Choice-decision determinants for the (non) adoption of energy efficiency technologies in households

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Choice-decision determinants for the (non-)adoption of energy-efficient technologies in households

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Abstract

Energy efficiency scenarios are developed in the national and international context to explore and evaluate different policy designs and visions of how energy will be generated, distributed and used in the future. However, these scenarios are often developed using conventional bottom-up modelling tools that, to only a limited extent, take into account decentralised decision-making frameworks, such as household investment decisions regarding energy-efficient technologies. The tools for modelling policy evaluation need to be improved to capture the factors determining the choice of technologies that affect household energy consumption and how these might be better influenced by means of energy efficiency policy instruments. In this paper, we present the first phase of a project analysing possible options to further improve microeconomic decision-making frameworks for evaluating energy efficiency policies and developing more realistic energy use forecasts for the household sector. The objective of the paper is to identify and explore a wide range of determinants – beyond the narrow but traditional 'rational model' technology choice approach – affecting and influencing households' purchase/investment decisions regarding energy-efficient technologies. Furthermore, and within the economic/engineering paradigm that dominates energy modelling tools, we focus on the specific, but relevant issue of discounting to simulate and assess household preferences regarding energy-efficient technologies. Based on an extensive literature review, we present a summary of the body of evidence developed in the field. The results show that capital and operating costs prove to have an important influence on technology choice. However, the evidence clearly suggests that a broader set of determinants need to be considered and that different determinants will influence households' technology choice in different markets under different circumstances and for different technologies. Even if pure economic parameters are examined, there is still a gap between what ex-post analyses reveal and the discount rates used in ex-ante modelling exercises. The results suggest that a larger representation of determinants in energy modelling tools is necessary to further enhance our understanding of household technology choice and thus the feasibility of such models in policy evaluation.

Introduction

Energy (efficiency) scenarios are developed in the national and international context to explore and evaluate different policy designs and visions of the energy future. These analyses are often developed using conventional energy modelling tools that, to only a limited extent, take into account and represent decentralised microeconomic decision-making frameworks, such as household investment decisions regarding energy-efficient technologies, solar cells and micro CHP. Driven by economic and engineering principles, bottom-up modelling tools generally use a traditional and limited 'rational' approach to reflect investment decisions and/or technology choice from the end-user perspective. These take into account aspects such as capital costs, discount rates and energy prices. In reality, microeconomic decision-making frameworks for energy-efficient technologies are far more complex and depend on multiple parameters rather than parameters that are purely energy-related or economic. Seminal work conducted by, for example, Lutzenhiser (1992) found evidence that consumers lack economic rationality in deciding to forego certain obvious energy-efficient measures.

In fact, one can safely argue that the approach of economic rationality is inadequate or too limited to properly represent consumers' technological preferences. As argued throughout this paper, investment and operating costs are relevant but represent only a part of a great variety of determinants that frame and drive consumer's energy-related decisions regarding technology choices. For instance, a combination of factors including design, comfort, brand, functionality, reliability and environmental awareness and others are likely to influence consumers' decisions regarding energy-efficient equipment. In order to better capture all, or just the key, determinants of the selection criteria for energy-efficient technologies, we need to further enhance models for energy use scenarios. In turn, such models are also essential for the evaluation of potential and actual policy instruments for energy efficiency. In this paper, we present the first phase of a project analysing possible options for taking into account decentralised and dynamic microeconomic decision-making frameworks to better evaluate energy efficiency policies and develop more realistic energy systems forecasts for the household sector.

The objective of this paper is twofold. First, we present a review in which we identify and explore a wide range of determinants – beyond the narrow but traditional 'rational model' approach – influencing households' (non-)adoption of energy-efficient technologies. The key guiding question is what determinant should be taken into account when analysing future energy (service) demands and evaluating different energy policy instruments using energy forecasting/modelling tools. Second, and within the above-mentioned economic/engineering paradigm that dominates energy modelling tools, we also explore the extent to which the findings on empirically estimated behavioural economic parameters correlate with decisions parameters used for energy-efficient technologies in certain energy modelling efforts. Within this economic context, we focus on the specific, but relevant issue of discounting to simulate and assess household preferences for the (non-)adoption of energy-efficient technologies. The paper addresses and compares the discount rates used in the models today and the implicit discount rate found in the literature.

