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Adoption of green technology

Do temporary electricity price shocks affect the adoption of heat pumps?

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Abstract

In this thesis, we aim to explore if temporary electricity price shocks affect adoption of heat pumps. In order to do this we construct panel data by combining sources from Enova and NordPool on number of subsidized heat pump installations and electricity spot prices for the different price areas in Norway. We then estimate a least square dummy variable regression with price area, yearly and monthly fixed effects to see whether fluctuations in average lagged electricity prices spur adoption of heat pumps. In addition, we use data from the Norwegian center for research data (NSD) to have a closer look at which household characteristics that correlate with the prevalence of heat pumps. In the interpretation of our results we rely on the theoretical underpinnings of bounded rational consumer behavior, with focus on myopic expectations and inattention.

Despite the temporary nature of the increases in the electricity price in our observations, we find that an average increase in the electricity price of one percent over the last four months leads to a significant increase in installations of 1.12 percent. Thus, we argue that temporary electricity price shocks indeed do affect households adoption of heat pumps. One explanation for our results is that consumers are myopic to the electricity price, adjusting their future price expectations as a result of the increase in the current electricity price. Another explanation is that temporary price shocks increases households attention, inducing information acquisition on energy efficient technology to dampen the costs of the next price increase.

Our results from NSD suggest that larger households living in an owner-occupied detached house are most frequent to have a heat pump installed. Even though these characteristics are likely to prevail for the Norwegian population as a whole, it might not be valid for the data provided by Enova due to the high up-front cost of subsidized heat pumps.

Keywords – Consumer behavior, uncertainty, electricity prices, energy efficiency gap

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1 Introduction

The adoption of energy efficient technology has both private and social benefits (Gerarden et al., 2017). An energy efficient heating system uses less energy to produce the same amount of heat compared to a less energy efficient technology. Hence, households can save energy and reduce their electricity bill, and at the same time contribute to the reduction of CO_2 emissions by investing in such technology. However, it has been shown that households do not invest in cost-effective and energy-conserving opportunities even though they appear to be profitable. This leads to a lower level of energy efficiency than what is socially optimal. In the literature, this is commonly referred to as the "energy efficiency gap" (Hirst and Brown, 1990; Jaffe and Stavins, 1994).

Various explanations have been put forward to explain the energy efficiency gap. Hirst and Brown (1990) and Jaffe and Stavins (1994) propose both structural and behavioral barriers as explanations to why we may not have achieved full energy-efficiency yet. Among the proposed structural barriers are limited access to capital, distortion in fuel prices, and government fiscal and regulatory policies. These are barriers that the consumers can not control. On the other hand are attitudes toward energy efficiency, information gaps, uncertainty about future fuel prices, and inattention suggested behavioral barriers which consumers to a larger extent can control. When deciding whether to invest in a more energy-efficient heating system or not, consumers face a trade-off between a high initial investment cost today and the long-run benefit of lower energy use and thus lower future energy costs. These behavioral barriers represent costs of adoption that are hard to observe and will consequently be underestimated when calculating the profitability of energy conservation investments. The presence of these obstacles prevents households from investing in energy efficient measures.

A well-cited engineering analysis on energy efficiency conducted by Granade et al. (2009) argues that the full potential of investments in energy efficiency has not been unlocked. They suggest that there is a potential to reduce annual energy consumption because of current barriers to engaging in more energy efficient practices and technologies. However, the prevalence of an energy efficiency gap is highly debated. Allcott and Greenstone (2012) argues that there may be other costs and benefits related to energy efficiency investments that are unobserved, including opportunity costs. Heterogeneity among consumers can also make investment profitable for some, but not all. This makes it harder to estimate the size of the energy efficiency gap, and if there actually is one. It can be rational for some households not to invest if the unobserved costs are substantial, even though the investment appears to be profitable.

According to Enova (2016), a household can save around 30 to 40 percent of the initial amount of energy used to heat the dwelling by installing a heat pump. The installation of a heat pump will reduce a household's energy bill, provide better indoor climate and a more even temperature. These are private benefits for the household. The social benefit of heat pump investments are emission savings stemming from an alternative use of electricity. The main source of electricity in Norway comes from hydropower plants. Therefore, the electricity produced is virtually emission free due to the renewable nature of water resources. The reduction in greenhouse gas emissions will not necessarily be directly connected to the energy savings in the residential sector. Reducing electricity usage in private dwellings releases energy that can be used in other sectors, where there is a larger potential of emission reductions. However, if households are uninformed or uncertain about the potential energy savings they may forego investment. This may impede a reduction of the energy efficiency gap.

Following the Paris Agreement on Climate Change, which took effect in 2016, Norway has an emission reduction target of at least 50 percent by 2030 compared to the 1990s level (Norwegian Ministry of Climate and Environment, 2021). Improving energy efficiency in the residential sector can have a large impact on energy use, as the residential sector as of 2020 accounted for 22 percent of final energy consumption in Norway (Energy Facts Norway, 2021b). Electricity is also the primary energy source for domestic usage. Consequently, reducing the electricity use in residential buildings may have a large impact on total electricity demand, which in turn can supply the ongoing electrification of other sectors.

In this thesis, we aim to examine to what extent higher electricity prices cause households in Norway to adopt more energy efficient heating systems. Our main focus is on the installation of heat pumps. Understanding the role of energy prices and the characteristics of households who invest in energy efficient technologies is crucial in designing good policies to spur adoption. Further, knowing the characteristics of households having a heat pump installed is relevant to see population differences between Norway and other countries, as well as providing information on which households undertake such energy efficient investments.

The novelty of this paper lies in the attempt to quantify the relation between electricity prices and adoption, and explore what characterizes the Norwegian households who undertake energy efficient investments. Hence, our research question is as follows:

Research question: *Do temporary electricity price shocks affect adoption of heat pumps?*

The Norwegian electricity prices have traditionally been low due to the abundance of water utilized in hydro-power plants (Energy Facts Norway, 2021a). Up until 2021, spikes in the electricity price have only been temporary. A temporary price shock should not affect the net present value of investing in more energy efficient technology. As the price shock will have passed before the heat pump is installed and ready for use, the actual profitability of investment should not change. Therefore, the expected future cash outflow of energy expenditure is assumed to be the same due to the temporary nature of the spike.

However, the price increase can make households change their investment behavior due to either changes in their expectations about future prices, or because of increased attention towards reducing electricity usage, spurring adoption of heat pumps. Households should therefore undertake precautionary measures to reduce their electric bill. By running a least square dummy variable regression with price area fixed effects, we find the effect of a one percent increase in the average electricity price the previous four months leads to an increase in heat pump installations of 1.12 percent. Our results suggests that households indeed are sensitive to temporary changes in the electricity price.

Further, most heat pumps are installed by households living in owner-occupied detached dwellings. Owner-occupied households can to a greater extent decide themselves if they want to install a heat pump compared to someone who rent their dwelling. In addition, those who are tenants may face a greater uncertainty about how long they will be living in the dwelling, and therefore also the profitability of installing a heat pump. Detached houses can be argued to be larger than for example apartments, thus there is more space to heat, making a eat pump more profitable. A large fraction of dwellings in Norway are detached houses (Statistics Norway, 2022a). Hence, this indicates that there is a great potential for heat pump installations in Norway, and policies should aim at reaching house owners of detached dwellings.

To answer our research question, we will begin by presenting relevant theoretical literature on decision-making under uncertainty. We will proceed with presenting empirical evidence on the adoption of energy efficient technology. In chapter 3, we describe the relevant characteristics of the Norwegian power market, and how the electricity price is determined. We will also briefly describe the market for heat pumps. Then we continue with providing descriptive statistics of our data and describe our empirical methodology, which is utilized to run a regression model in chapter 6. The results from our empirical analysis is then presented, before we in chapter 7 discuss the implications, robustness, and limitations of our results. Lastly, we answer our research question and provide some concluding remarks.

2 Literature Review

In order to put our research question into context, we will discuss the different assessments households must make before investing in a heat pump, taking uncertainty about future values into account. We also present empirical literature on energy efficient technology adoption.

2.1 Theoretical literature

A heat pump will be more energy efficient than for example an electric panel heater. Investing in a central heating system such as a heat pump will therefore reduce the energy use and the households' electricity bill. If one presumes that a heat pump is a normal good, a lower effective price of heating will increase consumption because electricity then becomes relatively cheaper (Gillingham et al., 2016). The income effect stemming from a lower price of electricity usage results in a further change of consumption towards the more energy-efficient good. This gives a rebound effect as households use more electricity after the energy efficient investment than they did previously, as the price of heating has become relatively cheaper. Rebound effects will therefore mitigate some of the future energy saving potential. If there are rebound effects, the financial net present value of installation will decrease or remain unchanged, but the household will reach a higher utility level as they can consume more heat at the same cost as before. For the energy use to be reduced after installing a heat pump, we therefore must assume that there are no rebound effects and that households prefer to keep consumption fixed at lower prices.

The household choice of keeping their existing heating system or adopting a more energy efficient one can be thought of as a two-stage process that occurs every month. In the first stage, the household decides if it wants to change the dwelling's current heating system. If the household does not consider an alternative heating system, it keeps the existing one for the following month. However, if the household considers alternative heating systems, it enters into the second stage. In this stage, the household observe the different heat pump alternatives and choose the alternative that maximizes their utility

$$\max_{a} \; u(a, b, s, r, \mathbb{E}[p], \mathbb{E}[e]) \tag{2.1}$$

where a is the action of installing an advanced heat pump and our variable of interest. b is the initial investment cost, s is the subsidy one can receive from Enova when installing a heat pump, and r is the subjective discount rate. $\mathbb{E}[p]$ and $\mathbb{E}[e]$ are the expected future price of electricity and the expected future energy use, respectively. We choose to model the maximization problem as maximization of utility and not optimization over the expected utility out of convenience, as we want to focus on how changes in expectations affect behavior.

When households decide whether to invest in a more energy-efficient heating system or not, they face a trade-off between the initial investment cost today and the long-run benefit of lower energy costs in the future. Moving from the first to the second stage, households must therefore take future expectations about the energy price and future consumption into consideration as this impacts the long-run benefits of investing. Whether the household considers a different heating system also varies with the price of electricity. However, the price varies by season due to different amounts of precipitation. In stage one, we therefore allow for seasonality. This way, one can take into account the temperature differences between months, which is likely to have a more severe impact on the installation in general.

If a spike in the electricity price is sudden and not expected to last, consumers may not even notice the price increase, or to an even lesser extent put in an effort and try to reduce their electricity bill. This despite of the potential future energy savings, and therefore also cost savings. Households may refrain from these investments as short temporary price shocks do not affect their net present value of investment in energy saving technology, everything else held equal. But, what if a rise in electricity price today changes the consumers expectations about future energy prices?

