington	2010m11	3.5061	1.3388	-7.9904	-7.7349
Marlborough	2009m7	4.2352	4.4240	-25.7151	-15.3158
Marlborough	2009m8	16.6893	17.1732	-19.3675	4.3196
Marlborough	2009m9	16.6893	17.1732	-19.3675	4.3196
Marlborough	2009m10	16.5792	16.8524	-17.6384	4.8076
Marlborough	2009m11	5.9809	4.1873	-8.8674	-5.2061

Marlborough	2009m12	-3.9926	-7.2180	-6.7793	-15.1035
Marlborough	2010m1	-9.4213	-13.3480	-7.8681	-19.7183
Marlborough	2010m2	-8.1064	-11.8693	-7.3601	-18.7077
Marlborough	2010m3	-2.3691	-5.3738	-6.8371	-13.5683
Marlborough	2010m4	6.7835	5.1146	-9.2022	-4.3826
Marlborough	2010m5	16.3144	16.4764	-16.8854	4.7324
Marlborough	2010m6	13.8227	14.4772	-22.9400	-0.9158
Marlborough	2010m7	7.6625	8.0611	-25.1224	-10.2873
Marlborough	2010m8	16.4041	16.9742	-20.3230	3.5831
Marlborough	2010m9	15.9299	15.9694	-16.1310	4.5022
Marlborough	2010m10	15.4335	15.3401	-15.3791	4.1275
Marlborough	2010m11	2.2451	-0.1074	-7.6308	-9.0125
Nelson	2009m7	8.8617	9.3260	-24.8431	-8.5076
Nelson	2009m8	16.7341	17.1653	-18.8794	4.5591
Nelson	2009m9	16.6855	17.0262	-18.1376	4.7663
Nelson	2009m10	15.2445	15.1046	-15.1297	3.9723
Nelson	2009m11	1.4008	-1.0739	-7.4229	-9.8618
Nelson	2009m12	-2.3691	-5.3738	-6.8371	-13.5683
Nelson	2010m1	-9.7312	-13.6958	-8.0218	-19.9407
Nelson	2010m2	-12.3384	-16.6046	-10.1858	-21.3893
Nelson	2010m3	-5.5586	-8.9924	-6.8595	-16.5337
Nelson	2010m4	5.5747	3.7187	-8.7076	-5.6225
Nelson	2010m5	14.1351	13.7483	-13.8986	2.9877
Nelson	2010m6	15.8433	16.4720	-21.2432	2.4819
Nelson	2010m7	12.7327	13.3628	-23.5148	-2.6335
Nelson	2010m8	16.6893	17.1732	-19.3675	4.3196
Nelson	2010m9	16.1991	16.3215	-16.6339	4.6724
Nelson	2010m10	13.0675	12.4677	-12.9416	1.9730
Nelson	2010m11	-0.7061	-3.4801	-7.0234	-11.9535
Tasman	2009m7	9.4256	9.9190	-24.6951	-7.6658
Tasman	2009m8	16.6855	17.0262	-18.1376	4.7663
Tasman	2009m9	16.7196	17.1779	-19.1242	4.4498
Tasman	2009m10	15.4335	15.3401	-15.3791	4.1275
Tasman	2009m11	4.7539	2.7732	-8.4039	-6.4625
Tasman	2009m12	-1.1246	-3.9571	-6.9653	-12.3633
Tasman	2010m1	-6.3144	-9.8472	-6.9543	-17.2015
Tasman	2010m2	-8.4459	-12.2515	-7.4714	-18.9777
Tasman	2010m3	-1.5414	-4.4319	-6.9147	-12.7693
Tasman	2010m4	7.9589	6.4759	-9.7401	-3.1765
Tasman	2010m5	15.6110	15.5629	-15.6292	4.2678
Tasman	2010m6	15.8433	16.4720	-21.2432	2.4819
Tasman	2010m7	13.1171	13.7575	-23.3274	-2.0327
Tasman	2010m8	16.5800	17.1104	-19.8491	3.9953
Tasman	2010m9	16.6395	16.9472	-17.8884	4.7963
Tasman	2010m10	15.0441	14.8567	-14.8812	3.8027
Tasman	2010m11	3.5061	1.3388	-7.9904	-7.7349
West Coast	2009m7	8.8617	9.3260	-24.8431	-8.5076
West Coast	2009m8	16.6893	17.1732	-19.3675	4.3196
West Coast	2009m9	16.5800	17.1104	-19.8491	3.9953
West Coast	2009m10	16.6893	17.1732	-19.3675	4.3196
West Coast	2009m11	14.3779	14.0423	-14.1422	3.2112
West Coast	2009m12	7.9589	6.4759	-9.7401	-3.1765
West Coast	2010m1	0.1346	-2.5209	-7.1619	-11.1242
West Coast	2010m2	-2.7794	-5.8403	-6.8102	-13.9605
