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DETERMINANTS TO DECREASING CO_2 EMISSIONS IN THE SWEDISH RESIDENTAL SECTOR

An empirical analysis of the policy instruments

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Abstract

In the light of increasing awareness of households' energy-related behaviour and their response to environmental policies, it is important to analyze those instruments that have achieved their objective to promote proenvironmental behaviour. Carbon dioxide (CO_2) emissions from the Swedish residential sector have decreased heavily since the 1990s, mainly due to households replacing their oil fired-boiler for an alternative heating system. With a panel data set on the actual number of oil-fired boilers in Swedish detached houses at district level from 1998 to 2012, this paper presents empirical evidence on the conversion decision of the households. Possible explanatory factors to the rapid conversion rate include increasing price of heating oil and specific policies targeted at fossil based heating such as a CO_2 tax, an information campaign and a conversion subsidy. The purpose of this paper is to study if these factors have a significant impact on the stock of oil-fired boilers in Sweden. The analysis applies a fixed effect panel data model and the results indicate that a higher oil price including the CO_2 tax, both alone and in interaction with its substitution price, and the information instrument have a significant negative effect on the number of boilers in use, while the subsidy does not. Following the results we will discuss the policy implications, in Sweden and beyond.

Key words: residential heating, environmental policy, CO2 emissions

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Contents

1. Introduction

In 2010 all industrialized countries made a commitment at the United Nations Climate Change Conference, to design national long-term strategies in order to reach lower CO_2 emissions. The European Commission set the goal for Europe to decrease the union's emissions with 85-90 percent by 2050 (Naturvårdsverket 2014). As a consequence, Sweden is obliged to report their emission level every second year both to the European Union and the United Nations Framework Convention on Climate Change, UNFCCC. The report should include what measures are being taken to decrease the emissions and declare how efficient they are. These reports are performed by the Swedish Environmental Protection Agency (EPA).

Upon request from the EPA, we were asked to perform a subanalysis for the coming report in 2015 on the underlying factors that contributed to the decreased carbon dioxide emissions from the residential sector. In 2007, the emissions from the residential sector had decreased by 70 percent since 1999 (Naturvårdsverket & Energimyndigheten 2007), mainly due to a shift away from oil based heating, in form of oil-fired boilers, towards other residential heating systems (RHS) such as central district heating and heat pumps (Naturvårdsverket & Energimyndigheten 2007). Several policy instruments were implemented to target these oil-fired boilers since the 1990s, yet there has been no thorough evaluation of the effect of the policies while interacting.

The creation of cost effective policies relies on the experience from previously implemented instruments. However, it is challenging to learn from a particular policy if it is deployed in a package, an instrument mix, since its effect needs to be disentangled. The Swedish residential sector is an example where such a mix is believed to have had an effective result. Furthermore, as heating accounts for 37 percent of all energy consumed in Sweden (Naturvårdsverket & Energimyndigheten 2006) it plays an important role in climate change mitigation strategies. The strong decrease in the sector's emissions could prove important lessons for future attempts to induce structural technology shift. This paper presents empirical evidence on the replacement decision of the households.

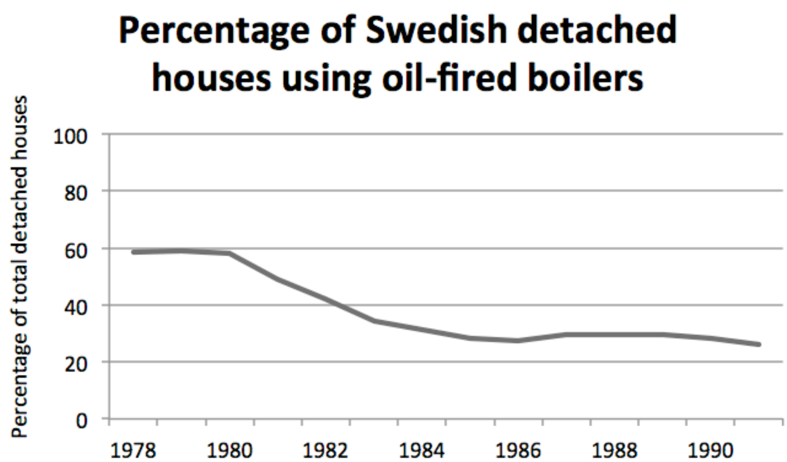
To obtain specific information regarding the policy and the targeted technology, interviews were conducted with government staff at several agencies, and a data set was constructed containing the actual number of oil-fired boilers in Swedish detached houses at district level. The aim of this thesis is to empirically answer what policy instruments did have a significant impact on the replacement rate of oil-fired boilers within the residential sector in Sweden.

2. The oil-fired boilers in Sweden

The oil-fired boilers were a common heating system in the mid 1900 century all over Sweden. In the beginning of the century up until 1940, approximately 15 percent of all houses built were installed with an oil-fired boiler to heat the resident (SCB 2006). The two following decades, 1940-1960, the oil heating systems gained popularity and more than a quarter of all houses built were equipped with one. The trend remained up until the beginning of the 1970s, yet from this point there was a strong decline in share of houses that were built with this type of residential heating system (RHS) (SCB 2006). The decline was mainly due to the oil crises in the 1970s and the national investments in nuclear power. In general, the oil dropped from being the primary energy source in society, accounting for almost 80 percent the energy supply in 1970, by about one-third partly due to the expansion of nuclear power 1973-1985 (Nilsson, Åhman & Nordqvist 2005). This implied that other heating alternatives became economically preferable to oil and from 1980 onwards, the number of houses built with boilers were negligible (SCB 2006).

The boilers became politically interesting in the beginning of 1990s as the debate about the fossil dependence intensified and resulted in a policy instrument. An energy tax targeting all sources of energy had been introduced decades earlier, yet this tax was mainly implemented for fiscal reasons (Ekonomifakta 2014). A carbon dioxide tax was implemented in 1991 and this excise duty aimed directly at lowering the carbon dioxide emissions. It was therefore not only a source for a greater fiscal income for the state, but instead an instrument targeted at lowering the demand of fossil fuel by making the good significantly more expensive to consume. A decade later, in 2001, a green tax reform was implemented meaning the carbon dioxide tax was heavily increased (Naturvårdsverket 2004). In 2012, the carbon dioxide tax consisted of 26 percent of the total price a household would pay for one unit of heating oil.

As the graph below shows, there has been a steady decline in the number of existing oil-fired boilers in the residential sector from the 1970s to the early 1980s without any policy targeting the RHS specifically. Recent national data show that almost 84 percent of the existing boilers in 1998 were converted by the end of 2012. This is explained by approximately 30,000 to 40,000 oil-fired boilers annually being replaced by alternative heating systems (Boverket 2008). Reports suggest that this steady conversion rate is a result from the increasing price of heating oil throughout the decade, due to the higher world market price of oil and the heavy taxation. Today, due to the high operating cost of a boiler it is economically viable for virtually all Swedish detached houses that serve as a permanent home to replace their boiler for an alternative RHS (Boverket 2008).



Graph 1: Percentage distribution of Swedish households with an oil-fired boiler.

Source: Mahapatra & Gustavsson (2008), SCB (2006)

When switching from an oil-fired boiler to a residential heating system (RHS) based on alternative energy, there are numerous alternatives. The most common replacement alternative is a heat pump (Boverket 2008), meaning that the household use electricity as input to extract heat from another element. Geothermal heat pump, air heat pump and earth heat pump are just some subcategories, and these are highly effective. In fact, heat pumps can obtain the same indoor temperature using three times less energy in kWh as an oil-fired boiler (Energirådgivningen 2014), meaning the operational cost for a pump is rather low. Another popular alternative to oil boilers is district heating. However, in Sweden, this choice is only available if the municipality or a private firm decides to invest in the area. Hence, it is more common in densely populated areas. Unfortunately, no actor in the market has kept data on the expansion of the district heating network on municipality level. The last alternative is a boiler using biofuel such as firewood or pellets as fuel which is an inexpensive alternative for rural households that have access to the woods (Energirådgivningen 2014). Investment cost, operating cost and efficiency level have evolved differently for each alternative during the period of study. This makes it challenging to model the substitute price for a boiler taking all alternatives into account.

In order to reach the political goals of the residential independence of fossil fuel, the Swedish Energy Agency financed a nationwide information campaign called the 'Climate and energy consultation' that was implemented on a large scale in 2001. This initiative aimed at providing impartial information to the households about heating alternatives that serves both the financial situation for the households as well as the climate. The service is mainly provided through telecommunication and the households are provided with both substantial information as well as direct cost calculations for individuals who wish to change or improve their residential heating. Aside from heating alternatives, the programme also provides advice on how to improve energy efficiency, for example residential insulation. From the start up until 2012, the total cost for this policy has been more than 900,000,000 SEK for the government (Energimyndigheten 2014).