To account for uncertainty and expectations about future electricity prices, the general net present value formula can be adjusted and transformed it into a more subjective one, which is different for every household. The components of such a net present value model, when we consider investing in a heat pump, are

$$NPV = -b + \frac{(e^0 - \mathbb{E}[e^1])\mathbb{E}[p_1]}{1+r} + \frac{(e^0 - \mathbb{E}[e^2])\mathbb{E}[p_2]}{(1+r)^2} + ... + \frac{(e^0 - \mathbb{E}[e^{t+T}])\mathbb{E}[p_{t+T}]}{(1+r)^{t+T}} \tag{2.2}$$

where b is the initial investment cost of installing a heat pump, including the Enova subsidy, the price of the heat pump, and cost of installation, which we assume is known for the household today. Furthermore, e^0 and $\mathbb{E}[e^1]$ is the energy use before the installation and expected energy use after, respectively. $\mathbb{E}[p_t]$ is the expected electricity price, and r is the discount factor, which may vary over time. The larger the expected energy price is, the higher are the potential savings from investing in a heat pump, as long as the expected energy use is the same. Equation 3.2 is a simplification of the net present value formula, where we ignore potential income and substitution effects as we believe the approximation will provide a sufficient intuition in relation to our research question. We therefore model energy consumption levels in time t to be independent on the price level in that period. We acknowledge that several other factors will impact the net present value of installation. For instance, the financial performance of a horizontal geothermal heat pump will also vary depending on economic impact factors such as time and location, fuel expense, inflation, electricity tariffs and monetary incentives (Cui et al., 2019). This is not included in equation 3.2. as we will focus on the variation in price and not other varying variables.

In his paper, Wirl (2008) investigates consumers decision on energy conservation investments, taking into account uncertainty. Consumers will decide differently depending on their expectations on how they think conservation will affect the fuel price. He argues that less rational consumers will not take into account the link between individual conservation measures, aggregate conservation, and how this affects energy prices. The paper distinguishes between two types of expectations, namely rational and myopic expectations. Consumers with rational expectations knows that aggregate conservation will impact the price of fuel. On the other hand, if the consumers have myopic expectations, they will undertake an investment based on the presumption that today's price will prevail forever. Even though this study focuses on fossil fuel price, it can be used as a suitable reference point for our research as well.

Following the framework presented by Wirl (1991), if a household has myopic expectations, it will extrapolate the current price into the future. Consumers then expect the future to look the same as today, meaning that today's price will also be the price in the future. Thus, an increase in the electricity price today implies that they will update and adjust their price expectations upwards. Myopic expectations will affect the variable $\mathbb{E}[p_t]$ in equation 2.2, making the investment more attractive, all else equal. A rise in the price of electricity and households' electric bills may induce investment in energy efficient heating systems as a precautionary action to dampen expected future cost jumps. If the future is uncertain, one will try to adapt to this uncertainty by shaping expectations based on what has happened in the past (Palley, 1993). Wirl (1991) finds that an expected future increase in liquid fuel prices dampens the current rate of demand even though the price is low today. This may be a sign of people adapting to their expectations and as a result adjust their demand. Based on this, we should expect an increase in adoption when there are temporary price shocks, even though the price increase in itself should not affect the net present value of investment, as argued above. This is because the "new" price works as a new reference point for the future price, making the net present value more positive.

In the standard economic model, consumers use all the available information to make decisions (DellaVigna, 2009). If households were fully informed, one should not expect a large change in installations of heat pumps when the electricity price changes as they would already have incorporated information about future energy costs in the net present value formula. However, laboratory experiments have shown that decision makers often simplify complex problems by processing only some of the information available (Gabaix et al., 2006). This is because the cost of gathering accurate information may be high due to time being a scarce resource. As it can be practically impossible to incorporate all available information before making decisions, people ignore information that is redundant when gathering information. If the installation level increases following a temporary price shock, this could be a signal of information gathering being considered to be more worthwhile.

The expected future electricity price is made up by the current market price of energy, and the actual retail price paid by the household as this depends on the type of contract the household has with their electricity provider. Consumers who have a fixed price contract will only take expected future consumption into account, as there rules no uncertainty regarding the electricity price they will pay in the future. This would make us expect the impact of a price shock on heat pump installations to be smaller than if all households had a spot price contract. However, most Norwegian households are on spot price contracts, and will therefore be fully affected by price shocks (Statistics Norway, 2022b). The small prevalence of fixed price contracts should consequently not have a huge impact on our results. The real world is complex and there are differences in individual expectations. For instance, price expectations, $\mathbb{E}[p_t]$, can depend on word-of-mouth, media coverage, and different expert opinions. Even though the underlying causes for changes in future price expectations can be various, we are interested in exploring whether fluctuations in the price of electricity affects the number of installed heat pumps.

2.2 Empirical literature

The empirical evidence on energy efficient technology adoption and whether consumers invest in more energy efficient technologies is more recent compared to the literature on the energy efficiency gap. We will focus on the findings from research on energy-efficient technology adoption and how this varies with energy costs and demographic characteristics.

2.2.1 Price elasticities and household characteristics

In a study from the Finnish home building market, Sahari (2019) investigates consumers' long-term technology investments and their sensitivity to electricity prices. The electricity distribution prices are persistent over time and therefore acts as a reasonable measure of the long-term price expectations. The study makes use of detailed consumer data and the heating decision when building a new house. Combining this data with electricity distribution prices, Sahari (2019) sets up a logit model of discrete choice with electric heating as the base choice to estimate the long-term price elasticity. She estimates that elasticity of demand for electric heating technologies with respect to the electricity price range from -0.42 to -1.56, depending on the distribution price level. In a study by Schulte and Heindl (2017), they estimates an own price elasticity for electricity between -0.431 and -0.501 regarding residential space heating demand in Germany. This implies that consumers are sensitive to changes in the electricity price when deciding to invest in energy-intensive durable goods. Increased electricity prices leads to a reduction in electricity demand, and the elasticity is therefore negative. Even though these studies estimate a price elasticity of electricity, this relates to our study as adopting an energy-efficient heat pump can be regarded as a measure to save electricity. Thus, the elasticities provided by Sahari (2019) and Schulte and Heindl (2017) provides a basis of comparison with our price elasticity which we find to be 1.12. An increase in electricity prices indeed leads to an increase in heat pump installations. This we will return to in the discussion.

In this thesis we will also explore the characteristics of households who have installed a heat pump. Sahari (2019) finds that the investment decision depends on both characteristics of the buildings and on socio-economic background of the agents. A higher level of education is associated with a strong preference for ground heat. Even though ground heat is also dependent on electricity, the unit cost of electricity is lower compared to electric heating systems, such as electric panel heaters. It is not possible to determine the underlying causes for the differences between household's technology choice. Sahari (2019) proposes that the effect of education may reflect a preference for energy efficiency or that those with a higher level of education has lower personal discount rates. In regard to dwelling status, house owners are more sensitive to electricity prices compared to households that do not own a detached house. Sahari (2019) and a study conducted by Schulte and Heindl (2017) find that low-income households respond less to changes in energy prices compared to households at the higher end of the income distribution. Larger households also tend to use energy more efficiently than smaller ones.

Utilizing data from a survey sent to a sample of households in 11 European countries, including Norway, Mills and Schleich (2012) estimate the relationship between adoption of energy efficient technologies, attitudes towards energy saving, and household characteristics. Even though there is a lot of heterogeneity between countries in household behavior, they find that higher levels of education is associated with higher levels of energy-efficient technology adoption and energy conservation. This effect tend to be large and positive at the university level. In regard to family structure and age composition, they find that households with young children and a higher share of members under the age of 65 tend to be more likely to invest in energy-efficient technologies. Mills and Schleich (2012) also find that among Norwegian respondents, 61 percent state that they engage in energy conservation practice and save electricity for financial reasons. This was a slightly larger percent compared to what was reported in several of the other countries. We therefore would expect Norwegian households to be sensitive to electricity price shocks and somewhat attentive towards energy conserving matters. One limitation of this study is that they do not have data on actual household energy expenditures. Hence, one cannot conclude that attitudes result in actual change in behavior.

2.2.2 Implied discount rates

Research from the United States finds implied discount rates of around 20 percent when looking at the effect of a subsidy on the purchase of energy efficient technology (Walls, 2014). Hausman (1979)'s work on discount rates in the purchase and use of energy-using durables, calculates discount rates from observed consumer behavior in the purchase and utilization of room air conditioners. He finds average implicit discount rates ranging from 15 to 20 percent.

The implied discount rates found by Walls (2014) and Hausman (1979) suggests that the payback time for the appliance needs to be shorter, or the energy savings have to be substantial for the investment to generate a positive net present value. A relatively high discount rate may imply that the household postpones the investment or choose to not purchase more energy-efficient equipment at all. This is because a high discount rate result in heavy discounting of future benefits. These discount rates are much higher than what is commonly used in engineering studies on energy-efficiency, and higher than the market discount rate (Burlinson et al., 2018). Hence, such studies may overestimate the demand for energy-efficient technology as these do not consider hidden costs faced by the consumers. Such hidden costs may be related to the gathering of information or uncertainty about future costs. Even though we are not able to observe the households discount rate, this may have impacted the adoption rate we find. If discount rates are as high as 15 to 20 percent, this is likely to reduce the profitability of investment and therefore also lead to a smaller impact of a price shock on heat pump installations.

2.2.3 Attentiveness to energy costs

It is costly to obtain full information, as this takes time and effort. Research from the United Kingdom finds evidence that consumers' inattention negatively affects the adoption of connecting to a district heating scheme (Burlinson et al., 2018). If the household is not interested in energy saving matters or does not engage in information acquisition, this act as barriers which prevent the installation of energy efficient technologies. This may therefore help in understanding why there might be an energy efficiency gap.

When considering installing a heat pump as measure to save energy and hence reduce the electricity bill, the price of energy may have an important effect. The incentive to save energy is weak when energy is cheap (Ewald et al., 2021). This intuitively makes sense. When the price of a good is cheap it is less to save from reducing the use of that good. Thus, households may not pay attention to more energy efficient heating systems as the electricity bill does not constitute a large fraction of households' expenditures. Applying data on energy consumption in the residential sector in the European Union countries and the UK from 1990 to 2018, Ewald et al. (2021) finds a negative relationship between energy consumption and price, when controlling for income and climate. These factors are important determinants of energy demand. Sweden, which is included in the study, works as a comparison to Norway because of the colder climate. They find large negative fixed effects for Scandinavian countries, which may be due to a higher adaption to the relatively cold climate. If Norwegian households have already adapted to the cold climate, we should not expect to see a large increase in adoption of heat pumps following a price increase.

