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Revisiting household energy rebound: perspectives from a multidisciplinary study

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Tilbakevirkningseffekter i husholdningenes energiforbruk: Perspektiver fra en tverrfaglig studie

Bente Halvorsen, Bodil Larsen, Harold Wilhite og Tanja Winther

I denne artikkelen studerer økonomer og antropologer bruk av varmepumpe i norske husholdninger. Som følge av en betydelig høyere virkningsgrad enn tradisjonell elektrisk oppvarming skulle varmepumpeteknologien teoretisk sett redusert elektrisitetsforbruket, men, som vi viser i artikkelen; når varmepumper blir tatt i bruk skjer det ingen endring i elektrisitetsforbruket selv om totalt energiforbruk går noe ned.

Målsettingen med artikkelen er å forklare disse resultatene ved hjelp av to koordinerte studier; en kvalitativ antropologisk studie basert på dybdeintervjuer, og en kvantitativ mikroøkonometrisk studie basert på informasjon fra Statistisk sentralbyrås forbruksundersøkelse for 2009 og informasjon om strømforbruk fra husholdningenes nettselskap. Resultatene fra disse to studiene utfyller hverandre. Den økonomiske studien kvantifiserer effektene av varmepumpeeierskap på forbruk av ulike energibærere, mens den kvalitative studien er med på å belyse hva som skjer av atferdsendringer i husholdninger som har skaffet seg varmepumpe.

Vi finner at noen husholdninger bruker mindre elektrisitet, mens andre bruker mer elektrisitet etter investeringen i varmepumpe. I den kvantitative studien finner vi at i gjennomsnitt bruker husholdninger med varmepumpe om lag like mye elektrisitet som husholdninger uten varmepumpe. Samtidig bruker de mindre ved og fyringsoljer i oppvarmingen, og de holder en høyere gjennomsnittlig innetemperatur, spesielt på kalde vintermorgener. Den kvalitative studien bekrefter disse funnene i tillegg til å identifisere ytterligere årsaker til de store tilbakevirkningseffektene i elektrisitetsforbruket. Den finner, som i den økonometriske studien, at husholdningene bruker mindre ved og fyringsoljer etter at de skaffet seg varmepumpe, og de holder en jevnere innetemperatur over døgnet. En hovedgrunn til det siste er at de ikke senker temperaturen om natten i samme utstrekning som før de skaffet seg varmepumpe. De varmer også opp et større areal enn før, ved at de åpner opp dører og varmer opp deler av huset som tidligere har stått kaldt.

Vi konkluderer med at norske husholdninger har tatt ut energisparepotensialet som ligger i en varmepumpe til økt komfort, både med hensyn til økt innetemperatur, mindre energisparing og redusert forbruk av mer arbeidskrevende energibærere som ved og fyringsoljer.

Revisiting household energy rebound: perspectives from a multidisciplinary study

Bente Halvorsen[ae], Bodil Larsen[be], Harold Wilhite[ce] and Tanja Winther[de]

Abstract

In this article, economists and anthropologists study the perplexing case of Norwegian households' heat pump ownership. The heat pump is a technology that theoretically should reduce electricity consumption by up to 25% compared with conventional electric heating, but, as we show, when taken into use results in little or no change in electricity consumption. We use a quantitatively based econometric analysis combined with qualitative interviews and observations with heat pump owners to explain this rebound effect in electricity consumption. The economic study quantifies effects of heat pump ownership on the consumption of all energy sources. We find that, on average, households with a heat pump use approximately the same amount of electricity as households without a heat pump. The interviews and observations help us to identify the reasons behind the rebound in electricity use, the most important of which are related to increases in the amounts of heating time and space.

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1. Introduction

It is often assumed that introducing more energy efficient technologies is a cheap and effective way of reducing energy consumption. However, several empirical studies indicate that the implementation of energy efficiency technologies results in unanticipated behavioural changes that reduce or eliminate the anticipated energy savings (e.g., Gram-Hanssen et al. 2012, Frondel et al. 2008), i.e. there are rebound effects. Despite decades of research, these rebound effects remain a ghost that haunts energy efficiency research and policy. Very few studies have managed to adequately quantify the rebound in energy use associated with specific household appliances; fewer yet have identified what households actually do that result in a rebound of their energy consumption. An important reason for this is that it is difficult to find detailed information on household behaviour and energy consumption in sufficiently large samples, so as to describe this problem adequately. Economists have quantified various behavioural changes resulting from the rebound effect based on data from the consumer expenditure survey (Halvorsen and Larsen 2013), whereas anthropologists have looked in more detail on how household heating practices change after investing in a heat pump (Winther and Wilhite 2014). However, neither of these studies alone gives an adequate picture of what is going on within the households after investing in heat pumps. The economic analysis does not have information on detailed changes in energy related behaviour, whereas the anthropological study is conducted on a too small sample to make any statistical inferences about the results.

The aim of this paper is to report the results of a coordinated quantitative and qualitative analytical approach to understanding the rebound effects of Norwegian household heat pump ownership. Within this multidisciplinary study, we synthesize the results from the two methodological approaches in order to shed additional light on what is really going on in Norwegian households after the installation of a heat pump. The questions for the qualitative study were based on the preliminary economic results and the need for deeper understanding of some of the specific findings. We start by describing the two sets of analyses and their results. We then discuss and compare the results, pointing to where they contradict, reinforce or supplement one another in coming forward to a more complete understanding of the household energy rebound from the investment. Finally, we conclude and discuss implications of the results.