Despite political instruments as the carbon taxation and the Climate and energy consultation, the annual conversion rate was considered to be too low and the oil-fired boilers were prioritized on the political agenda (Boverket 2008). A subsidy was implemented in 2006 as an instrument policy to speed up the conversion rate. The aim was to give financial support to households replacing their oil-fired boiler for another alternative. Since a new heating system is a substantial investment, the politicians wanted to lower the threshold for a switch. The government planned to issue 450,000,000 SEK during a period of five years, however, the funds were exhausted in just one and a half year. During the year that the subsidy was available, an additional conversion of 37,000 boilers was made in excess of the annual 30,000-40,000 (Boverket 2008). The Swedish National Board of Housing, Building and Planning performed an evaluation in 2008 of this political policy stating that the instrument was received as ad hoc by the public.

As a last remark on the declining oil-fired boiler stock, we were informed, throughout interviews with experts at the Swedish EPA, about two other potential explanatory factors to the successful decrease of boilers. The first one is a possible rise of environmental awareness among the Swedish public, since the threat of global warming gained recognition. A survey shows that 52 percent of the responding Swedes felt guilty when making a lifestyle choice that would negatively affect the environment (Naturvårdsverket 2009). The second potential explanatory factor could simply be that the expiration date of the boilers and the political agenda to remove these coincided. The life span of an oil-fired boiler is estimated to 30 years (Boverket 2008, Energirådgivningen 2013). Spot check data from the Swedish National Board of Housing, Building and Planning shows that the average boiler replaced with the subsidy was installed in 1975, indicating that the average existing boiler would pass its durability in 2005. We are therefore lead to believe that this story of success is not only due to policy instruments and the fact that is was economically viable for households to switch, but also is a matter of timing, as the oil-fired boilers were expiring after the beginning of the new millennium.

Hence, there are a number of factors that potentially could have caused the decline in the number of oil-fired boilers, such as the high oil price, implementation of carbon dioxide tax, the consultation programme and the conversion subsidy.

3. Current state of knowledge

In this section we will firstly explore the literature on energy and appliance choice, including RHS, and the analytical methods used. In the second part we examine the literature on the energy efficiency gap and reasons why individuals are reluctant to switch to more cost efficient, and environmentally friendly, appliances even though it is economically viable. Lastly, we will study what previous research says about designing policies and their instrument to overcome the resistance to switch; and to promote renewable energy. An instrument, e.g. a subsidy or a tax, is the means of an environmental policy to reach an identified goal (Stavins 2003).

3.1 Previous literature on choice of appliance and residential heating systems

There are numerous examples of economic literature on fuel alternatives, energy appliance choice and choice of RHS (Michelsen & Madlener 2012). When analyzing the choice decision of consumers with regard to energy appliance or residential heating system, the discrete choice method is often used with data on household level (e.g. Dubin & McFadden 1984, Nesbakken 2001). Two recent articles about the German space heating consumption both perform a discrete choice analysis using a multinomial logit model. Braun (2010) studies what determines a household's space heating type with three sets of variables as potential influences, namely building, socio-economic and regional characteristics. He finds that house characteristics influences the type of RHS installed, except for electric heating, and income has a weak influence. Further, the number of household members and regional variables, influence the choice of RHS. Michelsen & Madlener (2012) study homeowners' preferences for adopting innovative residential heating systems. They present an exhaustive literature survey on energy appliance choice and categorize the most common explanatory variables into four categories: socio-demographic-, home- and spatial characteristics; and RHS specific attributes. The authors themselves use 27 explanatory variables from these categories in their study. Examples of the most common explanatory variables are household income, age of the house, climate zone and the economic aspects specific to the RHS such as operational costs and possible grants. A disadvantage with the logit models just presented is their difficulties in capturing the complex dynamic process involved in the decision of buying a new appliance since it only accounts for the next period in time (Fernandez 2001). A proposed solution is the random-parameter, or mixed logit model, since it can allow for repeated choices over time. For example, Revelt & Train (1998) modeled households' choices of appliance efficiency level, by following the same individuals across several periods in time using panel data.

Despite the popularity of the discrete choice models, other methods of analysis should be mentioned. Fernandez (2001) argues that a duration model is preferred since it allows for a richer relationship between characteristics of the durable good, the likelihood of its replacement and the household's socioeconomic factors. The article by Fernandez (2001) does not include oil-fired boilers explicitly, however she studies space heating including gas, electricity and coolers. She concludes that both household demographics and product features have statistical power to explain the replacement decisions over time. One of the most interesting conclusions is that higher operation cost of the existing heating system correlates with the likelihood of replacement. Further, the study shows that the operation costs affect the timing of the replacement primarily through unobserved factors such as the product efficiency. As a last remark, the study concludes that variables such as household income, family size or urban location do not seem to affect the replacement decision.

3.2 Previous literature on the energy efficiency gap

The studies mentioned so far in this section assume fully rational agents. However, there is a recognized failure among consumers to make rational cost-effective investments in energy efficiency, which is commonly referred to as the energy efficiency gap[1] (Gillingham & Palmer 2014). Even though the term energy efficiency gap refers to the gap between the higher actual and the lower optimal energy use (Jaffe & Stavins 1994), as opposed to energy type, the issue is still relevant to this study since the

[1] Gillingham & Palmer (2014) provide an extensive overview of recent literature on the energy efficiency gap.

choice to switch from oil implies a cost-effective investment, and in most cases an improvement in energy efficiency e.g. when switching to a heat pump.

Behavioural economics is increasingly used to explain how behavioural anomalies contribute to the gap but empirical evidence show that market failures is still an important explanatory factor. Examples of these market failures explaining the gap include imperfect information for consumers, the principal-agent problem (e.g. tenant makes the decision on how much energy to consume while the landlord pays), credit constraints as the consumer cannot pay the upfront cost and lastly regulatory failures, since for example market regulation for electricity results in prices that differ from marginal cost (Gillingham & Palmer 2014). The same gap can also be explained by behavioural anomalies. Nonstandard preference is such an anomaly referring to agents displaying self-control problems with time-inconsistent preferences, meaning that they may have trouble staying with a decision that would yield a higher reward in the future. Other behavioural anomalies used to explain the gap would be nonstandard (systematically incorrect) beliefs and lastly nonstandard decision making, which includes limited attention and suboptimal heuristics. The concept of limited attention means that individuals sometimes make complex decisions based on merely a subset of the available information. To use suboptimal heuristics is another way to simplify decision making by using rules of thumb based on previous experience that lead to a suboptimal choice.

To simplify, the phenomena of behavioural anomalies can be described as consequences of consumers facing cognitive constraints and using heuristics to make decisions (Gillingham & Palmer 2014). It is in the policy makers' interest to link the behavioural anomalies and market failures to the energy efficiency investments, to improve related policies and address the gap. Policies used in this purpose include economic incentives, information strategies and energy efficiency standards (ibid 2014).

3.3 Previous research on environmental policies

In the last part of the literature section we will take a closer look at what previous research have found regarding effectiveness of policies addressing the energy efficiency gap and incentives to switch to renewable energy. We will investigate economic incentives and information strategies since these policies could effect a conversion decision, whereas energy efficiency standards rather apply to new appliances that are required to meet minimum efficiency levels. Evidence show that both economic incentives and information strategies can make a difference under the right conditions (Stern 1999), which we will return to by the later in this section. Economic incentives include taxes, cap-and-trade systems and subsidies. The most direct approach to decrease negative environmental externalities caused by a high energy consumption is to increase price of energy by taxes on emissions or the energy itself (Gillingham & Palmer 2014). Stern (1999) states that economic incentives have been proven to impact the most important environmental consumer behaviours, such as investments in home insulation and heating systems. Further, also non-monetary economic incentives have significant effect on consumer behaviour, such as carpools or travel lanes especially for buses. He concludes that combining non-monetary and monetary incentives increases the efficiency of them.

In attempts to address behavioural anomalies, the reliance on subsidies has increased (Gillingham & Palmer 2014). Subsidies may take the form of grants, rebates, tax incentives and low cost loans for purchase of energy efficient equipment. However, subsidies aiming at energy efficiency have received criticism for being funded by distortionary environmental taxes (Gillingham & Palmer 2014, Heffner & Ryan 2010). When designing incentives in form of subsidies, one needs to be cautious since there are some subsidies believed to promote inefficient and environmentally unsound practices (Stavins 2003). Subsidies that promote new technology, e.g. in form of an appliance, do not discourage the use of polluting technologies, as opposed to policies that raise the price of emissions (Jaffe et al. 2005). Secondly, technology subsidies can result in an excessive cost per unit of effect, due to the problem of *free riders* who would have bought the targeted technology even without the subsidy. This effect is partially offset by so called *free drivers* who purchase the product since their awareness was raised by the existence of the subsidy (Gillingham & Palmer 2014). The problem of free riders is larger for technologies that already occupy a certain share of the market and is thus quite known to consumers, and smaller for very new technologies which are less known to consumers and relatively expensive compared to substitutes (Jaffe et al. 2005).