A related field of study explores the housing market in Massachusetts and whether home buyers are attentive to fuel prices when buying energy-using durables. Myers (2019) use data on housing transactions and housing characteristics between 1990 and 2011 to estimate the effect of changes in fuel-prices on housing transaction prices. If home buyers are fully attentive, a change in fuel-prices should change the price of the house by the same amount as the change in the net present value of future energy savings or costs. The results find that home buyers do pay attention to energy costs and take future heating costs into consideration when buying a house. When the cost of heating increases, the housing transaction price decreases. The implied discount rate ranges from 8 percent to 10 percent, which is lower compared to the findings of Walls (2014) and Hausman (1979). Households being attentive towards the energy price therefore induces that an increase in electricity price can have a positive impact on heat pump installation, unless the price increase is too small to be noticed, as indicated by (Ewald et al., 2021).

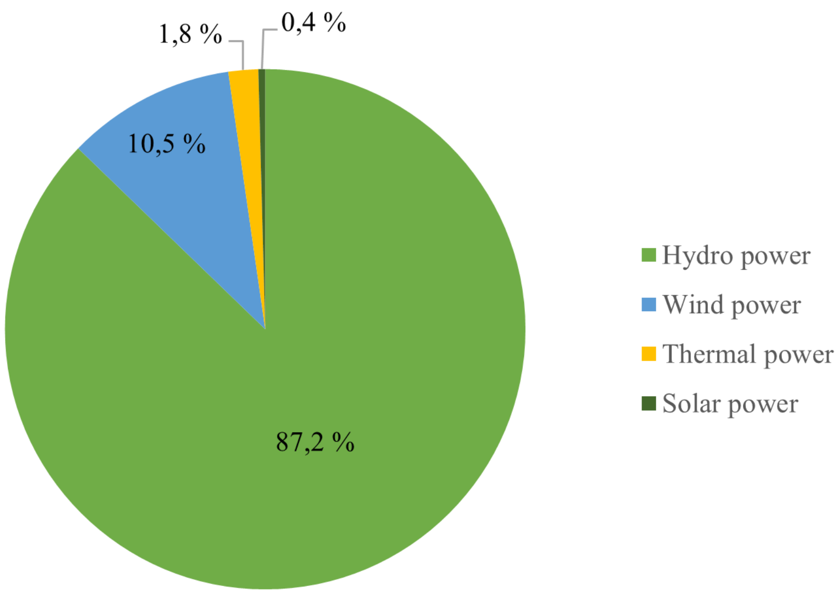
3 Background

3.1 Characteristics of the Norwegian power market

According to Energy Facts Norway (2019), an information page run in cooperation with the Ministry of Petroleum and Energy, the Norwegian power supply system has three fundamental functions: production, transmission and trade of electricity. A stable and reliable supply of electricity is key infrastructure in a welfare society. It is therefore important to secure a stable production of electricity.

One can divide the Norwegian electricity grid into three levels: the transmission grid, the regional grid, and the distribution grid. The transmission grid, operated by the Statnett and owned by the Ministry of Petroleum and Energy, connects both foreign and domestic producers with Norwegian consumers. The regional grid then links the transmission grid to the distribution grid. Households, considered to be small-scale consumers, are connected to the distribution grid. A household can not choose their local distribution grid operator as this is heavily regulated due to the potential of misuse of monopolistic power. However, consumers are allowed to choose their own power supplier. The power exchange NordPool is an important part of this market.

Norway has the highest share of electricity produced from renewable energy sources in Europe (Energy Facts Norway, 2021a). The main source of electricity stems from hydropower plants which utilizes water to produce electricity, as seen from figure 3.1 below.



Data source: Energy Facts Norway

Figure 3.1: Installed capacity in MW, 2021

The large share of electricity production coming from hydropower and the high storage capacity makes it easier to regulate the energy production depending on the consumption level. However, the precipitation can vary considerably between years, and this has consequences for the inflow of water to the hydropower plants and therefore the price of power. As well as providing Norwegian consumers with electricity, Norway is a part of the Nordic power cooperation and therefore exports the excess power production to countries like Sweden and Denmark, which are our most important power connections (Statnett, 2021). Even though the net export is positive, we import power in certain periods when the price is cheaper in the countries which we are connected to compared to the domestic prices.

3.2 NordPool and pricing of power

Norway is divided into five different price areas for electricity (Statnett, 2022a). These are south-east (NO 1, Oslo), south-west (NO 2, Kristiansand), mid (NO 3, Trondheim), north (NO 4, Tromsoe) and west (NO 5, Bergen), see figure 3.2. The availability of power may be different within the different areas. Precipitation and wind are some of the factors that affect how much power is produced within one area. Division of Norway into price areas enables exploitation of the power resources in an efficient way.

Figure 3.2: Price areas for electricity in Norway

Even though the potential energy of water can be stored in dams and be used to generate electric power in the future, electricity in itself cannot be stored. Therefore, the power supply is a complex matter and may cause heavy price fluctuations depending on supply and demand within a region. The reason for this is that the capacity in the power grid will not always be great enough to smooth the differences between the areas, leading to different prices between regions. Furthermore, the main transportation line for power between the northern and southern regions in Norway goes through Sweden. The Swedish energy prices and their capacity will therefore also impact the Norwegian energy prices. Therefore, due to limited capacity in the power grid, high electricity demand in one price area may lead to a higher electricity price, even if another price area has excess power supply. As an illustration, in September 2021, the price was 1084 EUR/MWh in eastern Norway in NO 1, while it was 513 EUR/MWh north in NO 4 (NordPool, 2022).

Every day, NordPool computes the system price of power for each hour of the following day, in the day-ahead market (Energy Facts Norway, 2022). This system price is computed assuming that there are no bottlenecks in the transmission grid and works as a reference price for power in the Nordic countries. In addition to the system price of power, NordPool computes the electricity price for the different price areas. This price of electricity takes into consideration bottlenecks in the transmission grid. It is the most important component that determines the price of power. Both suppliers and buyers of power participate in bidding rounds. Thus, the price makes sure that there is balance between the supply and demand of power.

Even though the price of electricity can vary considerably between years, the average price over the year in the different price areas on average tend to follow each other closely (NordPool, 2022). However, there has been substantial, long-lasting price increases in the past year, especially in the southern part of Norway. There are several reasons why this situation has arisen. The Russian invasion of Ukraine have affected the energy markets and European energy supply, leading to high prices on gas and coal. Even though Norway does not use power from gas or coal, their prices affect the Norwegian electricity prices due to the connection to the Nordic and European power market. In addition, the filling in the hydropower plants' reservoirs in southern Norway has been lower than usual, increasing the value of the water that is left, thus leading to higher prices (Statnett, 2022b). This is an example of the large price differences that can emerge between the price areas of electricity. While some effects, such as the Ukrainian war, is expected to last for a longer time, effects like the water fillings are assumed to be more of a temporary character. Statnett does not expect the large price differences that has prevailed the last year to last (Statnett, 2022a). In chapter 4 we will argue why we in our empirical analysis have chosen not to include data on electricity price from 2020 until today.

3.3 Enova

Enova was established in 2001 and is owned by the Norwegian Ministry of Climate and Environment (Enova, 2018). Their main task is to spur the adoption of new energy efficient technologies in private homes and among businesses. Enova support solutions where the technology development is relatively new and ready to be used in a large market. Emerging technologies normally have room for improvement when it comes to reducing the cost and improving the effective output of the technology (Norwegian

Ministry of Climate and Environment, 2022). Costs are typically high in the beginning, but will fall as the industry matures. Thus, Enova subsidizes investment in these markets in order to spur their development and increase innovation that enables the transition towards a low-emission society. They are therefore an important tool in shaping the future Norwegian energy system and cutting emissions.

Enova provides financial support to those who want to invest in emerging and sustainable technology, in addition to provide energy advising. They want to make it privately optimal to invest emerging technologies. Conservative, present biased, or risk averse agents may be reasons why investments in energy efficient technology end up being underfinanced (Civita, 2017). The subsidy provided is an attempt to reduce these effects and prevent underinvestment in socially desirable technology. As an example, one type of the subsidized heat pumps can cost over 120,000 NOK, depending on the heating effect (Enova, 2016). On top of this, one has to pay for the cost of installation. When installing such a heat pump a household can get up to 10,000 NOK in financial support. It can be argued that the amount of financial support is relatively low compared to the investment cost. It takes on average three weeks from the time Enova receives the receipt and documentation of a heat pump installation and to the subsidy is paid out to the household (T. Brekke, senior advisor Enova, November 7th, 2022).

3.4 Measures supported by Enova

3.4.1 Installation of heat pumps

We will focus on the adoption of heat pumps that are eligible to receive financial support from Enova, which are heat pumps used to generate water-borne heat. Such heat pumps utilize the energy from the surroundings to heat water for radiators and waterborne floor heating, as well as preheat tap water (Enova, 2022a). In addition, we have collected data on the removal of oil burners and oil tanks. Next, we will explain the characteristics of the systems in more detail.