2. Background

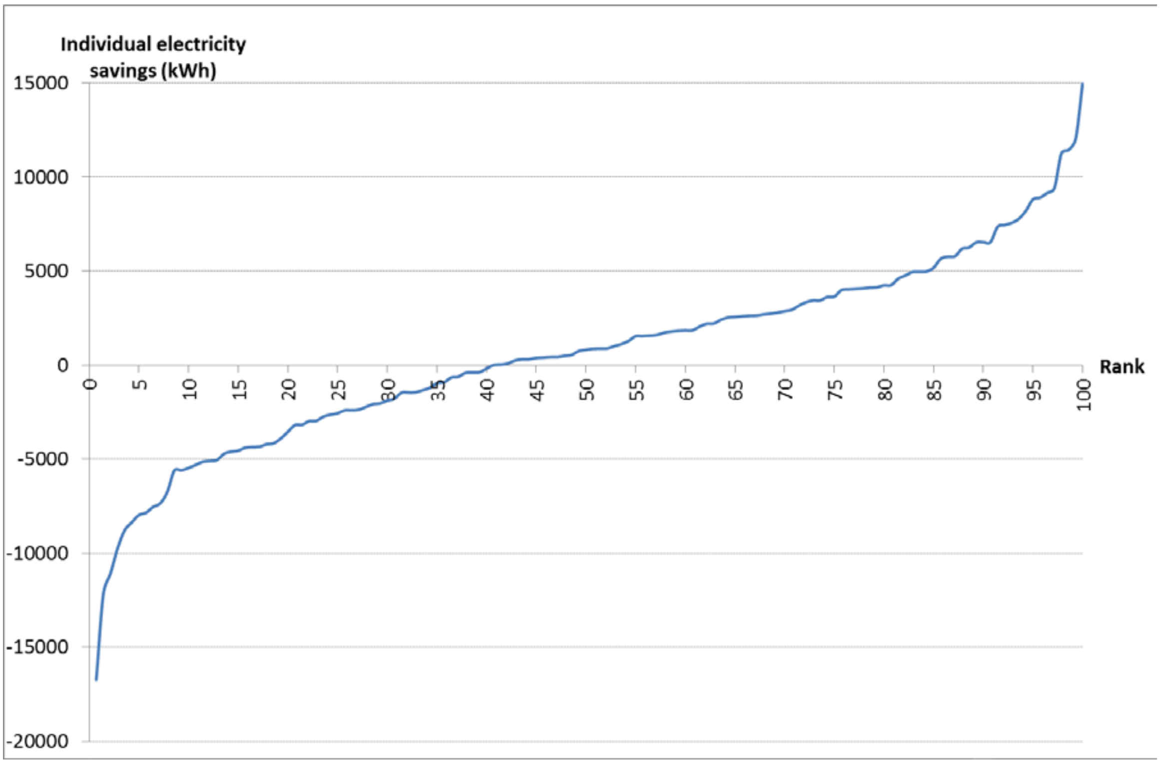
In Norway, one of the main uses of energy in households is for space heating. Depending on winter temperatures, energy prices and other factors, the proportion of energy for heating varies from 40 to 50 percent of household stationary energy consumption (Dalen and Larsen, 2014). Conventional electric heaters are the most common in Norwegian households. In Norway and other Nordic countries, the heat pump has been regarded as an important energy efficiency measure due to its potential to significantly reduce electricity consumption. In the year 2000, less than one percent of Norwegian households owned a heat pump. In 2012, a quarter of the households owned a heat pump, of which approximately 90 percent are air-to-air heat pumps. Air-to-air heat pumps use electricity, but they also use ambient heat from outside air to produce indoor heat. This means that the electricity consumption needed to heat a given indoor space to a given temperature is significantly less than when using conventional electric heaters. Given the theoretical savings potential of the heat pump, the expected reduction in household electricity and energy consumption from this technology transformation should be significant. This is, however, conditional on households not changing their heating practices in significant ways.

When we compare the mean electricity consumption of households with and without a heat pump using data from the Norwegian Survey of Consumer Expenditure (SCE) 2009, we find that electricity consumption does not differ significantly between the two groups. We also find this result when using data for other years of the SCE, and when applying different statistical approaches. Bearing in mind that the heat pump is technically more energy efficient than ordinary electric heaters, this implies that the rebound effect on electricity consumption appears to be approximately equal in size to the energy savings potential of the heat pump. This result seems to be robust across different data sets and analytical approaches.

To illustrate the size of the rebound effect of Norwegian heat pump ownership, and to exclude any systematic differences between households with and without a heat pump, we compare electricity consumption of the household the year before the household invested in the heat pump with their electricity consumption after the investment (for which we chose the year 2009).[1] The consumption is corrected for the difference in outdoor temperature in the investment year and the reference year 2009. The resulting electricity savings are sorted according to size and plotted in Figure 1. A negative (positive) number means that the household used more (less) electricity after investing in the heat pump. We see from the figure that some households use less electricity, whereas others (40 percent) use more electricity after investing in a pump. Descriptive statistics shows that the mean savings does not differ significantly from zero.