Information strategies are intended to address information market failures and non-optimal behavioural patterns by providing information on the benefits of proenvironmental behaviour. Product labelling is one form of information provision, which has been used for example on new cars to label their fuel (Gillingham & Palmer 2014). Information programmes have been shown in many studies to be fruitless, however small positive effects have been observed when the information programme is designed to incorporate theory from the fields of communication, social influence and human decision making. For example if the information is accompanied by a reminder of the social norms supporting the desired behaviour (Stern 1999). An information programme that use social norms to pressure consumers to reduce their energy consumption is when the consumer is provided with a report that compares its own energy consumption with its peers. Costa & Kahn (2013) find that such a programme has a significant effect on energy consumption and specifically that the size of the effect depends on political ideology. Hammar & Jagers (2003) find that individuals in Sweden who vote for the Green Party are the only party sympathizers who support a higher taxation on burning of fossil fuel, indicating that these voters are more likely to change their consumption behaviour in favour of less environmental impact. To summarize, with regards to information, if carefully designed and delivered it can modestly alter certain kinds of behaviour related to the environment (Stern 1999). However, it has had little impact on the most environmentally important household consumption behaviour such as the purchase of water heaters or automobiles (Stern 1999).

Researchers have studied how to best combine these instruments and the effects from their interactions. Studies show that large instrumental opportunities are missed when failing to combine the strengths of different instruments (Stern 1999). Further, he focuses on information and economic incentives to promote proenvironmental behaviour and finds that the effect from economic incentives can be increased when combined with appropriate information interventions. For example, the effectiveness of an incentive may depend on how well it is explained to people. One implication of his findings is that once an economic incentive is large enough to convince individuals that it is beneficial to change behaviour, it can be more effective to invest in improved information than to increase the incentive. Furthermore, if increasing the incentive beyond this point, *crowding out* may occur, meaning discourage those individuals with an intrinsic motivation who would have done it without any economic incentive.

4. Model

In this section, we present a basic model, which captures the intuitive logic of when a household will choose to switch their oil-fired boiler to an alternative RHS.

Consider a household which consumes the fixed amount of heating *x,* and *y* units of other goods, with the utility function $U(x, y)$. Since the household is limited in its consumption by the income, the household decides upon the consumption level of *x* and *y* facing a budget constraint:

$$x + y = I$$

The amount of heating needed in a household is assumed to be constant. In this model, the residential heating system (RHS) has oil as input at the initial stage. Further, the household is assumed to be rational in the sense that they wish to maximize the consumption of the *y* units of the other good.

The household is now presented two different types of input sources to their RHS, *oil* or *alternative energy*. Assuming both types of fuel are as efficient and provide the same level of utility, the household will choose the input source that will maximize the consumption of *y* units of the other good. Hence, the household will switch heating system if the operating cost of oil is higher than the operating cost of the alternative.

$$replacement \ \ iff \ \ oil \ > alternative$$

However, there are additional costs related to switching from oil to an alternative energy source that a household will take into account. Replacing the RHS requires a substantive investment and this will be considered by the household before switching. Further, extensive knowledge about alternative systems is required before taking the decision and a certain level of cognitive ability is needed to calculate the breakeven point of the investment with associated lower operating costs. When adding these factors to the decision equation, the household will switch heating system if the operating cost of oil is higher than the sum of the operating cost of the alternative input, the search cost and the investment cost.

$$replacement\ \ iff\ \ \ oil\ > alternative\ +\ search\, cost\ +\ investment\ cost$$

This expression can be rewritten as:

$$replacement\ \ iff\ \ \ oil - alternative\ >\ search\, cost\ +\ investment\ cost$$

Assuming that the household is rational, the model now predicts that if the price difference of oil and the alternative input is greater than the costs of seeking information and investing in a new system, the household will decide to switch.

Considering that there are still boilers installed in Swedish detached houses despite its cost inefficiency and with regards to the presented literature in Section three, the model must capture that households may act irrationally, in other words that they perceive the investment cost and search cost differently. Each household has a respective randomly distributed γ factor associated with their search cost. A higher γ implies a higher cost, or resistance, to obtain new information and take decisions based on it, which could be due to cognitive constraints, limited attention or the use of heuristics. The households also have a randomly distributed ϕ associated with their investment cost. A higher ϕ implies a higher resistance to the investment cost which could be explained by nonstandard preferences or a high risk aversion. With the resistance factors, the replacement equation can be described as:

$$replacement\ \ iff\ \ \ oil - alternative\ >\ \gamma\ (search\, cost)\ +\ \phi\ (investment\ cost)$$

Since the Swedish government set the goal to break the fossil fuel dependence for heating purposes in the residential sector by 2020 (Boverket 2007), they have created policy interventions targeted at all of the variables in the model above. Firstly, by introducing a carbon dioxide tax on fossil fuel, the difference of the cost of oil and alternative increased, promoting a switch. Further, by implementing the Climate and energy consultation, the cost of seeking information has been lowered and the information barrier is now at a minimum level. Lastly, the subsidy in 2006, lowered the investment cost for installment of a new RHS. Our model concludes that these three policy instruments should lower the threshold of when the switch from fossil heating to a renewable alternative system occurs. We aim to empirically examine if these policy interventions had the impact that the model predicts.

5. Data

5.1 Dependent variable

In this paper, the dependent variable is the number of existing boilers. By the national fire protection regulation, all oil-fired boilers have to be inspected and have maintenance biennially (Statens räddningsverk 2005). The inspections are reported to the Swedish Civil Contingencies Agency who has the national responsibility for these statistics. They have gathered the data since 1998 in their database, which we were granted access to (MSB 2009). According to the reporting system, the number of inspected boilers are reported to the fire department, which is not always at the municipality level. In some densely populated areas, the fire department have the responsibility for several municipalities clustered into the same department. Our data set therefore consists of observations for 183 districts, in which all 290 Swedish municipalities are included (see Appendix), during a period of fifteen years, 1998-2012. In the analysis, each district is viewed as an individual. Yet, data is missing on a national level for the years of 2004 and 2005 due to a reorganization of the responsible agency. Further, we have only included the data of boilers under 60 kW, meaning that we consider boilers in the residential sector installed in detached homes. Hence oil-fired boilers in neither apartment block buildings nor industries have been included in the set. One potential issue with the dependent variable is that we found notes in the database about manpower shortage among the inspectors. This results in a lower number of reported boilers in some years due to missed inspections and not due to replacements. As the districts later employed more staff, the number of boilers in use are reported to be increasing. The data then indicates that households installed new boilers, even though that was not the case. However, after close examination of the data, these issues did not seem to cause significant problems. With regards to the fire protection regulation, the variable will be used with a one year lag to capture the effect of the independent variables better.

5.2 Independent variables

The table below provides an overview of the variables included in the dataset. In the following paragraphs, each independent variable will be described in more detail. All variables are selected with motivation of the findings presented in Section 2 and Section 3.

Variable	**Description**
Boiler	Number of inspected boilers
Oil price	Total price of oil [öre/kWh]
Electricity price	Total price of electricity [öre/kWh]
Consultation	Annual consultation budget per district [SEK]
Subsidy	Payment per district [SEK per eligible house]
Income	Average income per district [SEK]
Green votes	Percentage of votes for the Green Party per district in each election

Table 1 : Variable description

Oil price

Firstly, we will include the price of residential heating oil as an independent variable in the regression. Households face a total oil price consisting of i) the net price of oil, ii) the carbon dioxide tax, iii) energy tax on heating oil and lastly iv) the value-added tax (VAT). The four components of the price varies only over time and not across individuals as the price is the same within the nation. A fifth component would be the distribution cost of getting the oil delivered to the house. Yet, since this cost is negligible for virtually all locations, we have chosen not to include it in the variable. The net oil price data was obtained from the Swedish Petroleum and Biofuel Institute (SPBI 2014), which records the yearly average price of one cubic metre heating oil. The net price includes the production cost and the gross margin. The price of the carbon dioxide tax, the energy tax on heating oil and the VAT, both per cubic metre of oil, was found at the Swedish Tax Agency's department for excise duty (Skatteverket 2014). All prices were given in SEK per cubic metre, but we converted it into öre per kWh to facilitate a comparison with the price of electricity. Further, these prices were adjusted to real prices with 1998 as a base year.