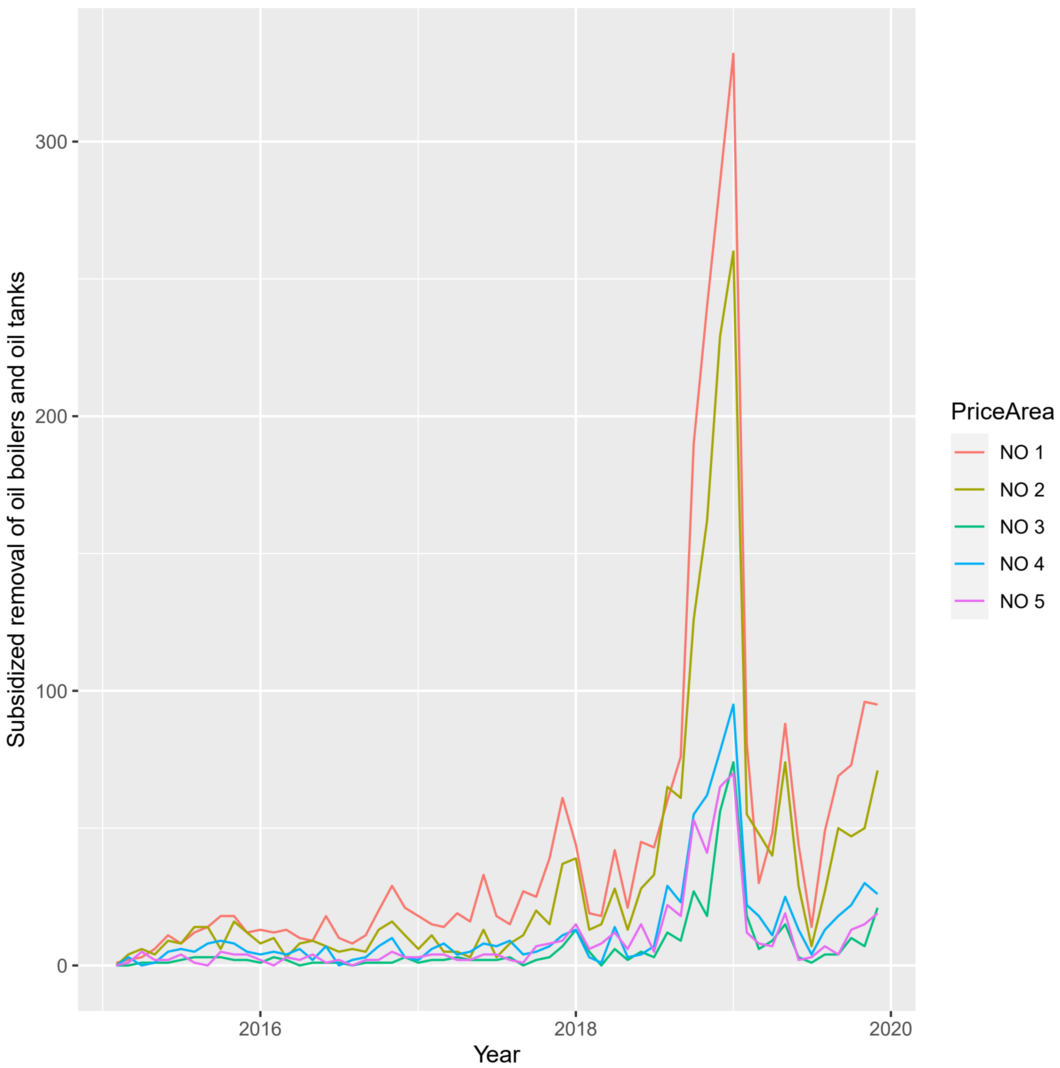
A heat pump is a device that uses electricity to transfer thermal energy from cooler surroundings to warm indoor spaces to make it warmer (Bredesen and Lorentzen, 2021). Common sources of heat are outdoor air, seawater, or a geothermal energy well. Heat pumps thus utilize electricity to get free heat from the surroundings and is therefore classified as technology that uses renewable energy. According to the Norwegian Heat Pump Association (NOVAP), a heat pump is two to five times as efficient as an electrical heater (Norwegian Heat Pump Association, 2022).

There are over 1.1 million heat pumps currently installed in Norwegian households (Norwegian Heat Pump Association, 2022). Data provided by NOVAP (Hagemoen, R.I.M, CEO Norwegian Heat Pump Association, September 5th, 2022) shows that out of approximately 1.5 million heat pumps sold until 2022 in the Norwegian market, 91 percent of these were air-to-air heat pumps. An air-to-air heat pump transfers heat from the air outside of the dwelling to the inside. Even though air-to-air heat pumps are the most common type used in Norwegian households, this type of installation was only supported by Enova up until 2003 as it was no longer characaterized as an emerging technology (T. Brekke, senior advisor Enova, September 21st, 2022). The prices, demand and technology is now more developed and not in a phase of early market introduction. The large fraction of air-to-air heat pumps is most likely due to the fact that the heat pumps for water-borne heat demands a larger upfront costs compared to air-to-air heat pumps.

3.4.2 Removal of oil boilers and oil tanks

From January 1st 2020, it was no longer permitted to use fossil fuels as a source of heating in Norwegian households (Enova, 2020). It was suggested to phase out oil boilers before 2020, and the bill was passed in 2012 (Meld.St.21, 2011-2012, p.13). Dwellings with an oil boiler or oil tank thus needed to remove these before 2020 and install alternative sources of heating. The removal of oil boilers and oil tanks were subsidized by Enova until 2020. Enova also recommended the installation of more energy efficient heating systems which they subsidize, rather than installations of electric heating systems. Thus, it is plausible to assume that the ban on fossil fuel heating had an impact on the adoption of more energy efficient heating systems, such as heat pumps.

The number of oil boilers and oil tanks removed in Norway from 2015-2020 for the different electricity price areas are depicted in figure 3.3 below. There was a massive spike of subsidized removals in the end of 2018 and a minor spike in the end of 2019. In general, the removals tended to spike just before the turn of the years. One explanation for this pattern of removal is that the amount subsidized by Enova changes from year to year. For instance, Enova increased the financial support to accelerate the removal of oil boilers in 2018. This was later reduced until the ban took effect (T. Brekke, senior advisor Enova, November 7th, 2022). As an example, the amount of subsidy was halved in 2019 compared to the 2018 level when removing an oil tank (Norva24, 2019). This relatively large change in the subsidy is likely to have incentivized households to apply for the subsidy before the amount they could receive was reduced. In addition, seasonal effects may also have impacted this pattern. People are likely to become more aware of electricity costs and different heating alternatives when the weather gets colder.



Data source: Enova

Figure 3.3: Subsidized removals of oil boilers and oil tanks, 2015-2019

4 Data

In the following sections, we will present our data collection method, how we have constructed our datasets, and provide descriptive statistics.

4.1 Norwegian centre for research data (NSD)

4.1.1 Data collection and cleaning

Every year, Statistics Norway conducts a survey on the living conditions among Norwegian households. These surveys contain data on housing conditions, health, sports, and outdoor life (Statistics Norway, 2022c). However, only every third year Statistics Norway collects data on the main source of heating in the households. The datasets relevant for our thesis are consequently pooled cross section data from 2012, 2015, and 2018 as the next survey update has not yet been determined. About 12,000 people over the age of 16 are randomly chosen to answer each survey by phone. In the three surveys from 2012, 2015 and 2018, there were 6,186, 6,393 and 5,981 final respondents, respectively. It is not possible to identify any of the respondents.

The datasets provided by Statistics Norway contain data on dwelling ownership status, residential environment, size of dwelling, type and standard of dwelling, economy, and size of the household, as well as the main source of heating (Statistics Norway, 2018). The survey data also contain information on which part of the country the respondent lives. In the data cleaning process, we have dropped all variables other than these matters, as we do not believe they will have an effect on the prevalence of heat pumps among the respondents.

We also added the educational level of the respondents in the data cleaning process. Education is grouped by the Norwegian Standard Classification of Education (NUS) (Statistics Norway, 2019). The NUS code consists of six numbers where the first number indicates the level of education, and the subsequent numbers indicate the subject classification. In the data provided by Statistics Norway, we have extracted only the the first number in the NUS code and connected this digit with the description of educational level. We do this because we only consider the level of education, and not the subject classification, to be relevant in our analysis.

The respondents may have more than one heating system installed, and have in those cases reported the various sources of heating in their dwelling. We have added a dummy variable taking the value 1 for those reporting having a heat pump, regardless of this being stated as their main source of heating or not. We are not able to distinguish which type of heat pump the household has installed. The prevalence of heat pumps will therefore also include air-to-air heat pumps, which do not receive financial support from Enova.

When conducting a survey, those who choose to answer might be different from those who do not respond, creating a non-response bias (Berg, 2005). We believe that the data in any case show some indication of characteristics of the Norwegian households and dwellings that has a heat pump installed, and in general can be applied to the population as a whole.

4.1.2 Descriptive statistics

The following tables provide descriptive averages and percentages of respondents reporting having a heat pump or not, within each category. We have chosen to highlight what we believe to be the most relevant characteristics of households having a heat pump. In table 4.1 below we see what characterizes the survey respondents. About 30 % of the respondents report that they have a heat pump installed.

Variable	Heat pump	No heat pump
Number of observations	5,631	12,929
Average age	49.8 years	47.4 years
Gender		
- Male	31 %	69 %
- Female	29 %	71 %
Mean income	688,134 NOK	585,692 NOK
Average number of people in the household	2.28	1.9
Education		
- Lower secondary education	29 %	71 %
- Upper secondary, basic	34 %	66 %
- Upper secondary, final year	34 %	66 %
- Post-secondary not higher education	35 %	65 %
- First stage of higher education, undergraduate level	29 %	71 %
- First stage of higher education, graduate level	23 %	77 %

Data source: Norwegian centre for research data (NSD)

Table 4.1: Characteristics of the respondents with and without a heat pump installed

We see that average number of people in the household and the mean income are higher for households with a heat pump installed than for those without. A higher number of people in the household implies that there are more people using electricity and a greater need for heating a larger part of the dwelling. This results in a greater saving potential from installing in energy efficient heating technology. Higher income implies that the upfront cost of installing a heat pump is more affordable. On the other hand, one could argue that low-income households and those who are more price sensitive are more likely to be attentive toward changes in the electricity prices and energy efficient technology such as heat pumps.

From table 4.1 we see no clear trend in the level of education regarding having a heat pump. The fraction of heat pump installation within each educational level are quite similar. It does not appear to be a clear pattern of higher education leading to a greater number of heat pumps. Other factors appear to be more important than education regarding the installation of heat pumps.

In table 4.2 we have included numbers on what type of dwelling that has a heat pump installed and where these households are located.

Variable	Heat pump	No heat pump
Form of ownership		
- Owner-occupier	38 %	62 %
- Housing cooperative	8 %	92 %
- Tenancy	12 %	88 %
House type		
- Detached house	43 %	57 %
- Row house	21 %	79 %
- Duplex house, three-person or four-person home	21 %	79 %
- Apartment building	3%	97 %
Location		
- Akershus and Oslo	15 %	85 %
- Hedmark and Oppland	37 %	63 %
- Rest of Østlandet	31 %	69 %
- Agder and Rogaland	39 %	61 %
- Vestlandet	36 %	64 %
- Trøndelag	36 %	64 %
- Northern Norway	35 %	65 %

Data source: Norwegian centre for research data (NSD)

Table 4.2: Characteristics of the dwellings with and without a heat pump installed

Owner-occupied dwellings more frequently have a heat pump installed, as seen from table 4.2. This is a plausible result since people who rent their dwelling or live in a housing cooperative may not have the possibility to install a heat pump without the owner's permission. Moreover, they do not have the opportunity to take the heat pump with them the day they move. In case of a tenancy, the lessor will in most cases not be the one paying the electric bill. Thus, the owner will have a weak incentive to install a heat pump. This is often referred to as a split incentive.

Dwellings which are detached houses will more often own a heat pump than other house types. A detached house can be considered to be bigger in general compared to for example a row house or an apartment. A bigger dwelling needs more electricity for heating, making the investment of an energy efficient heat pump more profitable due to larger potential energy savings. That the presence of heat pumps are greater in detached dwellings is not surprising, as this is the most common housing type in Norway (Statistics Norway, 2022a).