[1] Information on household electricity consumption in different years is collected from the household's electricity supplier.

Figure 1: Household electricity savings (kWh) before and after the heat pump investment, corrected for differences in outdoor temperature. N=141



Source: Norwegian survey of consumer expenditure 2009.

Surprised by the size of this rebound effect, we wanted to investigate the changes in heating practices responsible for this result and to explain why the savings differs so much across households. Could the investment in a heat pump really alter the way households use energy in their homes to the extent that the entire electricity savings potential embedded in the heat pump is completely offset by behavioural changes? And why do some households actually increase their electricity consumption after investing in a heat pump? These are the questions we set out to address in this article, using economic and statistical modelling supplemented with qualitative interviews.

3. The economic study

We know from the economics literature that heat pumps and other energy efficient technologies result in behavioural rebound effects when they are taken into use. The economic drivers for rebound effects are associated with the reduction in energy costs needed to produce the same amount of services (heat, hot water, etc.) as a result of the increased energy efficiency. The first of these economic drivers is referred to as price effects; the use of a heat pump will make it cheaper to use electricity relative to other energy sources, since the user price of electricity for heating is reduced. Households that have a paraffin oven, a fireplace or a wood stove may choose to use the heat pump instead, and as a consequence use more electricity and less wood or fuel oils compared to the situation before installing the pump. The reduction in energy costs also means that households have more money available for other purposes after the energy bill is paid, hereafter referred to as the income effect. This income effect may be used to increase consumption of energy goods or increase the consumption of other goods and services. Increases in energy consumption may also result from increased production of services at home, such as an increase in indoor temperature in order to achieve higher comfort or a change in other energy related habits. These behavioural changes increase electricity consumption relative to the energy savings potential embedded in the heat pump, and may negate some or all of the energy savings potential of the heat pump.

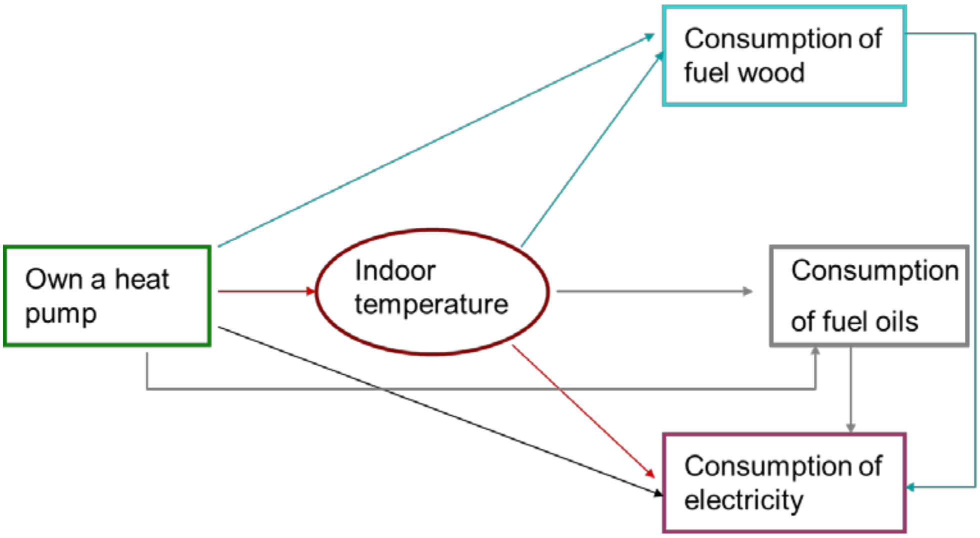
3.1. The econometric model

We use empirical data at the household level, in combination with an econometric modelling of the behavioural changes, to quantify the effects of heat pump ownership on household energy consumption. We decompose the total effect on the electricity consumption in various behavioural components, such as changes in indoor temperature and consumption of energy sources other than electricity. The econometric analysis helps us to quantify the consequences for energy consumption of the changes that households make in their everyday energy consuming tasks after investing in a heat pump. In what follows, we give a brief description of the main structure of the behavioural econometric model and the results from the analysis (see Halvorsen and Larsen 2013 for details).

We analyse the responses of 1111 households to the 2009 Survey of Consumer Expenditure. We have information on the households' expenses of all goods and services, household and housing characteristics such as type of dwelling, number of household members, residential area, heating equipment and other conditions that affect energy consumption in the household. For example, the data set includes self-reported information about how well the house is insulated, which electrical appliances people have, indicators for energy-saving behaviour and indoor temperature in the living room on cold winter mornings. Information about electricity consumption is collected from the electric utilities with the consent of the respondents. Information about the outdoor temperature is taken from the Norwegian Meteorological Institute and applied to each household by municipality. Energy prices are calculated for individual households using information from the survey about the expenditure and quantity of energy used. Descriptive statistics on the data set are given in the Appendix, Table A.1.

To analyse how heat pump ownership affects energy consumption, we develop a behavioural model that makes it possible to decompose the total effect on various behavioural components. The basis for the model is a household production framework, where the household decides on the level of heating services they want to produce (i.e., indoor temperature), and how they want to produce the heating services (that is, with which combination of heating equipment). From these decisions, we may infer how heat pump ownership affects household energy consumption by looking at differences in indoor temperature and consumption patterns based on whether the household owns a heat pump or not. The differences in behaviour between the two groups indicate possible sources of rebound effects in energy consumption. We look at both direct behavioural effects of owning a heat pump, such as using the pump for cooling during summer, and indirect effects through differences in indoor temperature and the use of firewood and fuel oils. The basic structure of how heat pump ownership affects household energy consumption in this behavioural model is described in Figure 2.