Electricity price

There is a variety of alternative residential heating systems, operating on different forms of energy. As discussed in Section 2, both investment and operating cost for the alternatives have changed significantly over the period of study. Furthermore we do not have annual household data on what the converting households switched to. However Boverket (2008) provides data on the most common replacement alternative when converting with funds from the subsidy. Among them, 43 percent, the largest fraction, replaced their boiler with some type of heat pump which all run on electricity. Therefore we will include electricity price as the substitution price of heating oil. The electricity price consists of both the market spot price and an energy tax. Some regions in northern Sweden are subject to a lower energy tax on electricity due to the fact that they are situated closer to the large rivers with hydropower plants (Energimyndigheten 2014). Hence, the total electricity price does not only vary over time, but also over districts. The yearly mean net price on electricity in Sweden[2] is obtained from Statistics Sweden (SCB 2013) and the energy tax rates are obtained from the Swedish Tax Agency's department for excise duty (Skatteverket 2014). All prices are adjusted to real prices. As a last remark, we want to clarify that there might be an issue to only consider the alternative operational cost and not the investment cost for replacing the boiler. Yet, since the latter is highly volatile for different type of heating pumps, it has not been taken into consideration. Instead, we have added another independent variable to the model to capture the household's willingness to invest in a new heating system.

Consultation

Thirdly, the information programme Climate and energy consultation is included. The data were channeled through a contact at the Swedish Energy Agency and contains the allocated budget per municipality from 1998 to 2012. When examining the data, it became clear that the size of the budget differs a lot between municipalities, but also that municipalities with a lower population receives a relatively higher budget than densely populated municipalities, meaning a lower per capita budget in highly populated districts. This has been interpreted to be due to a high setup cost for delivering the services, and a low marginal cost to serve an additional user. Hence, dividing the budget per capita

[2] The electricity net price was the same nationally until November 2011, then the electricity spot price was differentiated over four regions in Sweden. Considering the last year in our data set is 2012 we will not take into account this division since we have lagged the dependent variable, i.e. the number of boilers.

will not capture the correct effect of the consultation. Instead, this variable will be expressed as the total SEK allocated annually to each district in real prices.

Subsidy

The data set on the subsidy payments was constructed by an employee at The Swedish National Board of Housing, Building and Planning for this study specifically with data originating from their database. We received observations on the amount of payments during the period that the policy was active, namely in 2006 and the first half of 2007. When considering that the subsidy was ad hoc in its implementation and that it was available one and a half year, we concluded that it is most accurate to view the subsidy as a one-time event. Hence, the variable is lagged with one year so that the entire effect would be captured during the following inspection. There is a risk with not differentiating the subsidy over the two years, but since our data on the number of boilers lacks in timing precision, we believe it is the most accurate to include all the households who converted with funds from the subsidy in the same year with one year lag. Lastly, we decided to express the variable as the total amount of subsidy payments in each districts, divided by the number of houses built before 1975 in the area. Dividing the payments by capita would be incorrect since some municipalities have a larger proportion of the population living in apartment block buildings, which are not eligible to the policy. It is only small residential houses built before 1975 that are included in the pool of potential users of oil-fired boilers since houses constructed later are highly unlikely to have an one installed (SCB 2006) due to the emergence of nuclear power from 1973 (Nilsson et al. 2005). After examining the data we found that the amount distributed per eligible house varied across districts, indicating that some districts were more eager to apply than others. To summarize, the variable will be expressed as the total amount of SEK paid to each district, adjusted to real prices, divided by the number of eligible houses in each district, lagged with one year.

Average income

We have chosen to add the average yearly income to capture the socio-economic characteristics of each district. A richer district can be assumed to have a larger financial possibility to do investments in an alternative heating system. Further, a higher income may correlate with higher education, which can reflect a greater knowledge about the benefits of switching to renewables. Again, since our dependent variable is aggregated, we have chosen to also include the average annual income at the district level. For districts with several municipalities, we calculated the unweighted average to obtain the yearly mean income at district level. The data on annual average income on the district level were retrieved from Statistics Sweden and adjusted to real prices (SCB 2012).

Green votes as a proxy for environmental awareness

The last independent variable aims to capture the attitude of the households. Since annual data of the Swedish population's true environmental awareness is missing, we have to use a suitable proxy. In the literature, we have found that sympathisers for the Swedish Green Party are in favour for more stringent environmental politics, which indicates that these voters have a higher environmental awareness than others. Hence, we collected data from Statistics Sweden (SCB 2010) on the number of Green votes per municipality from the elections in 1998, 2002, 2006 and 2010. The votes were divided by the municipality's population at the time for the election, times the election participation rate in each election. The variable is therefore the percentage of the district's population voting for the Green Party in each election.

5.3 Excluded variables

Prior empirical research commonly use climate zones as an explanatory variable when determining the RHS (Michelsen & Madlener 2012). At an initial stage of our research, we considered including the yearly mean temperature of each district, to investigate what impact the climate has on the conversion decision. A household in a district with a longer and colder winter is likely to be more sensitive to the operational cost of its RHS than households in a district with shorter and less cold winters. However, the Swedish Meteorological and Hydrological Institute's does not provide data on average temperature on municipality level during a longer period of time free of charge. Hence, we will not include a temperature variable.

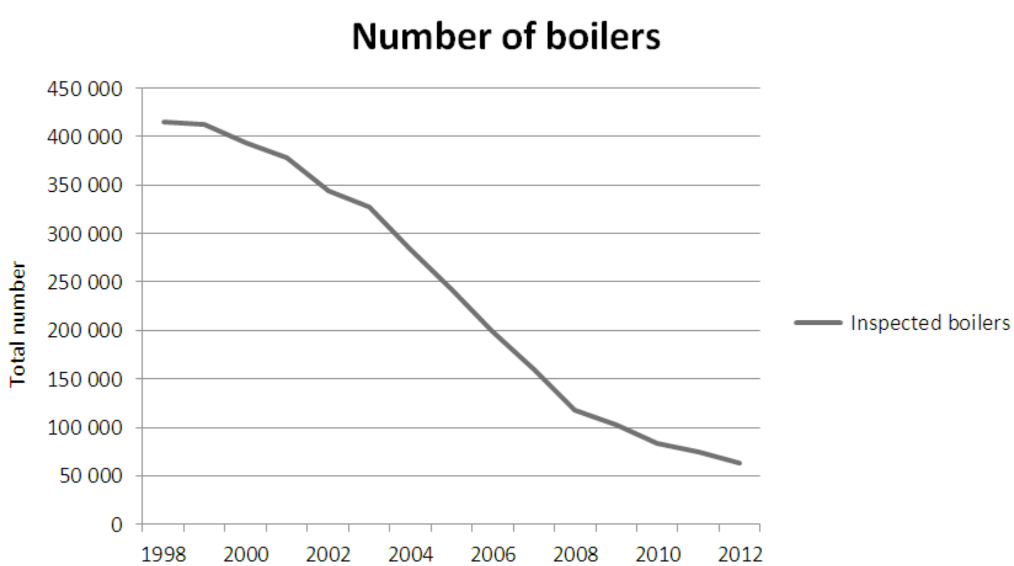
Another important factor in the replacement decision would be the age of the boiler. An average lifetime of a fired-oil boiler is 30 years (Boverket 2008, Energirådgivningen 2014). At the end of its lifetime, the household is likely to be less resistant to change for another RHS than when it is still operating. However, there has been no data collected on the age of boilers currently installed in Swedish households. Between 1940 and 1970, oil-fired boilers were one of the most common RHS being installed in newly built houses (SCB 2006). Consequently, we considered taking the age of the house as a proxy for the age of the boiler. Furthermore, both Braun (2010) and Michelsen & Madlener

(2012) found that the age of the house is a significant determinant of the choice of RHS. However, there is no data on municipality level of houses being constructed before 1975, i.e. the time period when the boilers were being installed. Given this lack of data, and the failure to find a valid instrument, we abandoned the idea to include the age of the boiler. Additionally, Boverket (2008) concludes that roughly 70 percent of the boilers being replaced as a result of the subsidy in 2006, had been produced later than 1970, indicating that many boilers had been replaced since the original installation and therefore making the house age an invalid proxy.

Lastly, we have not included the substitute price for other alternatives apart from the heat pumps i.e. electricity price. As previously discussed in Section 2 and in Part 5.2 there is not enough sufficient data to include all the substitute prices.