For all regions there has been an increase in the share of heat pumps between 2012 and 2018. From table 4.2 we see that in Oslo and Akershus there is clearly a smaller part of the survey sample reporting owning a heat pump than in the rest of Norway. 15 % of the sample living in Oslo and Akershus reports having a heat pump, while in the other regions the share is above 30 %. This may be due to the fact that Oslo consists of many people living in apartment buildings and have a higher degree of people renting their homes, thus not being in a situation allowing them to install a heat pump.

It is important to keep in mind that several of the characteristics of households with a heat pump installed ought to be correlated. By estimating a logistic regression, we can check the conditional relations of the descriptive data on the probability of having a heat pump. The logistic regression table can be found in the appendix table A1.1. The results show that age and number of household members have a significant positive effect on the probability of having a heat pump installed. Further, living in anything but an owner-occupied detached house reduces the probability. More people living in the household will in many cases result in a demand for a bigger living space, making it more profitable to install a heat pump as it is more space to heat up. A larger dwelling will also in many cases mean living in a (detached) house rather than an apartment.

Income, education and gender do not appear to have any clear impact. The impact of these variables might be captured through the other variables, such as form of ownership or house type. Size and type of dwelling is likely to be correlated with income, as those with higher earnings to a greater extent can buy their own dwelling and afford a bigger living space. Age and higher education is also associated with higher income.

4.2 Enova and NordPool data

Our dataset is panel data containing monthly observations on average electricity prices and subsidized heat pump installations for each of the five price areas.

4.2.1 Data collection and cleaning

Our final dataset used to perform our empirical estimations is a combination of data from our two different sources, Enova and NordPool. The dataset was originally for the period 2015 – 2021, but due to the Covid-19 pandemic hitting in early 2020, we have decided to focus only on the pre-pandemic period (2015-2019). During the pandemic, people's habits may have changed and this may have affected their decision to install an energy efficient heat pump. For example, due to restrictions regarding home office, people spent much more time in their homes and therefore used more heat and electricity than they normally would. The installation of a heat pump should thus be seen as more profitable. On the other hand, social restrictions urging households to avoid contact with others might have made people more reluctant to contact heat pump installers. The pandemic restrictions also varied over time and between municipalities and electricity price areas, affecting households differently.

The dataset from Enova is constructed by extracting data from their Power BI dashboard which is available on their website (Enova, 2022b). The Power BI dashboard shows the monthly cases that they have handled and supported from 2015 to 2022, by county and municipality (see figure 4.1). In total, Enova has paid out 959,040,748 NOK and handled just over 53,500 cases in the years 2015-2019. It was not possible to automatically download the data from the dashboard's interface. Further, Enova could not hand us data containing the location of installations, as the information could become personally identifiable. Downloading the data from the dashboard was therefore done manually, selecting each municipality one year at the time in order to see detailed installation numbers for every month.

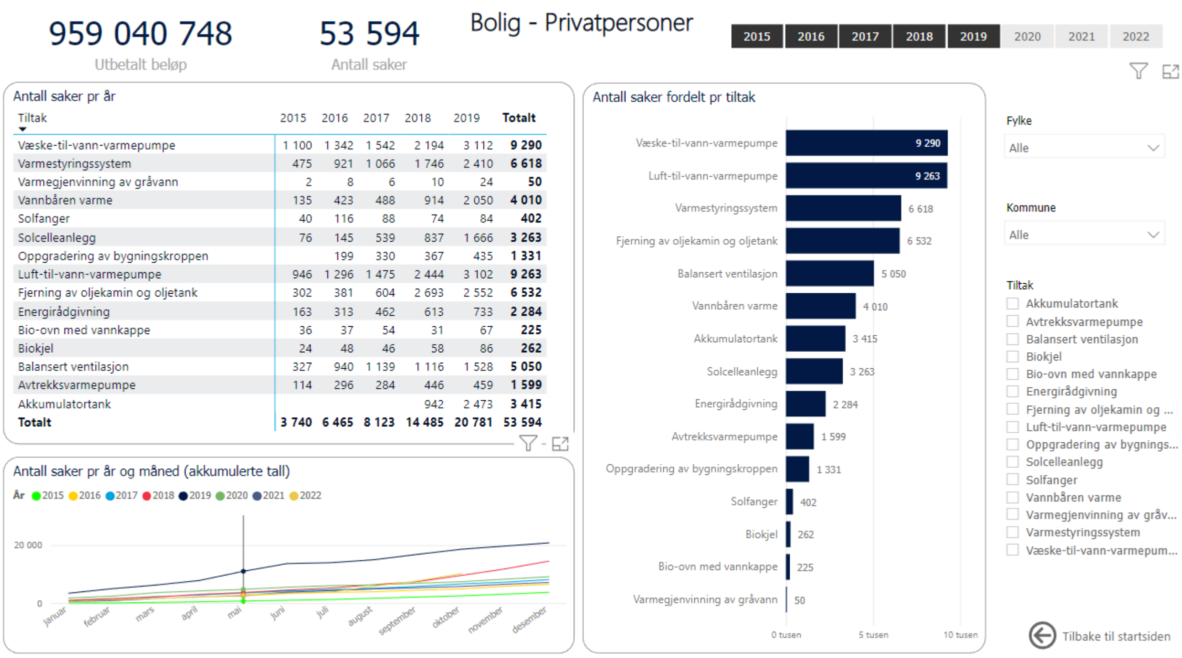


Figure 4.1: Screenshot of the Microsoft Power BI dashboard on Enova's website

We have extracted the data for monthly installations of subsidized heat pumps and removal of oil boilers and oil tanks for the period 2015-2019, for each municipality in Norway. There are no observations in January 2015, so our dataset consequently begins in February 2015. In the data cleaning process for the Enova dataset, we have manually sorted each municipality into the correct price area, using the NVE map of different price areas (The Norwegian Water Resources and Energy Directorate, 2022b). We have then summed up the monthly installations and fossil fuel removals for each area. As we present data on installations per price area and not municipality, the information we provide cannot become personally identifiable.

As presented in chapter 3.4, air-to-air heat pumps are not subsidized and data on monthly installations are therefore not available (Norwegian Heat Pump Association, 2022). If we were to include air-to-air heat pumps in our data, we would expect the impact of a price increase to be larger. An air-to-air heat pump installation is more feasible as households does not face the budget constraint due to a lower upfront cost. We will discuss the external validity of our sample in chapter 7.2.2. We still believe that the installation of more advanced types of subsidized heat pumps will be interesting to investigate. Knowing what spurs the use of Enova's subsidy offer is important in order to design good and accurate energy policies.

The data from NordPool contains hourly electricity prices for the five price bidding areas. The electricity price is the hourly day-ahead prices per price area in NOK. These numbers are updated daily in line with the day-ahead price setting. We have downloaded the average monthly spot prices for each region in Norway from 2015 to 2019. The prices are measured in NOK/MWh, but we have transformed the prices into øre/kWh as this is what is stated on the households electric bill.

The two datasets from Enova and NordPool are merged based on date and price area, allowing us to see the average monthly electricity price and subsidized heat pump installations for each region. Even though some of the municipalities are part of more than one price area, this applied only to a few. Hence, we do not believe that this will impact our results.

The total electricity cost paid by the consumer is the sum of the retail price of electricity and the distribution network tariff per kWh of electricity used. Even though the distribution network tariff may change, this remains relatively stable over the period (The Norwegian Water Resources and Energy Directorate, 2022a). This is due to the fact that the electricity distribution market is heavily regulated, and this restricts large price changes. As households can not choose their distribution network operator, it is most meaningful to study how the households respond to changes in the retail price of electricity.

We do not have access to the actual retail price faced by the household, as this is dependent on the type of contract and which is proprietary information to the retailing companies. Therefore, we have chosen to use electricity spot price as a default retail price for the price of electricity. Even though the households have the opportunity to change their electricity retailer and the type of contract they have, we consider the electricity price from NordPool to be exogenous because it lays the foundation for the price paid by customers, independent of the type of retail contract.

4.2.2 Construction of variables

In the dataset we have constructed lagged price variables for previous months. From this we constructed a variable taking the mean of the first four lags to get the average lagged price. We found this variable to be the most appropriate for our model. When adding individual lagged variables for different months, the coefficients have been inconclusive in their impact and significance. Average prices therefore appear to be more appropriate for our regression.

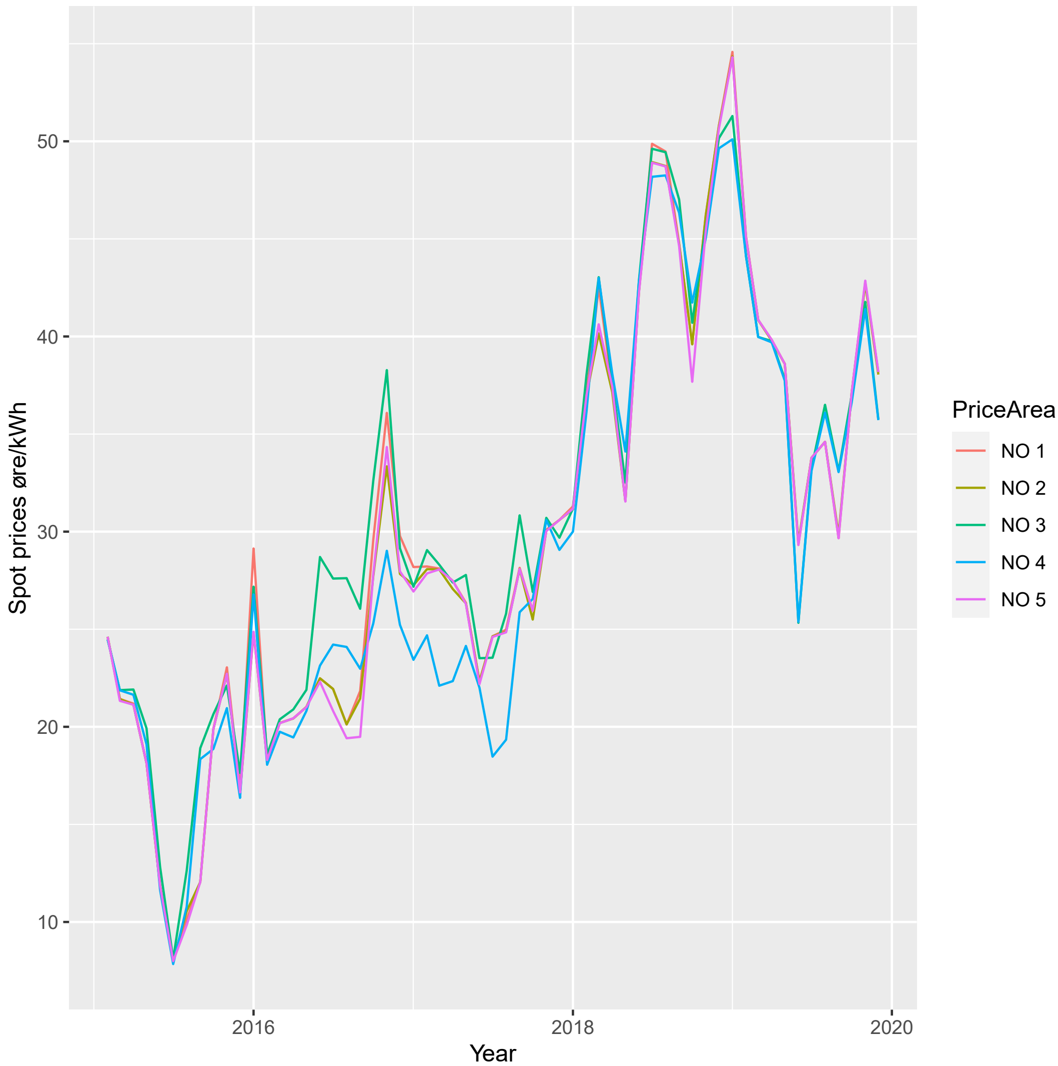
The process from a household experience the price increase until the installation is registered by Enova is natural to assume takes more than one month, but less than four. This is because the process involves an increase in the price, then deciding which heat pump to invest in, getting the right heat pump installed, sending the subsidiy application, and finally the case being registered by Enova. On varmepumpe.no, a website that collects installation options from different suppliers, private customers have the possibility to choose when they wish to have the heat pump installed (Nettbureau AS, 2022). They can choose between "as soon as possible", "within 1 month", "in 1-3 months", and "later/do not know". Adding the time from Enova receives the documentation until it is registered in the PowerBI dashboard, it is therefore plausible to assume that it in most cases will take no more than four months, but not less than a month.

