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Heat savings and heat generation technologies: Modelling of residential investment behaviour with local health costs

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HIGHLIGHTS

- Heat saving investment and heat technology choice are interdependent.
- Health damage costs should be included in private heating choice optimisation.
- Flexibility in heating technology choice reduce the optimal level of saving investments.
- Models of private and socioeconomic optimal heating produce different technology mix.
- Rebound effects are moderate but varies greatly among consumer categories.

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ABSTRACT

The trade-off between investing in energy savings and investing in individual heating technologies with high investment and low variable costs in single family houses is modelled for a number of building and consumer categories in Denmark. For each group the private economic cost of providing heating comfort is minimised. The private solution may deviate from the socio-economical optimal solution and we suggest changes to policy to incentivise the individuals to make choices more in line with the socio-economic optimal mix of energy savings and technologies.

The households can combine their primary heating source with secondary heating e.g. a woodstove. This choice results in increased indoor air pollution with fine particles causing health effects. We integrate health cost due to use of woodstoves into household optimisation of heating expenditures.

The results show that due to a combination of low costs of primary fuel and low environmental performance of woodstoves today, included health costs lead to decreased use of secondary heating. Overall the interdependence of heat generation technology- and heat saving-choice is significant. The total optimal level of heat savings for private consumers decrease by 66% when all have the option to shift to the technology with lowest variable costs.

1. Introduction

Three quarters of final energy supplied to the EU households is consumed for space heating (ODYSSEE, 2009). A considerable share of this energy goes to cover heat losses that can be eliminated by employing well known techniques, such as improving thermal insulation of building envelope and replacing windows with more efficient ones i.e. energy refurbishments. It has been estimated that by refurbishing existing buildings in the EU-27 countries, it is technically possible to reduce heat demand by 40% by 2030 (European Commission, 2011). There is, however, a large gap between these technical options and the actual investments made. Understanding the investment behaviour and existing incentives is crucial when analysing investments into energy refurbishments and the policy measures that can affect the behaviour of, for instance, homeowners.

About 20% of primary energy in Denmark is consumed for space heating in buildings (DEA, 2011). For households the heating share is 70–80% of the final energy consumed in the household. The technical heat saving potential of energy refurbishments in the Danish building stock is estimated to be 75–80% by 2050 (Tommerup and Svendsen, 2006). It is very important that we provide cost reflecting fuel prices and remove distorting barriers for private investments in energy refurbishments if we are to realise the economically attractive part of energy savings.

When a new building is constructed, decisions determining the energy efficiency of the building, and at the same time heat source

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and heating technology are made. These are long-term investment decisions that define thermal comfort level, energy demand for heating, fuel dependency and heating costs, as well as environmental impacts of the building for at least a couple of decades. These choices can only be changed in the long term in connection with a larger renovation of the building (Siller et al., 2007). Thus, choices, made during construction/renovation of buildings are significant for overall energy consumption in a country or region.