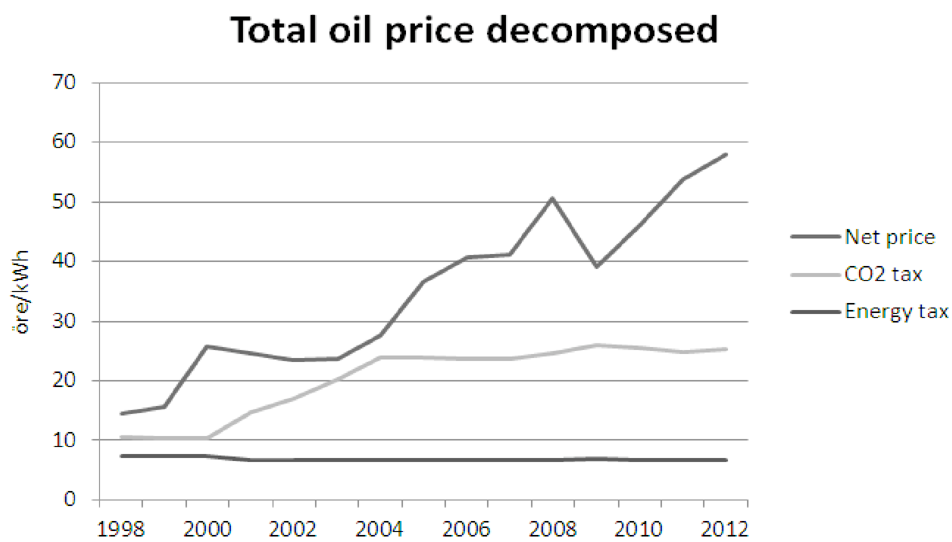
5.4 Descriptive statistics

In this part we will graphically show how some of our variables have developed over time. As described in Section 2, the number of boilers has decreased since the 1970s. In Graph 2, the number of boilers inspected during the studied period of 1998-2012 is presented. As shown, there has been a steady decrease during the last 15 years and only a fraction of the oil-fired boilers still remain in use.



Graph 2 Number of boilers in Sweden, for the years 1998-2012

Source: MSB (2009)

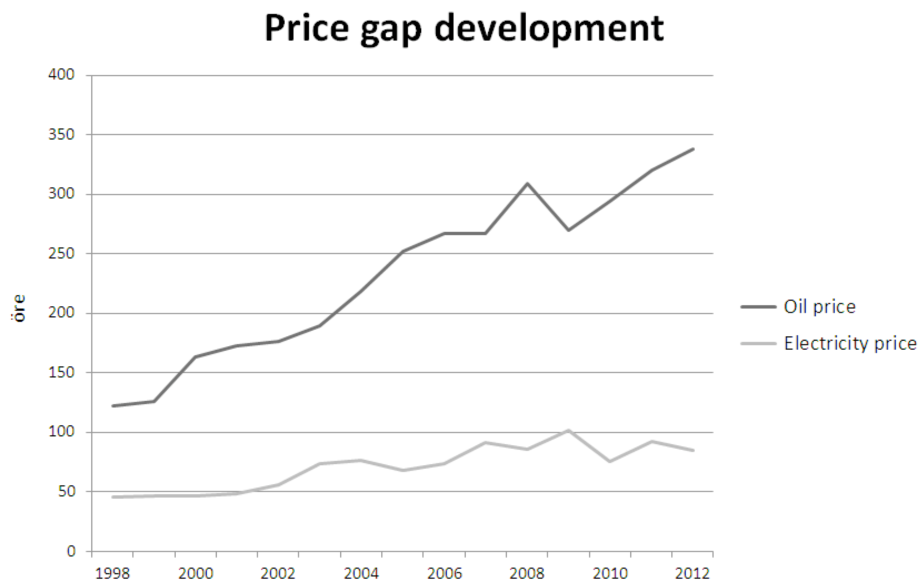


Graph 3 Total oil price decomposed into factors, 1998-2012.

Source: Skatteverket (2014), SPBI (2014)

Secondly, a graph of the total oil price decomposed into factors is shown above in Graph 3. In absolute terms, the energy tax has nearly remained the same during these fifteen years, meaning that this tax is relatively less important. The carbon dioxide tax was increased in the beginning of the century, yet leveled out since 2004 and has almost remained the same in absolute terms during the second half of the studied period. The net price, on the other hand, has increased drastically due to an increasing market price of oil. Except the dip in 2008 due to the financial crises, the net price of heating oil has a steady upward trend. The last component of the total price of heating oil is the VAT. Since this factor is 25 percent of the other factors combined, it only reflects their price development and has therefore not been included in the graph.

The last graph gives an intuition of the cost gap that a household faces when deciding to heat the resident with a boiler running on heating oil compared with the most common replacement choice, namely a heat pump running on electricity. The cost gap captures the combination of a sharp increase of oil price at the world market and the fact that a resident using oil needs three times as much energy in kWh compared to when using a heating pump, as the latter technology is three times more efficient. Hence, this is the cost gap between the heating alternatives that a household face when needing a constant amount of energy for heating.



Graph 4 The energy input cost gap between oil and electricity based heating, 1998-2012.

Source: Skatteverket (2014), Skatteverket (2013), SPBI (2014)

6. Empirical Methodology

6.1 Research question

The aim of the thesis is to answer if the variables i) oil price ii) consultation, iii) investment subsidy, iv) income or v) Green votes had a significant negative impact on the stock of oil-fired boilers in Sweden.

6.2 Panel data model

Our data contain observations from 183 districts in Sweden over fifteen years, 1998-2012. Since the sample of individuals is large and the years are few, a panel data regression is considered the most appropriate. With a panel data model, we can control for individual fixed effects, i.e. effects that are common across time for a particular district but might vary across different districts. Such factors can be unobserved or unmeasured, and examples are geographic location, infrastructure or intelligence level (Wooldridge 2008). Hence, panel data allows us to control for factors that could cause omitted variable bias in a cross section data regression.

6.3 Regression model

In this section we will link our theoretical framework from Section 4 to our regression model. In order to answer the question above, our basic regression model is defined as below. The variable of total oil is not decomposed into its components since the household will only face the total price. Hence, the replacement decision will only be based on the total price.

$$lag\_boilers \ = \ \beta_0 + \beta_1 total\ price\ of\ oil + \beta_2 consultation + \beta_3 lag\_subsidy + \beta_4 income + \beta_5 green\ votes\ + \varepsilon$$

However, a household is likely to also consider the operational cost of the substitution when making the replacement decision. Hence, an extended regression model was made to capture the dynamics of the difference of oil price and the price alternative (i.e. electricity price in this study), just like the basic model in Section 4. Households are likely to base their replacement decision on the comparison not only on the current oil and electricity price, but rather the price development of both over the last year. Therefore we will include an interaction term between the two variables, which is the price difference in oil subtracted with the price difference in electricity.

$$price\ difference = (p_t^{oil} - p_{t-1}^{oil}) - (p_t^{electricity} - p_{t-1}^{electricity})$$

Hence, the variable *total oil price* in the basic regression will be replaced by the variable *price difference*. Apart from this, the extended regression model has the same variables as the basic model, i.e. *consultation, subsidy, income* and *Green votes.*

$$lag\_boilers \ = \ \beta_0 + \beta_1 price\ difference + \beta_2 consultation + \beta_3 lag\_subsidy + \beta_4 income + \beta_5 green\ votes + \varepsilon$$

7. Results

7.1 Basic regression

The result of the basic regression is presented in the table below. As doing a regression on a panel data set, we performed a Hausman test to secure a consistent estimate. Random effects were rejected due to inconsistency, hence fixed effects was applied on the regression. Consistent standard errors have been provided with the command robust, which controls for hetroscedasticity (Wooldridge 2008).

Basic Regression

VARIABLES	(1) Boilers	(2) Boilers	(3) Boilers	(4) Boilers	(5) Boilers
Total oil price	-30.616**	-22.116**	-22.116**	-22.478**	-12.812**
	(2.918)	(1.930)	(1.930)	(1.948)	(4.812)
Climate and Energy Consultation		-0.002**	-0.002**	-0.002**	-0.002**
		(0.000)	(0.000)	(0.000)	(0.000)
Subsidy				0.186	0.104
				(0.155)	(0.186)
District mean income					-0.017+
					(0.009)
Percentage of Green voters					-13,026.533*
					(6,325.281)
Constant	3,790.605**	3,654.399**	3,654.399**	3,693.365**	6,354.405**
	(230.205)	(178.632)	(178.632)	(180.848)	(1,491.217)
Observations	2,148	2,148	2,148	2,124	2,124
R-squared	0.317	0.401	0.401	0.403	0.420
Number of districtid	183	183	183	181	181

Robust standard errors in parentheses
** $p<0.01$, * $p<0.05$, + $p<0.1$

Table 2 presents the result of the first regression.

Source: writers' work

Firstly, the fuel price is found to have an important effect on the choice of the residential heating system. On a 1 percent significance level, an increase in the oil price by one öre/kWh will result in a decrease in the number of existing boilers by 12.8, holding everything else constant. The coefficient decreases from 30.6 when adding more regressors and removing these from the residual. The results show that the households are indeed affected by the operational cost when choosing whether to convert or not. At the same significance level, the coefficient of consultation also has a negative impact on the number of boilers. For one more unit (SEK) spent on consultation, the number of boilers will decrease with 0.0018 per district on average, holding everything else constant. The result is stable when adding more variables to the regression. Hence, the regression shows that the policy instrument of consultation has made an impact on the replacement decision. As for the investment subsidy, there are no significant results. When looking at the two last explanatory variables not subject to an instrument, the coefficient for the average income is only significant at a 10 percent level. Given the low significance level it may be futile to draw any conclusions. The results weakly imply that an increase of the district's average annual income by one SEK, would result in a decrease of the number of boilers by 0.015 per district, holding everything else constant. At the 5 percent significance level, the number of votes on the Green Party has a substantial impact on decreasing the number of boilers. The results suggest that one percentage point increase of votes for the Green Party in a district, will decrease the number of boilers with 13,026 per district, holding everything else constant.