If we were to add lagged price variables for a longer time period than four months, this rises the question of how long it takes from a household's attention is caught until the action of installation takes place. If it does take more time than four months, several other factors may have impacted the decision process rather than the increase in the electricity price. Further, a study from the United States on consumers response to marginal or average electricity prices conducted by Ito (2014), finds that households respond to lagged average price rather than the lagged marginal price. The study also finds that "lagged prices with more than four-month lags have negligible effects". In appendix table A1.2, we have added several average lags to our model. Only the average lagged price of 1-4 months is significant at the one percent level, in line with the findings by Ito (2014).

We do not include the price of the current month in the regression. Households usually receive and pay their electricity bill after the exact electricity consumption has been calculated. It is therefore plausible to assume that consumers are attentive to the most recent electricity prices, but not the contemporaneous price. In addition, we know that Enova uses around three weeks from a household sends them a subsidy application until it is registered and paid out (T. Brekke, senior advisor Enova, November 7th, 2022). This is further supported in appendix table A1.2, where adding the current electricity price appear to have an insignificant impact on installation of heat pumps.

4.2.3 Descriptive statistics

In the figures following below we will have a closer look on the development of the average electricity spot prices and installations of heat pumps.



Data source: NordPool

Figure 4.2: Electricity spot prices in øre/kWh from 2015-2019

Figure 4.2 shows the development of the electricity price in øre/kWh from 2015 up until 2020. We see that the electricity spot price inhabits an increasing trend. However, it varies considerably across the year, even though it does not appear to be a clear pattern of monthly seasonality. For example, July has both some of the lowest prices registered, but also some of the highest. The monthly price spikes are all temporary. The price is quite similar across the different price regions over the years, with price area NO 3 (Trondheim) and NO 4 (Tromsoe) having some larger deviations from the other areas in 2016 and 2017.

The installations of heat pumps also vary across years. Figure 4.3 depicts the installations of heat pumps in the different price areas. We have used a logarithmic scale to better show the variation within each price area over time. The pattern of installations appear to be quite equal across all the price areas. For instance, all areas experience a spike in installations in January 2019 and mid 2019. The variation in the level of installations between each price area will mostly be due to differences in number of inhabitants.

Data source: Enova

Figure 4.3: Logarithm of subsidized installations of heat pumps 2015-2019

In table 4.3 we show descriptive statistics regarding price and installations for the different price areas. All variables on price are stated in øre/kWh. We see that the maximum, minimum, and average electricity price is quite similar in all price areas.

Price area	*N*	*Price Max*	*Price Min*	*Price Avg.*	*Total installations*
NO 1	59	54.6	8.0	30.0	9525
NO 2	59	54.3	8.0	29.7	3984
NO 3	59	51.3	8.1	30.7	3302
NO 4	59	50.1	7.8	29.1	1071
NO 5	59	54.3	8.0	29.6	1679

Table 4.3: Summary statistics

5 Empirical Methodology

In this part of the thesis, we describe the empirical methodology applied to answer our research question presented in the introduction. We have considered a panel data linear regression with fixed effects to analyze the data.

5.1 Choice of regression model

Our panel data has a cross-sectional dimension, which is the different price areas, in addition to a time-dimension spanning from 2015 – 2019. As previously elaborated, the price of electricity can vary between and within the price areas. Temperature and precipitation are explanations for price fluctuations within the areas over time, as well as explanations for temporary price differences between the areas. In addition, bottle necks of the transmission grid, climate and demand can affect the prices between price areas. Some of these effects may affect both the dependent variable, *log(heat pump installations)*, and our independent variables. This would be a violation of the zero conditional mean assumption, which states that the regression's error terms need to be uncorrelated with the explanatory variables of the model in order to get unbiased results that we can causally interpret.

Our panel data is likely to inhabit unobserved time constant factors, a_i, between the different price areas, which also affect our dependent variable, y_{it}. Some factors might not be exactly, but will be close to, constant over the time period we are looking at. For instance, climate will differ between the price areas, and is likely to affect both installation of heat pumps and the electricity price. This can be seen as the composite error term, v_{it}, consisting of an idiosyncratic error x_{it} that varies over time, and the time-constant effect a_i, so v_{it}=u_{it}+a_i. Using pooled OLS will then provide both biased and inconsistent results as our explanatory variable is endogenous since $Corr(x_{it}, a_i) \neq 0$. Therefore, we will use a least square dummy variable approach (LSDV) when estimating the effect of electricity price on heat pump installations. This estimation method allows us to take the unobserved time fixed effects into account by letting the intercept across the different price areas vary. We therefore include a set of dummy variables for each cross-sectional unit. The LSDV approach will only look at the changes within each price area and not the variation between them. We use the dummy variable regression rather than a fixed effects (FE) estimation as the number of price areas are quite small, with N=5. LSDV and FE provide equivalent results, but FE will be more efficient when N is large.

By using LSDV we have corrected the model for any fixed differences between the price areas. However, we have not corrected for any omitted time-varying variables that might correlate with our explanatory variables, so that $Corr(x_{it}, u_{it}) \neq 0$. For instance, unobserved factors such as willingness to pay for electricity and heating may affect the electricity price through demand. Furthermore, willingness to pay for electricity may affect heat pump installations as a measure to reduce energy use and hence the electricity bill that will be faced by the household. As this can be varying over time, it will not be accounted for when using LSDV. Even though this can be a potential weakness and causing our dependent variable to be endogenous and thus bias our results, we assume the impact to be small.

Using LSDV to account for a_i and assuming there are no other omitted variables affecting both the dependent and independent regression variables, our regression estimations will be unbiased. In addition, we use heteroskedasticity and autocorrelated corrected standard errors (HAC).

5.2 Model specification

We aim to estimate average adoption rate while controlling for area-specific trends in installations. The following regression specification is used for our estimation:

$$\begin{aligned} log(heat\ pump\ inst.)_{it} =& \theta_1 + \theta_2 NO_2 + \theta_3 NO_3 + \theta_4 NO_4 + \theta_5 NO_5 + \\ & \beta_1 log(AP4ml)_{it} + \\ & \sum_{t=1}^{t} \gamma_t Year_t + \sum_{m=1}^{m} \mu_m Month_m + u_{it} \end{aligned} \tag{5.1}$$

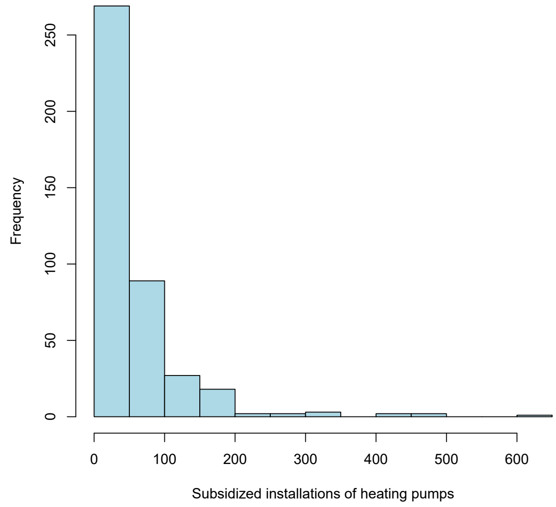
The regression has monthly, yearly, and geographical fixed effects, where April 2015 is the base period. Our main variable of interest is *AP4ml*, which is short for *Average price 1-4 months lag*. We have included the four price area dummies, leaving NO 1 (Oslo) as the base price region in order to avoid the dummy variable trap. θ_1 represents the intercept for area NO 1, while $\theta_1 + \theta_2$ gives us the intercept of price area NO 2 (Kristiansand). While we let the intercept for the price areas vary, we do not let the slope coefficients differ as we find the addition of such interaction terms to have a negligible impact.

The year dummies are meant to pick up the yearly effects that affect the installations of heat pumps in all price areas with the same magnitude a given year. We have included year dummies in the regression for several reasons. First, it captures the time left until the ban of fossil fuel heating systems. As households in the process of removing oil tanks and oil boilers were encouraged to replace it with more energy efficient heating technology, the ban is likely to have had an impact on removals and therefore also installations of heat pumps. The number of fossil fuel removals itself cannot be included in the model as it may cause a problem of simultaneity. Second, the dummies also captures the trend in the price variable. By including a full set of time dummies, we cannot estimate the effect of any variable whose change across time is constant. For example, we will not be able to pick up any effect changing on a yearly basis, such as yearly changes in the sensitivity to electricity prices.