West Coast	2010m3	7.1794	5.5726	-9.3768	-3.9763
West Coast	2010m4	9.8228	8.6451	-10.7222	-1.2703
West Coast	2010m5	16.5047	16.7421	-17.3878	4.8005
West Coast	2010m6	14.4458	15.1060	-22.5366	0.0910
West Coast	2010m7	11.4497	12.0352	-24.0500	-4.6099
West Coast	2010m8	16.5005	17.0516	-20.0871	3.8004
West Coast	2010m9	16.1593	16.7623	-20.7881	3.0796
West Coast	2010m10	16.3144	16.4764	-16.8854	4.7324

West Coast	2010m11	9.0932	7.7943	-10.3174	-2.0148
Canterbury	2009m7	10.4833	11.0276	-24.3828	-6.0764
Canterbury	2009m8	16.5792	16.8524	-17.6384	4.8076
Canterbury	2009m9	16.6395	16.9472	-17.8884	4.7963
Canterbury	2009m10	16.4041	16.9742	-20.3230	3.5831
Canterbury	2009m11	11.5374	10.6555	-11.7955	0.4627
Canterbury	2009m12	3.9239	1.8187	-8.1224	-7.3097
Canterbury	2010m1	-0.2863	-3.0013	-7.0890	-11.5403
Canterbury	2010m2	-3.9926	-7.2180	-6.7793	-15.1035
Canterbury	2010m3	-0.2863	-3.0013	-7.0890	-11.5403
Canterbury	2010m4	5.1656	3.2473	-8.5531	-6.0414
Canterbury	2010m5	15.9299	15.9694	-16.1310	4.5022
Canterbury	2010m6	14.7272	15.3871	-22.3294	0.5541
Canterbury	2010m7	11.4497	12.0352	-24.0500	-4.6099
Canterbury	2010m8	15.6579	16.2967	-21.4666	2.1467
Canterbury	2010m9	15.2445	15.1046	-15.1297	3.9723
Canterbury	2010m10	15.7765	15.7728	-15.8799	4.3928
Canterbury	2010m11	6.7835	5.1146	-9.2022	-4.3826
Otago	2009m7	-0.7279	-0.8813	-26.2070	-22.4989
Otago	2009m8	15.8433	16.4720	-21.2432	2.4819
Otago	2009m9	16.7196	17.1779	-19.1242	4.4498
Otago	2009m10	16.5005	17.0516	-20.0871	3.8004
Otago	2009m11	11.5374	10.6555	-11.7955	0.4627
Otago	2009m12	9.0932	7.7943	-10.3174	-2.0148
Otago	2010m1	6.3839	4.6527	-9.0323	-4.7927
Otago	2010m2	0.5563	-2.0394	-7.2419	-10.7054
Otago	2010m3	3.5061	1.3388	-7.9904	-7.7349
Otago	2010m4	11.8593	11.0350	-12.0194	0.7842
Otago	2010m5	16.6893	17.1732	-19.3675	4.3196
Otago	2010m6	9.9660	10.4861	-24.5416	-6.8556
Otago	2010m7	7.0267	7.3886	-25.2532	-11.2260
Otago	2010m8	13.1171	13.7575	-23.3274	-2.0327
Otago	2010m9	16.4041	16.9742	-20.3230	3.5831
Otago	2010m10	15.6110	15.5629	-15.6292	4.2678
Otago	2010m11	7.1794	5.5726	-9.3768	-3.9763
Southland	2009m7	-7.7672	-8.4539	-26.4382	-32.5717
Southland	2009m8	12.7327	13.3628	-23.5148	-2.6335
Southland	2009m9	15.4539	16.1009	-21.6871	1.7867
Southland	2009m10	15.6579	16.2967	-21.4666	2.1467
Southland	2009m11	16.1991	16.3215	-16.6339	4.6724
Southland	2009m12	13.3483	12.8029	-13.1779	2.2440
Southland	2010m1	7.1794	5.5726	-9.3768	-3.9763
Southland	2010m2	6.3839	4.6527	-9.0323	-4.7927
Southland	2010m3	11.5374	10.6555	-11.7955	0.4627
Southland	2010m4	15.0441	14.8567	-14.8812	3.8027
Southland	2010m5	12.7327	13.3628	-23.5148	-2.6335
Southland	2010m6	-7.7672	-8.4539	-26.4382	-32.5717
Southland	2010m7	-3.5750	-3.9387	-26.3539	-26.5855
Southland	2010m8	7.6625	8.0611	-25.1224	-10.2873
Southland	2010m9	13.4803	14.1289	-23.1357	-1.4603
Southland	2010m10	16.5792	16.8524	-17.6384	4.8076
Southland	2010m11	8.3419	6.9206	-9.9283	-2.7838