7.2 Extended regression

As described in Part 6.3, an extended regression model was created to better capture the replacement decision of a household. The result of the extended regression is presented in the table below. Once again, the fixed effects gave the consistent estimate and robust standard errors have been used.

Extended Regression

VARIABLES	(1) Boilers	(2) Boilers	(3) Boilers	(4) Boilers
Difference in oil and electricity price	-0.885+	-5.972**	-7.237**	-3.166**
	(0.453)	(0.969)	(1.005)	(1.080)
Climate and energy consultation		-0.003**	-0.003**	-0.002**
		(0.000)	(0.000)	(0.000)
Subsidy			-0.679**	0.078
			(0.161)	(0.155)
District mean income				-0.038**
				(0.004)
Percentage of Green voters				-13,111.039*
				(6,376.781)
Constant	1,375.973**	2,241.051**	2,271.963**	9,262.044**
	(0.170)	(92.609)	(93.231)	(748.564)
Observations	2,148	2,148	2,124	2,124
R-squared	0.000	0.278	0.280	0.415
Number of districtid	183	183	181	181

Robust standard errors in parentheses
** p<0.01, * p<0.05, + p<0.1

Table 3 presents the result of the second regression.

Source: writers' work

When looking at the estimates from the extended regression, the coefficient of the interaction term for the price development of oil and electricity tells us how the stock of boilers is affected by a change in the oil price over the last year subtracted by the change in electricity price over the last year. Our results show that the variable has a significant impact on the number of boilers, at a 1 percent significance level. An increase of the price gap by one öre/kWh will result in a decrease of the number of existing boilers by 3.17 per district, holding everything else constant. The coefficient changes magnitude when adding more variables, due to a smaller residual. However, since the estimate is highly significant and does not change too much, it indicates a rather robust result. Again, the coefficient of consultation has a negative highly significant impact on the number of boilers. For one more unit (SEK) spent on consultation, the number of boilers will decrease with 0.002 on average per district, holding everything else constant. The coefficient remains quite stable when adding regressors, but decreases from 0.03 to 0.02 when adding the last two regressors. This is the same coefficient that we obtained from the basic regression, further suggesting that the result is rather robust. Regarding the estimate of the subsidy, it is not significant even at the 10 percent level. We interpret that, since the subsidy variable becomes significant only in one out of all models, the estimate is somewhat unreliable to interpret. The only coefficient that differed largely across the models was average income, since it becomes strongly significant at the 1 percent level in this regression. One more SEK in average annual income, would result in a decrease of 0,038 number of boilers per district, holding everything else constant. Lastly, our results for Green sympathisers are very similar in both the basic and the extended regression. At the 5 percent significance level, the results show that one percentage point increase of Green votes, will decrease the number of boilers with 13,11 per district, holding everything else constant.

8. Concluding discussion

This thesis aims to empirically evaluate the policy instruments targeted at the oil-fired boilers in Sweden. By first reading a substantial amount of literature on the subject and conduct interviews with experts, relevant variables have been selected and data from a vast amount of sources have been collected into a panel data set. Regressions have then been performed to see whether the empirical data support the prediction of our basic model.

We conclude that we obtained robust results from our regressions, which are coherent with the literature in the field of RHS in general and development of oil-fired boilers in Sweden in particular. As shown in the tables in Section 7, information spread, environmental awareness and lastly the price of oil, both alone and in interaction with its substitution price, are significant determinants of the number of boilers in Sweden. Income differed in significance between the two regressions, while the subsidy does not seem to have any significant effect on the stock of boilers in neither model. In this section we will discuss some of the potential weaknesses of our study and how our results can be used for future policy design.

8.1 Validity

Our results seem to be robust, yet there must be internal validity in order to say that they have causality. Firstly, there are shortcomings with regards to our data. As discussed in Section 5 the record over boilers from the Swedish National Board of Housing, Building and Planning seem to contain some flaws, specifically that a lower number of inspection staff is associated with a seemingly lower number of boilers. However, after closely examining the data set, these errors are shown to be minor. Moreover, such measurement errors are not likely to be correlated with the regressors, thus should not create any bias. We chose to lag the dependent variable as well as the subsidy. To sum up, we hold that the fire safety data used to specify the dependent variable, and the specifications we used for the policy variables and control variables such as income, altogether constitutes an accurate model specification. Thus, given our research on the conversion factors, our panel data set with a fixed effects model is the most suitable alternative to ensure internal validity to our knowledge.

Thirdly, our regression model leaves out a couple of important variables, such as the age of the boiler and the operational prices of other RHS substitutes apart from electricity price. These variables will end up in the residual. The variable for weather is controlled for with fixed effects, with respect to geographical differences. However, weather differences between years are still unaccounted for. Nevertheless, with regards to literature, the most important variables are specified in the regression and we evaluate any correlation between the omitted variables and the included ones to be unlikely. Hence there should not be any risk of omitted variable bias. Another problem might be that the proxy for environmental awareness is too vague, thus effecting the residual. If another party positioned close to the Green Party in certain green topics during one election, our variable might fail in capturing the environmental awareness. Ideally, this could have been solved by examining all the parties' green positions in the four elections, yet this assignment was considered too big for this study. Another topic related to internal validity is selection bias. But since all 290 municipalities in Sweden, clustered into the 183 districts, were included in the data there should be no risk of sample selection bias. In this kind of studies simultaneous causality bias may be present, since there might be some correlation between the regressions and the dependent variable. It could be thought that the policy maker's decision to commence the implementation of the subsidy policy instrument is likely to have been influenced by the number of existing boilers. However, as shown in Graph 2 there is a steady decline in boilers throughout the period, and there is no particular reason to assume that this specific level of stock of boilers in the few years preceding the subsidy policy would have affected the implementation decision in any strong way. It could also been thought that the money spent on the other policy instrument, the consultation programme, may be influenced by the conversion rate. However the risk of simultaneous causality for this variable should be small, since the consultation service also aims to inform about other topics, such as effective insulation.

Another potential issue could arise from the fact that we only have aggregated data at district level. This may cause problems since some clustered municipalities that are geographically close, might differ in socio-economical terms. This could be solved by dropping some of the most heterogeneous clustered districts from the regression. We chose however not to do so since such influences are likely to be leveled out through the dataset, and because these potential issues were considered to be outweighed by the benefits of having a larger dataset. Moreover, we would ideally have had data at household level including observations on the discrete choice the household made, i.e. to what alternative RHS the household switched to, and individual characteristics such as an even more precise measurement of environmental awareness, as well as the age of their boiler. Such data would have enabled a discrete choice analysis with a mixed logit model which is an appropriate method for RHS choice models.

Further, with regard to our method's shortcomings, we want to raise the potential issue of how the the resistance to adapt another technology has changed over these 15 years as the pool of households has changed. The households replacing their boiler in the beginning of the period studied, in 1998, could possibly be thought to be less resistant to switch for an alternative RHS than a household converting in 2012. Yet our panel data model cannot correctly capture this change in resistance level over time. However, other variables included in the model such as income and geography may well control for the effects of such potential resistance. In any case we investigated the possibilities to perform a difference-in-difference analysis for both instruments of consultation and subsidy. With that approach we could have studied the effect of the instruments by comparing a treatment group, who was subject to the instrument, with a control group that did not receive any treatment, i.e. consultation or subsidy. A difference-in-difference method is preferable since it provides a stronger causal relationship between policies and the impact when the characteristics of the household pool are changing over time. For example, we could have compared the effect of the subsidy on households that received it, with households whose application was rejected. Those two groups of households, both having applied for the subsidy but only one receiving it, are alike in the sense that they applied for the same subsidy and thus had the same resistance level. Another approach would be to find control groups based on potential regional differences in implementation timing. Unfortunately, the subsidy was implemented simultaneously across the country, and control districts could therefore not be found. The Swedish National Board of Housing, Building and Planning confirmed that the implementation only differed a couple of days at most between districts. Hence, a difference-in-difference approach to evaluate this instrument cannot be performed. Similarly, the consultation programme was implemented simultaneously across the country in 2001 except for 19 municipalities which started the consultation as late as in 2011. A control group of only 19 individuals out of 183 was considered far too small for such an approach. Yet, as the possibility has been scrutinized and no qualified control group could be found, this method had to be abandoned.

Nevertheless, with regards to both the data and the method's shortcomings, due to the reasons explained we still conclude that this study have internal validity, hence our estimates show an accurate causal effect on the stock of oil-fired boilers.