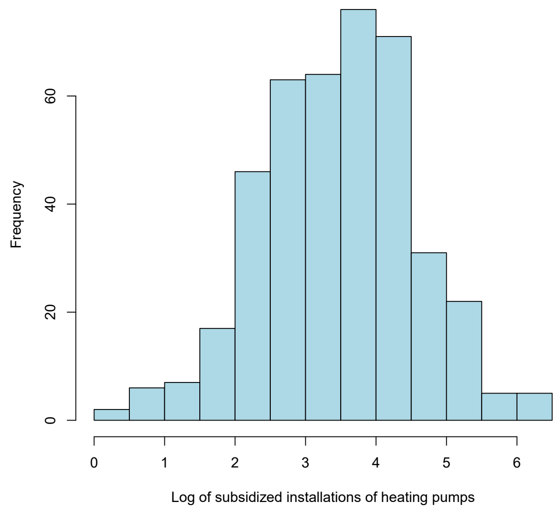
In the regression, we have also controlled for monthly effects. The role of the month dummies is to account for the fact that the installations may vary with the month of the year. For instance, temperature might affect the electricity price as well as the installation of heat pumps. Low temperatures is likely to increase the households demand for heat, making a heat pump more profitable and spurring adoption. In addition, cold weather can lead to higher electricity prices as more heat will be needed, increasing the demand. The electricity bill households face is therefore natural to assume will increase during the winter. The attention towards energy efficient heating systems may also increase in the colder part of the year since this is when there is a strong need for heating technology. We therefore find it useful to add month dummies, so that the price variables do not account for these aspects, and we can distinguish the price effect from any monthly effects.

Using a logarithmic transformation of the dependent variable in the model is a convenient way to transform its skewed distribution into becoming more normally distributed (Benoit, 2011). This is illustrated in figure 5.1. This log-transformation is also a way to account for the fact that different price areas have different population size and intercepts. An increase in electricity prices is assumed to lead to a different number of installations of heat pumps in the distinct price areas. It is therefore more natural to see the increases in the dependent variable as a percentage change rather than an absolute change, which is accomplished by doing a log-transformation.

Further, we also log-transform our main variable of interest, *AP4ml*. This let us take into account that an increase of one øre/kWh may have a different impact on installation of heat pumps depending on the price level. When testing for non-linearities in our model, we do find presence of such. Adding a quadratic price variable to the model yields a significant coefficient, supporting the presence of higher prices having a larger slope and a bigger impact on heat pump installations (see appendix table A1.3). For our main variable, we therefore look at a log-log model, allowing us to interpret the result as an elasticity. This is also in line with findings from Sahari (2019), which finds that the elasticity of demand for electric heating with respect to electricity price depends on the price level. An one percent increase in the explanatory variable, *Average price 1-4 months lag*, is then associated with a $\hat{\beta}_1$ percent change in installation of heat pumps.



(a) Installation of heat pumps



(b) Logarithm of installation of heat pumps

Figure 5.1: Histograms of the dependent variable using logarithmic transformation

6 Results

In table 6.1, we show the results from the LSDV estimation as described in chapter 5.2. The table report the variable coefficients and their HAC standard errors in parentheses. The yearly and monthly fixed effects are omitted from the regression result.

From the model we get that the effect of a one percent increase in the average electricity price leads to an increase of approximately 1.12 percent in the installation of heat pumps. This can be seen from the variable *Average price 1-4 months lag* in table 6.1. The coefficient is significant at the 1 percent level. The exact percentage change in installations can be calculated as $100 \times (e^{\beta_i \times ln\frac{101}{100}} - 1) = 100 \times (e^{1.12 \times ln\frac{101}{100}} - 1) = 1.121$ percent when the average spot price in the last four months increases by one percent. The standard error for this coefficient is 0.18, with a corresponding 95 percent confidence interval ranging from 0.94 to 1.3 percent.

As the mean electricity price for price area NO 1 is 30 øre/kWh, which can be seen from table 4.3, a price increase of one percent will then amount to 0.3 øre. This is a very small increase that we would not assume that households emphasize to a great extent. As the constant for price area NO 1 in April 2015 is 1.56 heat pumps, the increase in installations of a one percent increase in average price ought to be $1.56 \times 0.0112 = 0.0175$, which is less than one tenth of a heat pump. A 10 percent increase in average lagged price will result in a 11.27 percent increase in subsidized heat pump installations. As $\hat{\beta}_1$ captures the effect of average lagged price increases on the average installation of heat pumps, the size of the coefficient seems plausible. A small increase in the price is associated with a small, but significant, increase in heat pump installations.

For the other price areas, a one percent increase in average electricity price will lead to an ever smaller increase in heat pump installations. All the coefficients of the price areas are negative and significant when compared to price area NO 1. Holding all other variables constant, all price areas then have a lower number of heat pump installations compared to price region NO 1. For instance, price area NO 4 has approximately $100 \times (e^{-2.19} - 1) = -88.8$ % fewer installations of heat pumps compared to NO 1. The coefficients of the price areas captures the differences between the areas, which is quite substantial as seen from table 4.3. As previously argued, the huge difference between the areas is likely to be caused by differences in the number of inhabitants in the different regions, in addition to capturing any unobserved fixed effects.

Table 6.1: Regression table

	Dependent variable:
	log(Heat pump installations)
log(Average price 1-4 months lag)	1.12
	(0.18)
PriceArea NO 2	-0.82
	(0.07)
PriceArea NO 3	-1.07
	(0.08)
PriceArea NO 4	-2.19
	(0.08)
PriceArea NO 5	-1.75
	(0.08)
Constant	1.56
	(0.53)
Yearly FE	Yes
Monthly FE	Yes
Observations	275
R^2	0.82
Residual Std. Error	0.43
F Statistic	57.40
Note:	Prices in øre/kWh (HAC standard errors)

7 Discussion

7.1 Norwegian centre for research data

7.1.1 Implications of results

When designing policies to spur adoption of energy efficient technology, it is beneficial to know the main characteristics of households who have installed a heat pump. Such information can make market campaigns become more specific and better reach households who are more reluctant to invest in heat pumps. As seen from the descriptive data provided by the Norwegian centre for research data, about 30 % of the survey respondents have installed a heat pump.

Households most frequent to install a heat pump are characterized by a higher average number of people in the household and living in an owner-occupied detached house. These characteristics will therefore increase the probability of having a heat pump installed. More household members using electricity or living in a larger dwelling will increase the amount of heating needed, therefore affecting the net present value of investment as potential energy savings are larger. The difference between e_0 and $\mathbb{E}(e_1)$ in equation 2.2 is therefore expected to increase with these characteristics. A higher initial demand for electricity, e^0, makes the potential savings from installing a heat pump larger, as expected electricity demand after the installation, $\mathbb{E}(e_1)$, decreases. The net present value of energy efficient installation therefore becomes more positive, all else equal.

We find that income and education do not have an impact on the prevalence of heat pump installations in Norway. The studies of both Sahari (2019) and Mills and Schleich (2012) found that education has a great impact on energy-efficient technology adoption, and Schulte and Heindl (2017) finds that high-income households respond more to changes in energy prices than low-income households. There are several explanations for why our data differs from what appears to be the main characteristic of households investing in energy-efficient technology found in other studies. As argued in chapter 4, higher income, education, house type and form of ownership are all likely to correlate to some degree. Therefore, form of ownership and house type may capture the effect stemming from higher income or education. Further, regulatory policies to spur adoption of energy efficient technology may be different between countries, having an impact on which households undertake such investments. Another explanation is related to the Norwegian population's attitudes towards energy conservation, as seen from Mills and Schleich (2012). Norwegian households may be more informed and aware of financial aspects such as the electricity price and energy use, leading to greater investment in energy efficient technology in the population as a whole regardless of education.

Even though the data from NSD shows no difference in income and education levels regarding having installed a heat pump, the sample from Enova might be different. Installation of a heat pump supported financially by Enova may cost up to 120 000 NOK, while the NSD data also include those who have installed an air-to-air heat pump, which is considerably cheaper. When searching for heating alternatives, in stage two of the decision making process, the Enova subsidy would imply a reduction in investment cost b in equation 2.2. As it is more likely that low-income households face budget constraints, a subsidy can alter their investment decision. However, we would argue that the costs are too high and the subsidy is too small for this to happen. Low-income households also tend to be less price sensitive to changes in the electricity price, as shown by Schulte and Heindl (2017). This may suggest that low-income households are living closer to a minimum and not changing their behavior as a result of a higher electricity price. Even though we are not able to observe the characteristics of those who apply for a subsidy from Enova, it is plausible to assume high-income households are the ones who apply.

7.2 Enova and NordPool

7.2.1 Implications of results

From our estimated regression, we find that a price increase of one percent in the average electricity price over the past four months is associated with a 1.12 percent increase in installations. Thus, the effect of an increase in the electricity price appears to be influential on the decision regarding subsidized heat pump installations in Norway.

Our results are in line with the price elasticities estimated by Sahari (2019) and Schulte and Heindl (2017): people are indeed sensitive to changes in the electricity price. Our estimated elasticity of 1.12 percent is relatively similar to the price elasticities of electricity found by Sahari (2019), but larger than the results from Schulte and Heindl (2017) which is in the range of -0.43 and -0.5. The reason why Sahari (2019) and Schulte and Heindl (2017) find negative elasticities is that the alternative heating sources to a large degree are non-electric, and not necessarily heat pumps that uses electricity more efficiently. However, their estimates relates to our study as adopting an energy-efficient heat pump can be regarded as a measure to save energy and consequently reduce the demand of electricity. Norwegian households appear to substitute away from electric heating and towards energy efficient technology as the electricity price increases, reducing their demand for electricity in the future.

In our data, we only observe temporary price increases. Even though we believe temporary price increases have an impact on heat pump installations, the effect should not be relatively large. When the electricity prices are quite low, which generally has been the case in Norway, the consciousness and information gathering about current and future prices is not likely to be very large. In addition, the large upfront cost can result in less rational behavior. Our findings of an elasticity of 1.12 percent still seems plausible, especially when seen in relation to the low base number of installations in April 2015. So, what might be explanations for why increases in electricity price affects the installations of heat pumps?

One explanation for the result is that changes in electricity prices, even temporary ones, change the household's expectation about future energy prices. Consumers with myopic expectations will incorporate a higher future price for future time periods, rather than the previous prevailing price. This implies that the subjective expected future electricity price $\mathbb{E}[p_t]$ increases. From equation 7.1, we see that the payback-time of the investment will decrease, holding all other factors equal. This leads to a higher net present value, and the installation therefore appears to be more profitable, thus spurring adoption. A temporary price increase can make the expectations change as people are reminded about the possibility that electricity prices indeed can change, and that the experienced low price will not necessarily proceed in the future. Consumers therefore appear to be myopic in their price expectations, leading them to invest in energy saving technology.

$$\Delta NPV_i = \frac{(e^0 - \mathbb{E}[e^1])\Delta\mathbb{E}[p_1]}{1+r} + ... + \frac{(e^0 - \mathbb{E}[e^{t+T}])\Delta\mathbb{E}[p_{t+T}]}{(1+r)^{t+T}} > 0 \tag{7.1}$$

Another explanation for our significant results is that the temporary increase in the price of electricity induces households to search for information on energy efficient technology. Thus, a price spike leads them to enter what would be the second stage of the two-stage process described in part 2.1.2. When considering the alternatives of different heating systems, the households are likely to become more attentive to the benefits of installing a heat pump. Information pages and different digital tools make the potential energy savings more salient and accessible. When households gather information on the potential energy savings, higher electricity prices may shift the households' attention from short-term costs to long-term benefits. The price increase makes households more interested in dampening the costs the next time there is a price increase, and encourages the household to take the time and effort to find alternative heating options.