The IPCC report on Mitigation of Climate Change (IPCC, 2007) stresses the importance of integrated design – buildings, engineering systems and generation technologies should operate effectively together in order to utilise energy in the most efficient way possible. Decisions, regarding energy refurbishment and choice of heat generation technologies are interdependent. Several studies (Tommerup and Svendsen, 2006; Amstalden et al., 2007; Gaterell and McEvoy, 2005) have shown that the price of heat delivered to a building is a decisive factor for the economic effectiveness of energy refurbishments of buildings. Clearly, the price depends on the cost and efficiency of heat generation technology, fuel used as well as energy taxation. Contrary to heat consumers connected to a district heating system, homeowners with individual heating technologies have greater flexibility to decide upon the cost of heat by choosing technology and fuel. The challenge for these consumers is to find an optimal balance between investments into energy refurbishments and heat generation costs. The decision of how much to invest in energy refurbishments depends clearly on the cost-characteristics of different alternatives – investment and operation costs and fuel prices. Private decisions about saving investment are often assumed to include technology costs (both investment and operation) and avoided energy expenditures, but not health costs associated with local heat generation. Environmental externalities and co-benefits of heat generation technologies and heat savings are described in several studies (Jakob, 2006; Banfi et al., 2008; Clinch and Healy, 2001). At the same time, a number of studies analyse the effect of internalisation of air pollution related health externalities into the energy system planning, from the socioeconomic point of view. These studies focus either solely on power generation sector (Klaassen and Riahi, 2007; Rafaj and Kypreos, 2007; Zhang et al., 2007; Kudelko, 2006) or on both, heat and power production and supply (Gebremedhin and Carlson, 2002; Holmgren and Amiri, 2007; Zvingilaite, 2011). Health externalities are internalised in both, central heat and power production and individual heating by Zvingilaite (2013) in the analysis of the Danish heat and power system – from the socioeconomic point of view. While the residential heating sector is a main source of local air pollution and health effects, the externalities are not included in decisions by private homeowners except for the emission taxes included in fuel prices. For example, high wood consumption in heat boilers and particularly in wood stoves and fireplaces by the Danish households accounts for almost 70% of national emissions of fine particles $PM_{2.5}$ (Nielsen et al., 2010). These emissions increase air pollution level in residential areas and cause health damage locally and indoor (Olesen et al., 2010). Consequently, part of these health related costs from secondary heating technologies should be considered internal for the household decisions.

Consequently, in this paper we investigate and discuss two research questions:

- How can inclusion of local health costs change the investment decisions in the residential heating sector?
- How significant is the interdependency of heat saving measures and individual heat generation technologies?

We identify the main characteristics of individual heating – different consumer groups and their heat demand, primary and secondary heat generation technologies, fuels and their prices, including levies and energy taxes. furthermore we analyse heat saving potentials and costs in the analysed buildings. we construct an optimisation model for the private investment decisions by households and analyse scenarios with different investment flexibility. finally we assess the rebound effect of heat consumption, as a result of decreased variable heating cost per square metre of heated area.

2. Residential heating demand and externalities

Demand for heating is an important part of energy demand in countries with cold climate such as Denmark, and depends on a number of parameters of which some are individual and others are set by the regulatory and planning environment. Property tax schemes affect dwelling size and urban planning affect types of dwellings and heating sources. Building codes also regulate in detail the materials and heat loss of dwellings. Individuals demand indoor thermal comfort in their dwellings and primary energy for heating is thereby not directly providing use (or utility) to households.

This paper models the private integrated choice of heating technology and investments in energy savings. We start by discussing consumer control of the elements in the energy chain from comfort level to the primary fuel use.

The elements that drive the demand for thermal comfort level for a consumer are:

- income
- price of heat
- habits/preferences.

With rising income individuals increase their demand for heating comfort by increasing indoor temperature and heating more rooms a larger fraction of the year. Income elasticities are generally found to be considerably less than 1 for heating characterising it as a basic good in high income countries as e.g. the long term trend declining towards an elasticity of 0.5 found for the UK in Fouquet (2014).

An increase in the price of heating comfort reduces the demand by making people more aware of avoiding excess heating in areas not used and directly affects the indoor temperature they set. Empirical estimates for price elasticities are found in a broad range between -0.1 and -1. For example, Meier and Rehdanz (2010) find between -0.34 and -0.49 for the price elasticities of oil and gas in UK household demand for the two energy types. Results from Denmark (Leth-Petersen and Togeby, 2001) find elasticities for gas oil and district heating close to zero for the category of apartment blocks, due to lack of individual metering. The long term price elasticity for household heating demand in Denmark is found to be -0.37 (Møller Andersen et al., 2010) with the short term elasticity somewhat less (around -0.2).

Habits based on historical trends and social organisation of family life etc. affects the heat comfort demand, which is seen especially when comparing across countries. The demand for heating comfort is only the first step in determining the energy needed for heating purposes. The comfort level is a result of useful, energy delivered to a dwelling and energy efficiency of the building envelope. A homeowner is directly in control of the chosen comfort level and the investments that could improve energy performance of the building. Energy saving investments are undertaken as long as their costs per saved energy unit are below the costs of the supplied energy delivered for heating the house. The home owner on the other hand only controls some of the parameters that determine costs of the supplied heat. The