As a last remark, it is uncertain if this study would have external validity, meaning if the same results would be obtained if performing the analysis on another population or in another setting. Nevertheless, the subject of external validity is highly relevant for this study as the conclusions may be used as guidelines for other EU countries in their progress towards fossil fuel independence in the heating of their residential sector. Due to country specific characteristics, the results from this case study might differ if applied to other countries. Sweden is highly dependent on reliable RHS due to the long and cold winters. Hence, Swedish households might be more willing to switch heating systems as the volume of oil needed is larger than for households in other countries, implying that the investment is paid back faster here. Further, Sweden's electricity market differs from continental Europe e.g. due to access to hydro and nuclear power, implying that the price gap between oil and electricity price is higher than in other countries. Lastly, the attitude toward environmental issues among both Swedish households and politicians might differ considerably across EU countries. Nevertheless, the results of this study may still be sufficient as guidelines for other EU countries. As the laws, regulations and policies in the environmental field within EU are consolidating, the setting become more alike across the countries. Hence, the efficient instruments in Sweden are likely to have the same negative impact on the stock of boilers in other EU countries even if the estimates might differ slightly.

8.2 Policy implications

Our results are interesting when returning to the design of the policy instruments. The carbon dioxide tax has been targeted directly at the burning of fossil fuels, hence inhibiting the consumption of heating oil. Our results are in accordance with previous research claiming that it is an efficient mean for policy makers to change consumers' behaviour. Moreover, households do seem to consider the difference in price trends of substituting heating inputs. This is interesting from the policy makers' view, as the carbon dioxide tax is essential when politically wanting to determine the price gap between heating oil and its substitutes. Considering that the CO_2 tax has been rather constant in absolute terms since 2004, while the net price of heating oil drastically increased, there might be a possibility for the tax to follow the net price's development. Hence, our result can open up for the opportunity for policy makers to increase the relative importance of the CO_2 tax by initiating an even higher carbon dioxide tax. This would result in a lower threshold for a switch in the household's decision process of determining their RHS.

The results can also be used to evaluate the two other policies that the government implemented to target the oil-fired boilers. As stated before, 450,000,000 SEK was spent on the subsidy, which lasted for little over one year and 900,000,000 SEK was allocated on the consultation policy throughout 15 years. Our study concludes that consultation has been a successful policy, while the subsidy had no significant impact.

As seen in Section 3, policy makers need to be careful when forming a subsidy. If providing grants to households that would have converted even in the absence of the subsidy, the public funds will be used inefficiently due to these so called *free riders*. The free rider effect is more likely to become a problem when the target of the subsidy is well-known to the consumers and economically beneficial to them. Both these criteria were met when the subsidy was implemented, since the majority of households who had a boiler in 1970 already had converted and it was economically beneficial to most households due to the high oil prices. Considering that those households who had not yet converted in 2006, the year when the subsidy was implemented, had a high resistance to switch, i.e. a high φ factor in our theoretical model, the subsidy could have been more efficient if taking that fact into account. For example, the subsidy could have been targeted at low-income households or districts who might have difficulties in paying the upfront cost associated with the investment.
Alternatively, if aiming for a free driver effect, e.g. to affect households who display unwillingness to do research for themselves, then it could have been beneficial to focus more on information provision. Further, considering that risk averse households are likely to be positively influenced in their conversion decision when they observe the positive outcome of their peers, why not target areas where relatively fewer had converted previously? To conclude, the subsidy would have benefited from being targeted at certain households or areas, and from being combined with an information campaign. Finally, our results may spread new light on the political decision to implement it. The 450,000,000 SEK subsidy was introduced in early 2006, eight months before the governmental election to the Swedish parliament in September 2006. By its rapid implementation, we can suspect that the subsidy served as a political tool to win sympathies rather than as an effective environmental policy.

As a last remark on the subsidy instrument, we must discuss that even though our results indicate that the subsidy did not have any significant impact on the stock of boilers, we cannot exclude that an implementation of a subsidy today would give the same effect considering that the remaining pool of households still using boilers are the most resistant ones. Hence, the current pool might respond better to monetary incentives than the less resistant pool of 2006. This, however, leads to another discussion whether it is socio-economically efficient to target this last fraction of households using oil-fired boilers. When considering the cost of targeting this resistant group to reduce their carbon dioxide emissions, it is probably more cost-efficient to allocate these resources elsewhere to reduce the same amount of CO_2 emissions. For example, Boverket (2008) concluded that if the money allocated to the subsidy had been used to buy emission rights, but without consuming them, the CO_2 emissions would have been four times lower compared to what the subsidy aimed at.

Regarding the Climate and energy consultation programme, we can conclude that it has been successful in directing households away from fossil fueled heating systems. As the literature predicts, the effect is modest but significant. Possibly the effect of the subsidy could have been enhanced if the two instruments had been intertwined. Considering the resistance level to new technology of the remaining households with boilers, this information instrument has been successful in the targeting this feature. For example, not only do the consultation provide a web site with information and interactive energy cost calculations but they also provide a telephone service with consultants who will answer the same questions in person. Thus the results confirm the research that the information programme's benefit from incorporating insights of research on communication and human decision making.

Lastly, neither income nor Green votes may be direct subjects when designing policies targeted at breaking the fossil fuel dependence. But our result may indicate that the design of a policy focusing on another variable should target poorer districts as the results give indication that these face a higher barrier in their replacement decision, while richer ones are more likely to switch for renewables. With the same reasoning, the impact of Green sympathisers on oil-fired boilers reflects the fact that environmental awareness impact the willingness to switch to an alternative RHS. Hence, this supports that attitude and knowledge, i.e. information, is important in the replacement decision process.

8.3 Last remark

We can conclude that the Climate and energy consultation has been a successful policy when targeting a decrease in existing boilers. Further, the carbon dioxide tax is a key factor in the replacement decision, since it makes heating oil relatively more expensive compared to other sources of heating. Finally, 2006 year's subsidy did not have any significant effect on the number of boilers.

In the quest to develop the optimal cost-effective environmental policies, empirical studies are constantly needed to evaluate those policies proven to be effective in reaching their objective. The process of improving the policies is an important means to reach the goals set by the EU to decrease the emissions by 2050, both in Sweden and beyond.

9. References

Boverket 2008, *Mindre olja, bättre miljö - men till vilket pris*, Boverket, Karlskrona.

Boverket 2007, *God bebyggd miljö - fördjupad utvärdering av miljömålsarbetet 2007*, Boverket, Karlskrona.

Braun, F.G. 2010, "Determinants of households' space heating type: A discrete choice analysis for German households", *Energy Policy,* vol. 38, no. 10, pp. 5493-5503.

Costa, D.L. & Kahn, M.E. 2013, "Energy conservation "nudges" and environmentalist ideology: Evidence from a randomized residential electricity field experiment", *Journal of the European Economic Association,* vol. 11, no. 3, pp. 680-702.

Dubin, J.A. & McFadden, D.L. 1984, "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption", *Econometrica,* vol. 52, no. 2, pp. 345-362.

Ekonomifakta 2013, 09/11/2013-last update*, Konsumtionsskatter på el* [Ekonomifakta], [Online]. Available: http://www.ekonomifakta.se/sv/Fakta/Energi/Styrmedel/Konsumtionsskatter-pa-el/ [2014, 04/11].

Ekonomifakta 2014/05/08-last update*, Energi- och miljöskatter* [Homepage of Ekonomifakta], [Online]. Available: http://www.ekonomifakta.se/sv/Fakta/Energi/Styrmedel/Energi-och-miljoskatter/ [2014, 03/20].

Energimyndigheten 2014, *Interview with the Swedish Energy Agency*, Stockholm.

Energirådgivningen 2014, *Interview with the Climate and Energy Consultation*, Stockholm.

Fernandez, V.P. 2001, "Observable and unobservable determinants of replacement of home appliances", *Energy Economics,* vol. 23, no. 3, pp. 305-323.

Gillingham, K. & Palmer, K. 2014, "Bridging the energy efficiency gap: Policy insights from economic theory and empirical evidence", *Review of Environmental Economics and Policy,* vol. 8, no. 1, pp. 18-38.

Hammar, H. & Jagers, S. 2003, "Om svenska folkets acceptans av en skärpt miljöpolitik", *Fåfängans marknad,* , no. SOM-rapport nr 33., pp. 245-259.

Heffner, G. & Ryan, L. 2010, *Climate and Electricity Annual 2011*, International Energy Agency Publications, Paris.

Jaffe, A.B., Newell, R.G. & Stavins, R.N. 2005, "A tale of two market failures: Technology and environmental policy", *Ecological Economics,* vol. 54, no. 2–3, pp. 164-174.

Jaffe, A.B. & Stavins, R.N. 1994, "The energy-efficiency gap What does it mean?", *Energy Policy,* vol. 22, no. 10, pp. 804-810.