Figure 2: Model describing how heat pump ownership affects household energy consumption



Source: Halvorsen and Larsen (2013)

The behavioural model is estimated using the data from the 2009 Survey of Consumer Expenditure, in addition to complex statistical inference using econometrics, to quantify how heat pump ownership affects household energy consumption through differences in behaviour. The econometric analysis is conducted in three steps. First, we estimate factors affecting the chosen indoor temperature in the living room on cold winter mornings (hereafter referred to as indoor temperature), and how indoor temperature varies between households with different heating equipment (including heat pumps), housing types and other variables. Here, we are particularly interested in *how heat pump ownership affects the household's choice of indoor temperature*. Secondly, we estimate *how heat pump ownership and indoor temperature affect household consumption of firewood and fuel oil*, which are the two main alternative heat sources to electricity for heating in Norwegian homes, while also taking other factors into account, such as energy prices and income. Finally, we look at the effect of various factors (heat pump ownership, indoor temperature, firewood and fuel oil consumption, energy prices, income, and other household and residential characteristics) on household electricity consumption. In this part of the analysis, we are particularly interested in *how heat pump ownership, differences in indoor temperature and the consumption of firewood and fuel oils affect household electricity consumption*.

3.2. The results

The three steps mentioned above are estimated reclusively in order to be able to make inferences about causal relations, providing estimates for both the direct and indirect effects of heat pump ownership on household electricity consumption. The underlying estimations and calculations have been documented in Halvorsen and Larsen (2013). The estimation results are given in the Appendix, Table A.2 and A.3.

From the first step, we find a highly significant relationship between indoor temperature and heat pump ownership (see Appendix Table A.2). Households with heat pumps maintain, on average, a higher indoor temperature than households who do not own a heat pump.[2] This means that households with heat pumps use some of their reduced heating costs for higher comfort through higher indoor temperature. From the second step, we find that households owning a heat pump use less firewood and fuel oil than other households (only the effect on wood use is statistically significant). Further, households who maintain a lower indoor temperature use more firewood and fuel oil than other households. From the third step, we find that increased indoor temperature significantly increases electricity consumption. Together with the finding from step one, namely that households who own a heat pump maintain a higher indoor temperature than other households, this result implies that some of the technical electricity savings potential in the pump is offset by an increase in indoor temperatures. We also find that increased firewood and fuel oil consumption has a significant effect on electricity consumption (reduction). This result, taken together with the result from step two that households with a heat pump use less of these energy sources, implies that this effect also eats up a portion of the electricity savings potential embedded in the pump.

In Table 1, we sum up our results on how heat pump ownership affects household electricity consumption (measured in kWh), both through the direct effects (listed in section A of the table) and indirect effects (shown in section B). We see from the table that all of the indirect effects increases electricity consumption, *ceteris paribus*, and thus contribute to increasing the rebound effect. The indirect effects through increased indoor temperature and reduced consumption of wood and fuel oil are relatively large, and the strongest effect is associated with

[2] This result was also found in another data set, where households with heat pumps maintained a significantly higher indoor temperature than households without a heat pump (see Dalen and Halvorsen 2013).

the increase in temperature. Together, these behavioural changes imply that households with a heat pump consume over one thousand more kWh electricity per year compared with other households.

Table 1: Decomposition of the predicted effect on electricity consumption of owning a heat pump, kWh, SCE 2009

	Effect (kWh)
A. Direct effects of owning a heat pump	***-764***
Constant	2 546
Stating that they use the heat pump for cooling during the summer (0, 1)	72
Stating that they may use the heat pump for heating the entire residence (0, 1)	274
Stating that they consume less fuel oils after installing the heat pump (0, 1)	59
Number of substitution possibilities (alternative heating sources)	-3 714
B. Indirect effects of owning a heat pump	***1 058***
Increased indoor temperature	484
Reduced consumption of fuel oil	204
Reduced consumption of firewood	370
C. Total effect of owning a heat pump	**295**

Source: Halvorsen and Larsen (2013).

If we turn to the direct effect of heat pump ownership, we can see from Table 1 part A that, on average, this effect (in total) implies a reduction in electricity consumption. We have decomposed the direct effect into different drivers, some of which reduce and some which increase electricity consumption. The biggest positive direct effect of heat pump ownership comes through a large and highly significant constant term. This constant contains the effect of all behavioural differences (not specified by a separate variable) between households with and without a heat pump. Unfortunately, we do not have information in the data to explain these, but a cause may be reduced use of other energy savings measures, such as turning off lights. Households with a heat pump engage in many different changes in their behaviour which together contribute to increasing their electricity consumption, *ceteris paribus*. In section 4 we use the qualitative material to account for these changes.