When households are inattentive or uninformed about the potential energy savings they may forego the investment. Assuming that the investment in a heat pump is a net positive investment, inattention leading to underinvestment implies that Pareto improvements can go unrealized (Sallee, 2014). If households demand too little energy efficient technology because of inattention, then any measure that will increase attention toward efficiency can help reduce the energy efficiency gap. If households were perfectly rational and fully informed those who face a positive net present value should already have installed a heat pump. A temporary price increase should then not affect the level of adoption. However, as we do see such an effect, households' subjective net present value may change by focusing their attention towards long-term electricity savings.

High, but in our study unobserved, discount rates can make the investment unattractive to some households, as consumers may be reluctant to invest when they do not see a quick payback time (Walls, 2014). However, research has shown that people behave inconsistently and apply different discount rates depending on the time frame of when the benefits accrue (Fehr, 2002). People tend to be impatient when the benefits arise in the near future, but for events that are far enough in the future, people are prepared to be patient. As argued by Fehr (2002), one explanation for why behavior is inconsistent when considering short- and long-term behavior is that, throughout evolutionary history, future rewards have been uncertain. Most of the rewards from energy savings take place in the far future, which is why we might see an increased adoption rate when the electricity price increases. People may want to commit to this type of investment to be sure to be able to save money in the future.

7.2.2 Robustness and limitations

As seen from regression table 6.1, the coefficient of *Average price 1-4 months lag* is significant and positive. Its direction and magnitude also appears to be reasonable. Still, there are several factors that might have impacted our results.

Our data is only on the households who have applied for and received a subsidy from Enova. Thus, our sample may be more attentive and informed compared to the rest of the population. The fact that people request a subsidy might be a sign that they are better informed. It could also be that people who are better informed also are more attentive to the energy prices and economy measures. If this is the case, the nature of our data may have contributed to biasing the adoption rate upwards compared to the general population. In addition, our sample is likely to have a higher income than the general population due to the high up-front cost of installation, as argued in chapter 7.1.1. The external validity of our sample might therefore be low, making it hard to apply the results to the population as a whole.

Another question is if the included time-dummies sufficiently capture the effect of the ban against oil tanks and oil boilers. If the removals of these correlate with electricity price in addition to their removal being accelerated by the ban, this can interfere with our results. Our analysis may then suffer from low external validity, where the presence of the ban makes it hard to apply the results to the time after the ban took effect.

We have corrected the model for any fixed effects between the price areas that may affect our results. But, as explained in chapter 5, we have not corrected for any omitted time-varying variables, such as willingness to pay for electricity, that might correlate with our explanatory variables. Thus, our regression may be underspecified, causing biased results. We could control for endogeneity by using IV-estimation, but due time constraints it has not been possible to account for this in our thesis.

Another drawback of our analysis is that we lack information on the exact moment of the decision regarding energy efficient installations, and instead conduct our regression based on when Enova register the installations. We have assumed that it takes about four months on average from the decision is made until the installation and registration has been completed, but this may also take shorter or longer time. Since *Average price 1-4 months lag* is over a time period of four months, it will be somewhat imprecise for estimating the attention effect electricity price may have on installations. The lack of precision between the moment of decision making and Enova's registration may cause the impact of the coefficients to be reduced, as it becomes harder to capture the direct effect of a price increase on the action of installing a heat pump.

When adding the lagged price variables independently and not as an average of multiple months, we get contradictory results where some coefficients are significant and negative, while others are significantly positive. This is an indication of multicollinearity, where the prices are too highly correlated to separate the individual monthly effects on installations of heat pumps. Adding additional average lags to our model supports the fact that separating the price effect between the different months is difficult, as seen from appendix table A1.2. When adding different variables, such as the current electricity price and average lagged prices for month 5-8 and 9-12, the level of significance and magnitude of these coefficients change. Only the variable we include in table 6.1, *Average price 1-4 months lag*, is consistent and significant at a one percent level.

In addition, it should be highlighted that the data from Enova is collected manually. Errors might therefore have occurred, both regarding the number of installations, but also on categorizing the municipalities into the correct price areas. If such errors do exists, it may impact all of our coefficients in any direction, depending on which manual error that has happened. For instance, registering that some municipalities installed more heat pumps than they actually did due to typing errors will likely cause an increase in our main variable of interest. The occurrence of such errors ought to be small but should still be mentioned.

8 Conclusion

In this thesis, we have explored if temporary electricity price shocks affect the adoption of heat pumps. In order to answer our research question, we have used a least square dummy variable approach with price area, yearly and monthly fixed effects to estimate the impact of electricity prices on the level of installations of subsidized heat pumps. From our results, we get that an average increase of one percent in the average electricity price over the previous four months is associated with an increase of 1.12 percent in installations. The effect of an increase in the electricity price appears to be influential on the decision of heat pump installation. In addition, we have looked at household characteristics that appear to be associated with a higher prevalence of heat pumps.

The direction and significance of our regression result is in line with much of the presented previous literature on energy efficient technology adoption. The impact of electricity prices on heat pump installations may be due to myopic price expectations, where a household adjusts their future price expectations as a result of an increase in the current electricity price. Their perceived profitability of investment will then increase. The presence of myopic expectations can possibly lead to an inefficiently high incentive to invest, as households who in reality do not face a positive net present value choose to invest due to inaccurate beliefs about future prices.

Another explanation is that the temporary price increase induce households to search for information on energy efficient technology. It might lead them to emphasize the long-term gains of heat pumps rather than the short-term costs, thus spurring adoption. The increased adoption rate will then be desired as long as the information gathering does not come at the expense of information acquisition on other important aspects. If the higher adoption rate following a price shock is driven by a higher degree of information acquisition, it can be valuable to design policies which inform the public about the potential electricity savings from investing in energy-efficient technology. Making information salient and available will reduce the costs of gathering information. This way, the potential of behavioral interventions to reduce electricity consumption can be realized.

Our results indicate that households indeed are sensitive towards changes in electricity prices. Even though we find that price shocks result in an increase in heat pump installations, actions other than installing a heat pump can be done by the household to reduce their future electricity price variations and dampen the effect of future price shocks. For instance, choosing fixed price contracts will reduce the future uncertainty and act as an insurance against future price increases. This may then reduce or remove the effect of myopic price expectations and any presence of inefficiently high adoption. At the same time, fixed electricity prices can reduce the increased information acquisition which follows a price shock and the following adoption in energy efficient technology.

The data provided by the Norwegian center for research data shows that the number of persons in the household and living in an owner-occupied detached house are characteristics that appear to correspond with the installation of energy efficient heating technology. As a large fraction of dwellings in Norway are detached houses Statistics Norway (2022a), this can indicate that there is a great potential for heat pump installations in Norway. Policies should therefore aim at reaching house owners of detached dwellings. Even though these characteristics are for the Norwegian population as a whole, it might not be valid for the data from Enova on subsidized heat pumps, as these advanced heat pumps demand a high up-front cost.

Further research could look at the effect of electricity price fluctuations on other types of energy efficient technology, preferably with a lower cost of installations than heat pumps. One could also use more detailed data and link households and their characteristics to their investment in energy efficiency. In addition, it would be of interest to see how the more long-lasting increases in electricity prices in 2021 and 2022 have impacted the installation of heat pumps and other energy efficient technologies.

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Appendices

A1 Additional regression tables

A1.1 Logistic regression

The regression is estimated by using a logistic regression, where the dependent variable is a dummy taking the value 1 if the household has reported owning a heat pump. Base characteristics in the presented regression are no education, male, owner-occupier, detached house and the base region is Oslo and Akershus.

Table A1.1: Logistic regression

	Dependent variable:
	Heatpump_installed
Age	0.004
	(0.001)
Income	0.00
	(0.00)
Household members	0.13
	(0.02)
Ed: Lower secondary	−0.95
	(0.65)
Ed: Upper secondart, basic	−0.83
	(0.65)
Ed: Upper secondary, final year	−0.81
	(0.65)
Ed: Post-secondary	−0.89
	(0.65)
Ed: Higher education (undergraduate)	−1.00
	(0.65)
Ed: Higher education (graduate level)	−1.24
	(0.65)
Woman	0.01
	(0.04)
Housing cooperative	−0.52
	(0.1)
Tenancy	−1.02
	(0.07)
Row house	−0.83
	(0.07)
Duplex house	−0.78
	(0.06)
Apartment building	−2.50
	(0.10)
Hedmark and Oppland	0.62
	(0.08)
Rest of Østlandet	0.44
	(0.06)
Agder and Rogaland	0.84
	(0.06)
Vestlandet	0.80
	(0.06)
Trøndelag	0.84
	(0.07)
Northern Norway	0.64
	(0.07)
Observations	18,021

A1.2 Regression with additional lags

Table A1.2

	Dependent variable:	
	log(Installations)	
	(1)	(2)
log(Price)	-0.16	
	(0.19)	
log(Average price 1-4 months lag)	1.31	1.09
	(0.24)	(0.31)
log(Average price 5-8 months lag)	0.53	0.77
	(0.28)	(0.36)
log(Average price 9-12 months lag)		0.49
		(0.3)
PriceArea NO 2	-0.8	-0.78
	(0.07)	(0.08)
PriceArea NO 3	-1.09	-1.1
	(0.08)	(0.09)
PriceArea NO 4	-2.18	-2.13
	(0.09)	(0.1)
PriceArea NO 5	-1.71	-1.67
	(0.08)	(0.09)
Constant	0.18	-2.32
	(0.78)	(1.33)
Yearly FE	Yes	Yes
Monthly FE	Yes	Yes
Observations	255	235
R^2	0.829	0.825
Residual Std. Error	0.42	0.42
F Statistic	51.22	47.70
Note:	Prices in øre/kWh (HAC standard errors)	

A1.3 Checking for non-linearities

Table A1.3

	Dependent variable:
	log(Installations)
Average price 1-4 month lag	-0.05
	(0.03)
(Average price 1-4 month lag)^2	0.001
	(0.0004)
PriceArea NO 2	-0.82
	(0.05)
PriceArea NO 3	-1.03
	(0.06)
PriceArea NO 4	-2.20
	(0.06)
PriceArea NO 5	-1.76
	(0.07)
Constant	5.01
	(0.34)
Yearly FE	Yes
Monthly FE	Yes
Observations	275
R^2	0.84
Residual Std. Error	0.40
F Statistic	62.20
Note:	Prices in øre/kWh (HAC standard errors)