Klöckner, C.A., Sopha, B.M., Matthies, E. & Bjørnstad, E. 2013, "Energy efficiency in Norwegian households - Identifying motivators and barriers with a focus group approach", *International Journal of Environment and Sustainable Development,* vol. 12, no. 4, pp. 396-415.

Mahapatra, K. & Gustavsson, L. 2008, "An adopter-centric approach to analyze the diffusion patterns of innovative residential heating systems in Sweden", *Energy Policy,* vol. 36, no. 2, pp. 577-590.

Michelsen, C.C. & Madlener, R. 2012, "Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany", *Energy Economics,* vol. 34, no. 5, pp. 1271-1283.

MSB 2009, *Årsuppföljning LSO* [Homepage of Swedish Civil Contingencies Agency], [Online]. Available: https://msb.se/sv/Forebyggande/Tillsyn--tillsynsvagledning/Skydd-mot-olyckor/Tillsynsvagledning/Arsuppfoljning-LSO/ [2014, 02/15].

Naturvårdsverket 2014, *Sveriges klimatpolitik* [Homepage of Swedish Environmental Protection Agency], [Online]. Available: http://www.naturvardsverket.se/Miljoarbete-i-samhallet/Miljoarbete-i-Sverige/Uppdelat-efter-omrade/Klimat/Klimatpolitik/ [2014, 05/05].

Naturvårdsverket 2009, *Allmänheten och klimatförändringen 2009*, Naturvårdsverket, Stockholm.

Naturvårdsverket 2004, *Fortsatt grön skatteväxling*, Naturvårdsverket, Stockholm.

Naturvårdsverket & Energimyndigheten 2007, *Den svenska miljöstrategin utveckling*, Naturvårdsverket, Stockholm.

Naturvårdsverket & Energimyndigheten 2006, *Ekonomiska styrmedel i miljöpolitiken*, Naturvårdsverket, Stockholm.

Nesbakken, R. 2001, "Energy Consumption for Space Heating: A Discrete-Continuous Approach", *The Scandinavian Journal of Economics,* vol. 103, no. 1, pp. 165-184.

Nilsson, L., Åhman, M. & Nordqvist, J. 2005, "Cygnet or ugly duckling - what makes the difference? A tale of heat-pump market developments in Sweden", *European Council for an Energy Efficient Economy (ECEEE),* vol. ECEEE 2005 Summer Study, pp. 1033-1044.

Revelt, D. & Train, K. 1998, "Mixed Logit with Repeated Choices: Households' Choices of Appliance Efficiency Level", *The review of economics and statistics,* vol. 80, no. 4, pp. 647-657.

SCB 2013, 02/20/2013-last update*, Elpriser för olika typkunder, tidsserier* [Homepage of Statistics Sweden], [Online]. Available: http://www.scb.se/sv_/Hitta-statistik/Statistik-efter-amne/Energi/Prisutvecklingen-inom-energiomradet/Priser-pa-elenergi-och-pa-overforing-av-el-nattariffer/Aktuell-Pong/6429/Tabeller-over-arsvarden/Elpriser-for-olika-typkunder-tidsserie/ [2014, 04/11].

SCB 2012, *, Sammanräknad förvärvsinkomst för boende i Sverige hela året* [Homepage of Statistics Sweden], [Online]. Available: http://www.statistikdatabasen.scb.se/Selection.aspx?px_path=START__HE__HE0110__HE0110A&px_tableid=SamForvInk1&px_language=sv&px_db=ssd&rxid=adbafd8f-23d4-42be-8796-bd4448aa030c [2014, 04/15].

SCB 2010, *, Kommunfullmäktigeval* [Homepage of Statistics Sweden], [Online]. Available: http://www.statistikdatabasen.scb.se/Selection.aspx?px_path=START__ME__ME0104__ME0104A&px_tableid=ME0104T1&px_language=sv&px_db=ssd&rxid=e530ae52-26b1-4489-bd25-e64950d95ffb [2014, 04/02].

SCB 2006, *Energy Statistics for One- and Two-Dwelling Buildings in 2005 [Energistatistik för småhus 2005].*, Statistics Sweden, Örebro.

Skatteverket 2014, 05/03/2014-last update*, Tidigara skattesatser på bränslen och el* [Homepage of Swedish Tax Agency.], [Online]. Available:

http://www.skatteverket.se/download/18.15532c7b1442f256baec6bc/1395932735502/skattesatser%2Bmed%2Bhistorik.xls [2014, 05/03].

SPBI 2014, 05/02-last update*, Årsmedelpriser för uppvärmningsbränslen* [Homepage of Swedish Petroleum and Biofuel Institute], [Online]. Available: http://spbi.se/statistik/priser/mer-prisstatistik/arsmedelspriser-uppvarmningsbranslen/ [2014, 11/02].

Statens räddningsverk 2005, *Statens räddningsverks föreskrifter och alla råd om rengöring (sotning) och brandskyddskontroll*, Norstedts Juridik AB, Stockholm.

Stavins, R.N. 2003, "Chapter 9 Experience with market-based environmental policy instruments" in *Handbook of Environmental Economics*, eds. K. Mäler & J. Vincent, Elsevier Science, Amsterdam, pp. 355-435.

Stern, P.C. 1999, "Information, incentives, and proenvironmental consumer behavior", *Journal of Consumer Policy,* vol. 22, no. 4, pp. 461-478.

Wooldridge, J. (ed) 2008, *Introductory Econometrics*, 4th edn, South Western College, USA.

Appendix

List of all municipalities that were clustered into districts:

Blekinge län

Västra blekinge rtj

Karlshamn
Olofström
Sölvesborg

Östra blekinge rtj

Karlskrona
Ronneby

Dalarnas län

Dalarna mitt rtj

Borlänge
Falun
Gagnef
Säter

Södra dalarnas rtj

Avesta
Fagersta
Hedemora
Norberg

Västerbergslagens rtj

Ljusnarsberg
Ludvika

Gävleborgs län

Gästrike rtj

Gävle
Hofors
Ockelbo
Sandviken

Älvkarleby

Norrhälsninge rtj
Hudiksvall
Nordanstig

Södra hälsningslands rtj
Bollnäs
Ovanåker
Söderhamn

Jämtlands län

Jämtlands rtj
Berg
Bräcke
Krokom
Ragunda
Strömsund
Östersund

Jönköpings län

Höglandets rtj
Nässjö
Vetlanda

Kalmars län

Emmaboda-Torsås

Ölands rtj
Borgholm
Mörbylånga

Kronobergs län

Värends rtj

Alvesta
Växjö

Östra kronobergs rtj
Lessebo
Tingsryd
Uppvidinge

Skåne län

Sydöstra skånes rtj
Simrishamn
Sjöbo
Tomelilla
Ystad

Stockholms län

Attunda
Järfälla
Knivsta
Sigtuna
Sollentuna
Upplandsbro
Upplands väsby

Storstockholm
Danderyd
Lidingö
Solna
Stockholm
Sundbyberg
Täby
Vallentuna
Vaxholm
Värmdö
Österåker

Södertörn
Botkyrka
Ekerö
Haninge
Huddinge
Nacka
Nykvarn
Nynäshamn
Salem
Södertälje
Tyresö

Södra roslagen
Danderyd
Täby
Vallentuna
Vaxholm
Värmdö
Österåker

Södermanlands län

Västra sörmlands rtj
Katrineholm
Vingåker

Uppsala län

Enköping-Håbo

Östhammar-Tierp

Värmlands län

Bergslagens rtj
Degerfors
Filipstad
Hällefors
Karlskoga

Kristinehamn

Karlstads rtj
Karlstad
Munkfors
Forshaga
Grums
Kil
Högboda

Västernorrlands län

Högakusten-Ådalens rtj
Härnösand
Kramfors
Sollefteå

Medelpads rtj
Sundsvall
Timrå
Ånge

Västmanlands län

Mälardalens rtj
Hallstahammar
Surahammar
Västerås

Västra mälardalens rtj
Arboga
Kungsör
Köping

Västra Götalands län

Allingsås - Vårgårda

Tidaholm-Falköping

Mitt bohuslänsrtj
Lysekil
Munkedal

Storgöteborgs rtj
Göteborg
Härryda
Kungsbacka
Lerum
Mölndal
Partille

Södra älvsborgsrtj
Bollebygd
Borås
Mark
Svenljunga
Tranemo
Ulricehamn

Västra skaraborgsrtj
Essunga
Grästorp
Lidköping
Vara

Östra skaraborgsrtj
Gullspång
Hjo
Karlsborg
Mariestad
Skövde
Tibro
Töreboda

Örebro län

Nerkes rtj
Askersund

Hallsberg
Kumla
Laxå
Lekeberg
Lindesberg
Nora
Örebro

Östergötlands län

Motala-Vadstena

Östra götalands rtj
Linköping
Norrköping