We find that households using the heat pump for cooling use more electricity than other households, all other things being equal, although this effect is small and not statistically significant. We also find that heat pump owners who heat the entire residence with the heat pump use more electricity than other households with a heat pump.[3] In the questionnaire, respondents with heat pumps were asked whether they use less oil after they installed the heat pump. We find that households that answered yes to this question use significantly more electricity than other households with heat pump. This effect comes in addition to the indirect effect of reduced wood and oil consumption (in section B of Table 1). All the direct effects discussed above indicate that heat pump

[3] We do not have information in the data to find the cause for this, but it may be that these households heat a larger share of the residence compared to households with a heat pump who do not have this opportunity.

ownership increases electricity consumption, and thus reduces the realization of the technical potential for energy savings. We have only managed to identify one direct effect of heat pump ownership that implies reduced electricity consumption, and that is the effect of having the opportunity to use several different energy sources for heating, measured by how many types of heating equipment the household possesses. We find that this variable has a large effect on the electricity consumption, implying that households with alternative heating options save more electricity than those who have fewer options to the heat pump.

To summarize Table 1, the reductions through the direct effects are not large enough to offset the large increase in consumption due to the indirect effects. In total, we find a small (and insignificant) increase in electricity consumption for households that own a heat pump compared with other households, which is consistent with what we found applying other statistical approaches. We therefore conclude that the overall electricity savings potential, through the technically efficient heat pump, is offset by the reduced use of alternative fuels and other behavioural changes.

Table 2: Effects on household energy consumption of owning a heat pump, kWh, SCE 2009

	Effect
Total energy consumption (kWh)	***-2 180***
Consumption of electricity (kWh)	295
Consumption of fuel oils (kWh)	-693
Consumption of firewood (kWh)	-1 782

Source: Halvorsen and Larsen (2013).

While Table 1 sums up the effects of heat pump ownership on household *electricity* consumption, Table 2 shows the effect on *energy* consumption. Since households with a heat pump use less firewood and fuel oil than other households, yet have approximately the same electricity consumption, we would expect energy consumption to be reduced. This is also what we find, as the reductions in firewood and fuel oil consumption far exceeds the small increase in the use of electricity. This means that when all energy sources are accounted for, the introduction of heat pumps in Norwegian homes has increased the energy efficiency of heating. However, as documented, several mechanisms (direct and indirect effects) contribute to producing rebound, which implies that a large share of the potential for energy savings is not realized when heat pumps are taken in use. For understanding the causes of the rebound effects further, we now turn to the anthropological study.

4. The qualitative study

The rebound effects quantified in the econometric study suggest that households make many changes in how they heat their residences after investing in a heat pump. However, the econometric study subsumes many behavioural changes in a big and highly significant constant term. In order to better understand how people use heat pumps and other energy sources, we deploy a qualitative study that give more contextualized information on how households change their heating practices after acquiring a heat pump. In this section, we briefly present and discuss the results of the qualitative study (see Winther and Wilhite 2014 for details).

4.1 Sample characteristics and themes for interviews

The qualitative study is based on 28 in-depth interviews with Norwegian households owning a heat pump, conducted in their homes. All of the families interviewed lived in a detached house. Each had a chimney and either a wood stove or wood-burning fireplace. Almost all of the houses had electric floor heating in bathrooms and, in a few cases, also in other rooms, and all houses were equipped with electric resistance ovens in several rooms. See Appendix Table A.4 for a summary of the sample's characteristics.

The interviews included questions on people's motivation for purchasing the heat pump, how and from whom they had learned how to use it, and how they interacted with the heat pump in daily life. We asked how the heat pump was being used in combination with other heating sources and how heating practices were related to other home practices (e.g. time management and cleaning), as well as about people's perceptions of comfort and convenience. We also asked about their views on the potential economic gains from using heat pumps as compared to other heating devices.

4.2 Analysis of interview responses

An important finding from the interview sample is that the purchase of the heat pump was sometimes done in conjunction with either a change in heating source, such as replacing the oil heater and when refurbishing and expanding the house. This is consistent with reports from studies of heat pump purchases in Denmark and Australia (Christensen et al. 2011, Maller et al. 2012). Only seven out of the 28 families in the sample had kept the existing structure of the house and simply added the heat pump to the existing heating system. For those who expanded the size of the house, the increase in the energy needed to heat the expanded space is an important explanation for the rebound effect, i.e. the reduction in the net decrease attributable to the heat pump.

The second source of rebound we identify is consistent with the findings from the econometric study: those with multiple heating sources tend to change the mix of energy sources used, using less wood and increasing their use of electricity. Some families had replaced oil burners and extensive use of wood with the heat pump, and because heat pumps consume a certain amount of electricity, these families correctly thought their electricity consumption had increased and that their fuel oil and wood expenses had gone down (though few actually monitored this). Other families had solely used electricity for heating before obtaining the heat pump, and a few of these respondents said that electricity consumption (and costs) had decreased because of the heat pump. This finding points to the rather obvious observation, that households with previous use of oil heaters and extensive use of wood are likely to increase rather than reduce their electricity consumption after installing a heat pump. After acquiring the heat pump most families reported that they use the heat pump as their main heating source and that they only use the wood stove or fireplace during particularly cold periods or on special occasions, such as when having guests over.

A third important source of rebound is related to increased comfort and convenience. The use of the heat pump eliminates the hard work of starting and maintaining a fire in the wood stove or fireplace. Respondents often highlighted how quickly the temperature can be adjusted with the heat pump's remote control, even though most families rarely changed the temperature setting. Many respondents said they were pleased that the heat pump provided an 'even temperature', which they maintained by keeping the heat pump running day and night, including when they were away from home for a weekend or for longer periods. 'You avoid the discomfort of coming home to a cold house and having to wait for the heat' was a typical statement. A concern for children's comfort and safety (no need to be careful about the fire) was also given as an advantage of heating with the heat pump. Interestingly, respondents claimed they did not raise the indoor temperature after obtaining the heat pump. However, their detailed accounts of how they modified their heating habits, e.g. by letting the heat pump run 24 hours a day, 7 days a week instead of starting a fire in the morning, reflects that an increase in average temperature had indeed taken place. Given that perceptions of comfort are shifting (Wilhite et al. 1996; Shove 2003), people's lack of reflexivity might imply that their bodies have adjusted to higher temperatures. We found that most people do not keep track of how indoor temperatures have changed.

The discussion above reflects the important result from the qualitative material: the heat pump leads to an expansion of *heating time*. The increased temperatures on cold mornings are a symptom of this expanded heating time, because the families not only keep a higher temperature in the mornings but also at night and when they are away from home. A second dimension of the comfort rebound has to do with an *extension of the total space of the house that is heated*. In contrast to point sources such as electric resistance ovens or stoves, our respondents gave detailed accounts of how the pump distributes the heat to several rooms. In order to even out the temperature throughout the house and to avoid experiencing uncomfortable temperature differences in various parts of the house, many said they tended to keep the doors between various rooms open, allowing the heat to flow between rooms.

The factors explaining the extensions in heating time and heated space are not uniquely rooted in people's desire for more comfort. The air-to-air heat pump is in fact designed to transport and circulate air in order to function optimally, thus this heating technology favours open solutions and invites a practice of keeping doors between rooms permanently open and heating larger volumes of space. This effect of the technology's design (or 'script', cf. Akrich 1994) is strengthened through the advice and information provided by installers and matches people's preferences for an extension of comfort to more rooms in the house. Similarly, many respondents referred to the installer's recommendation to let the heat pump run continuously and not 'mess with' the set temperature or turn it on and off. Independent of whether this is correct or not, most families believed that they should keep a constant temperature. In sum, the technical advice encourages the practice of maintaining even temperatures throughout the house and increasing comfort. The respondents often rationalized or legitimized their comfort increases by attributing them to 'expert' technical advice.

A fourth category of comfort rebound is a residual of other adjustments. In our qualitative study, examples in this category include attending to children at night (keeping doors open to be able to hear them), maintaining safety and air quality (avoiding moisture), and co-joint practices such as drying clothes (leaving the laundry to dry in front of the heat pump).

The qualitative study does not give a basis for quantifying changes in either energy or electricity consumption (as this information is not available). Most of the respondents in the interviews were not able to say for certain whether they had saved energy or reduced their energy costs after introducing the heat pump. Their uncertainty was due to variable outdoor temperatures, shifting electricity prices, their shifting uses of various energy sources for heating, modified routines and not following closely changes in their electricity bills. To shed more light on this, we integrate the findings from the econometric and qualitative approaches.

5. Synthesized results

The qualitative study has sought to disentangle the motives and ways in which people acquire and take heat pumps in use. By this we mean the ways heat pumps form part of, and modify, the social practices into which they are integrated, whether related to heating, time management or other concerns. Far from observing energy savings as the main drive or the result when adapting heat pumps, the interaction between family members, with their knowledge, motives and expectations, and the technology, with its script for optimal heating comfort led to practices that increase electricity consumption. This may explain why the econometric analysis finds that the rebound effect completely offsets the initial electricity savings potential of the heat pump.

The results from the two analyses both complement and supplement one another. We have summarized the main findings from the two analyses in Table 3.

Table 3: Synthesized results. Effect on electricity consumption of heat pump ownership[a)]

	Economic study	Anthropological study
A. Direct effects of owning a heat pump	-	
Constant	+	
Expansion of heating time		+
Expansion of heated living space		+
Expanding the structure of the building		+
Improvement of air quality, att. to children, safety, dry clothes		+
Stating that they use the heat pump for cooling during summer	+	+
Stating that they can use the heat pump for heating the entire residence	+	+
Stating that they consume less fuel oils after installing the heat pump	+	+
Number of substitution possibilities (alternative heating sources)	-	
B. Indirect effects of owning a heat pump	+	
Increased indoor temperature	+	+
Reduced consumption of fuel oil	+	+
Reduced consumption of firewood	+	+
C. Total effect of owning a heat pump (electricity rebound)	+	+

[a)] The sign "+" indicates that the specified variable leads to increased electricity consumption and "-" that electricity consumption decreases. The signs shown for the anthropological study indicate the observed relevance (and direction) of factors observed among the interviewed households.

Both studies find reductions in the use of firewood and fuel oils for heating, and that the temperature in the living room is increased during cold winter mornings. The results from the qualitative study identify changes in heating practices which are not discernible in the data applied in the econometric study (and which thus end up in the constant term for the direct effects in Table 1). This includes behaviour such as an increase in the size of heated living space, which was found to be a result of structural changes to the house and due to opening of doors to previously unheated areas. Both studies also find that people switch from fuel oils and firewood to electricity. In addition, some of the comfort and convenience motives unveiled in the qualitative study, such as not having to build and maintain a fire are important supplements to the econometric analysis. The qualitative study gives us a better understanding of which changes in household behaviour lies behind the big positive non-decomposed constant term in the econometric results.

Based on the interview responses about changing practices, we can say with some degree of certainty that some households reduced their electricity consumption and some most likely increased it. The latter is due to increases in heated living space and switching from fuel oils and firewood to electricity as their main heating source. This variation in how heat pump ownership affects energy consumption is also evident in the economic analysis, based on the comparison of the electricity consumption before and after installing a heat pump (illustrated in Figure 1).

6. Conclusion

Over a period of ten years, approximately a quarter of Norwegian households acquired a heat pump. This rapid development happened with almost no subsidies or other support from government policies. We have not seen a similar structural change in heating technology in Norwegian homes since the transition from oil and wood to electricity in the 1970s and 1980s. Our analysis shows that while there is a rebound in total electricity used after the installation of a heat pump, the overall energy efficiency has increased because households consume less energy to heat up the same space at a given temperature (although the amount of space heated has increased).

In this analysis, we have synthesized the findings from two coordinated studies, one quantitative micro econometric study and one qualitative study. Somewhat surprisingly, the data used in the economic study showed that average electricity consumption does not differ significantly before and after acquiring a heat pump, but that there is a large variation in the savings among households. Nearly half of the households actually use more electricity after purchasing the heat pump than before, and very few achieve the entire savings potential embedded in the heat pump in the form of reduced electricity consumption. This may seem like an anomaly, but the results from this triangulated analysis help us understand what goes on in Norwegian homes when they install a heat pump.

Both studies show that many households increase indoor temperature and change their main heating source from fuel oils and firewood to the heat pump (which runs on electricity). In addition, many households increase the heated living area and reduce both the use of night setbacks and lowering the heat while away from home. As we have shown, the reasons behind these changes are closely linked to people’s concern for comfort and convenience and also their perception that heat pumps are less costly to use compared to other heating sources. From the face-to-face meetings with users of heat pumps there is little doubt that many people appreciate the heat pump for providing them with this increased comfort. As a result, the behavioural changes explain why households with a heat pump use approximately the same amount of electricity compared to households without a heat pump. It is important to note that although much of the energy savings potential of the pump is offset by behavioural changes, the variation in how households adapt is very large. This is a reflection of the heterogeneity among Norwegian households with respect to heating practices, preferences and motivations for installing a heat pump.

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Appendix A. Descriptive statistics of the data from the Survey of consumer expenditure 2009

Table A.1. Descriptive statistics for key variables in the econometric analysis, 1111 households, 2009

	Mean	Min	Max
Electricity consumption (kWh)	19 044	1 272	56 221
Purchases of firewood (kWh)	4 186	0	42 000
Purchases of fuel oils (kWh)	733	0	58 480
Own a heat pump (0,1)	0.25	0	1
Own an air-to-air heat pump (0, 1)	0.22	0	1
Own another type of heat pump (0, 1)	0.03	0	1
Have electric floor heating (0, 1)	0.75	0	1
Own a fuel wood burner (0, 1)	0.82	0	1
Own a pellet stove (0, 1)	0.01	0	1
Own a central heating system (0, 1)	0.06	0	1
Own a central heating system with other families (0, 1)	0.03	0	1
Number of electric heaters	3.39	0	16
Area with electric floor heating (m^2)	0.79	0	18
Number of wood burners	0.99	0	7
Number of paraffin or fuel oil burners	0.07	0	10
Number of heating sources in total	2.28	1	5
Electricity is the main heating source (0, 1)	0.41	0	1
Fuel oil is the main heating source (0, 1)	0.04	0	1
Firewood is the main heating source (0, 1)	0.20	0	1
Indoor temperature in the living room on cold winter mornings (^oC)	21.3	15	26
Outdoor temperature in February (heating degree days)	584.3	426	991
Dwelling size (m^2)	141	8	480
Live in a detached house (0, 1)	0.58	0	1
Live in a semidetached house (0, 1)	0.09	0	1
Live in a block of flats (0, 1)	0.13	0	1

	Mean	Min	Max
Live in a farmhouse (0, 1)	0.08	0	1
Number of years in the current residence	13	0	76
Number of household members	2.96	1	8
Number of persons with an income	1.48	0	4
State that they use the heat pump for cooling during the summer (0, 1)	0.062	0	1
State that they use less fuel oils after installing the heat pump (0, 1)	0.017	0	1
State that the heat pump can heat the entire residence (0, 1)	0.16	0	1
The residence is well insulated (0, 1)	0.66	0	1
Number of layers in the windows	2.20	1	3
Reduce indoor temperature during the night (0, 1)	0.48	0	1
Own an energy saving shower (0, 1)	0.66	0	1
The energy expenditures are included in the rent (0, 1)	0.29	0	1
The electricity expenditures paid by the employer (0, 1)	0.01	0	1
Age of main income contributor in the household	47.74	19	87
Price of electricity (NOK/kWh)	0.83	0.002	5.16
Price of fuel wood (NOK/sack)	67.18	8.33	312.50
Price of fuel oils (NOK/liter)	10.30	4.67	60
Total expenditures (NOK)	482 934	68 108	2 876 670

Source: Survey of consumer expenditure 2009, Statistics Norway.

Table A.2. Maximum likelihood estimation of indoor temperature, and fuel oil and firewood demand. °C, kWh

Variable	Indoor temperature (°C)		Fuel oil demand (kWh)		Firewood demand (kWh)	
A. Continuous function						
Constant	46.5701	***	-133 466	*	17 648	
Own a heat pump (0, 1)	**0.3869**	*******	**-695**		**-1 781**	*******
Price of electricity (NOK per kWh)			1 386		-415	
Price of fuel oils (NOK per liter)			-163		48	*
Price of firewood (NOK per sack)			-0.8		-40	***
Total expenditures (NOK 10 000)			722	**	90	
Number of household members	0.0586	*				
Electricity main energy carrier (0, 1)					-1 323	**
Central heating system (0, 1)			9 637	***		
Common central heating (0, 1)	0.9565	***				
Number of oil-burning stoves			2 467	***		
Number of electric heaters			-716	*	-176	*
Number of firewood stoves					1 413	***
Electric floor heating (0, 1)					-873	*
Heating degree days in January	-0.0022	***			4.1	
Heating degree days in July	0.0037	***				
The residence well insulated (0, 1)	-0.2876	**				
Economy shower (0, 1)	-0.2233	**				
Three-layer windows (0, 1)	0.1138	**				
Electricity bill paid by employer (0, 1)	0.5968	*				
Number of years in current residence					59	***
The year of moving into the residence	-0.0123	***				
Mechanic air ventilator (0, 1)	0.5310	**				
Use of night setback (0, 1)	-0.1694	*				
Automatic system for night/day setback (0, 1)	-0.1826					

Variable	Indoor temperature (^oC)		Fuel oil demand (kWh)		Firewood demand (kWh)	
Self-owned detached house (0, 1)			209 762	**		
Live in a block of flats (0, 1)			-10 867	**		
Farmhouse (0, 1)			10 289	***	6 227	***
Semi-detached houses (0, 1)	-0.2788	*				
Predicted indoor temperature (^oC)			**6 711**	*****	**-647**	
Predicted indoor temp. in detached houses (^oC)			**-10 030**	******	**97**	******
Standard deviation	1.4816	***	5 789	***	5 227	***
B. Probability of zero demand						
Constant			2.8293	***	0.8192	***
Fuel oil as main energy carrier (0, 1)			-3.0503	***		
Firewood main energy carrier (0, 1)					-1.0185	***
Heating degree days in February			-0.0020	**		
Number of household members					-0.1314	***
Number of firewood stoves					-0.6510	***

* Significant at 10%, ** significant at 5%, *** significant at 1%

Table A.3. Maximum likelihood estimation of electricity consumption, kWh

Variables	Coefficient	p-value
A. Effects on the constant term		
Constant	-25 812	0.0968
Net floor space (m^2)	51	0.0000
Own a detached house (0, 1)	1 976	0.0005
Farmhouse (0, 1)	2 711	0.0089
Heating degree days in January	13	0.0000
Common central heating system (0, 1)	-3 148	0.0403
Own a pellets stove (0, 1)	-7 077	0.0879
Number of income contributors	807	0.0034
Number of electric heaters	368	0.0000
Area with electric floor heating (m^2)	206	0.0683
Number of tumble dryers	665	0.0863
Number of freezers	736	0.0104
Number of PC's	334	0.0408
Correction variables:		
Moved into current residence in current year (0, 1)	-1 369	0.0771
Can use firewood for heating (0, 1)	1 326	0.0525
Electricity bill paid by the employer (0, 1)	-2 716	0.0809
Energy expenditures included in rent (0, 1)	-1 172	0.0481
B. Price and income effects		
Price of electricity (NOK per kWh)	-2 317	0.0000
Price of fuel oils (NOK per liter)	-74	0.0620
Price of firewood (NOK per sack)	-1	0.9153
Total expenditures (NOK 1000)	389	0.0000
C. Ownership of heat pumps		
Constant	**2 546**	**0.2837**
State that they can use the pump for cooling during summer (0, 1)	**1 161**	**0.1784**
State that they can use heat pump to heat the entire residence (0, 1)	**1 671**	**0.0435**

Variables	Coefficient	p-value
State that they use less fuel oil after installing a heat pump (0, 1)	**3 438**	**0.0352**
Number of substitution possibilities	**-1 628**	**0.0231**
D. Predicted instruments		
Indoor temperature (^{o}C)	**1 252**	**0.0756**
Fuel oil consumption (kWh)	**-0.2943**	**0.0000**
Firewood consumption (kWh)	**-0.2077**	**0.0038**
E. Standard deviation	**6 083**	**0.0000**

Table A.4: Characteristics of the 28 families interviewed in the qualitative study, No. of households

Type of home/building	Detached	26
	Semi-detached	1
	Flat in detached house	1
Type of tenure	Own	27
	Rent	1
Time of installation, heat pump	About to be installed/just moved in	3
	1-2 years	8
	3-5 years	12
	6-15 years	5
Type of heat pump	Air-to-air	22
	Air-to-water	2
	Geo thermal, water-to-water	4
Family status (adults)	Only male	1
	Only female	2
	Both male and female	25
Adult respondents per interview	Male	4
	Female	8
	Both male and female	16
Age of respondents	20s and 30s	6
	40s and 50s	13
	60s and 70s	9
Children living at home	Yes	15
	No	13