On the whole, this paper seeks to provide a basis for the discussion and advancement of the feasibility and appropriateness of the energy modelling tools used to evaluate policies influencing choices of energy-efficient technologies by the household sector. The initial hypothesis guiding this research is that the economic/engineering paradigm dominating bottom-up energy modelling tools for assessing household energy use is too simplified. We also begin from the view that socio-economic and techno-behavioural aspects are numerous and complex and that these are not represented in the models. That is to say these have not been integrated into the decision-making criteria governing for technology adoption. However, the two approaches should be combined to enhance the usefulness of energy modelling tools in policies targeting the household sector. In general, this paper should be considered a discussion/background study and a starting point for further research and analysis.

Determinants of choice in the (non-)adoption of energy-efficient technologies

The key determinants of technology choice generally considered by energy modelling tools are capital and operating costs. In many cases, investment costs are a key determinant. Due to high investment requirements, capital costs become a key barrier to investment in energy-efficient technologies. For the (non-)adoption of efficient household technologies, there is however, a difference between capital and operating costs. Kempton and Montgomery (1982) showed that immediate cost (i.e. capital cost) is ascribed a higher priority than long-term savings (see also Dupont, 1998; Hall and Reed, 1999; Uitdenbogerd, 2007; Boonekamp, 2007). The relevance of operating costs is often measured as 'low' in studies of determinants of choice for the adoption of energy-efficient technologies. Several studies present the lack of knowledge and awareness that prevents adopters from fully comprehending or taking into account the importance of this determinant. For instance, DuPont (1998) found that most US consumers (80 percent) stated that they were unaware of the annual operating costs for recently purchased appliances. There is compelling evidence that consumers often lack knowledge regarding costs and benefits related to energy efficiency (see e.g. Sanstad and Howarth, 1994).

However, the literature presents numerous determinants affecting investment decisions in energy (efficiency) technologies in the household sector beyond the usual economic/engineering factors (e.g. capital and operation costs, technology efficiency, emission factors) used in bottom-up energy modelling tools for the household sector (see e.g. Stern, 1986; Lutzenhiser, 1993; Wilhite et al., 2000; Uitdenbogerd, 2007). Many determinants are described in terms of co-benefits or non-energy benefits. These include improved comfort, noise reduction, functionality, performance, quality, reliability, design, etc. (see e.g. Stern and Aronson, 1984; Mills and Rosenfeld, 1996; Amman, 2006; Stoecklein and Skumatz, 2007). Other important factors that appear to significantly affect technology choice include knowledge on energy efficiency and environmental awareness. In fact, the literature offered numerous examples of the positive correlation between environmental awareness (and commitment) and the adoption of energy-efficient technologies (see e.g. Palmborg, 1986; Banks, 1999; Barr et al., 2005; Darby, 2006). Several studies have also analysed investments decisions for technologies in demographic terms (see e.g. Hirst, 1984; Wilk and Wilhite, 1985; Palmborg, 1986; Lutzenhiser, 1992; Abrahamse et al., 2005). Some of these studies have shown that income has an effect on investment decisions (see e.g. Dillman et al., 1983; Curtis, 1984; Black et al., 1985; Costanzo et al.,1986; Stern, 1986; Bartiaux et al., 2006; Herring et al., 2007). Others have shown no, or only a low, correlation between income and the adoption of efficient technologies (see e.g. Ruderman, 1987; Ürge-Vorsatz and Hauff, 2001; Barr et al., 2005). In parallel, certain studies identified a correlation between education and investments in energy efficiency (see e.g. Ürge-Vorsatz and Hauff, 2001), while others did not observe the same relation (see e.g. Curtis et al., 1984). Besides demographic differences, households apply a number of determinants relating to lifestyle and socio-cultural issues (see e.g. Aune et al., 1995). Lifestyle may support both the adoption or non- adoption of energy-efficient technologies. Several studies have shown that investments in low-energy houses and energy-efficient appliances have been supported by owners in terms of perceived status, social recognition and pride (see e.g. Condelli et al., 1984; Wilk and Wilhite, 1984; Gordon and Dethman, 1990; Martinez et al., 1998; Diamond and Moezzi, 2000; Guerin et al., 2000; Farhar, B. et al., 2002; Gram-Hanssen et al., 2007).

In all, the literature reviewed concludes that decisions practiced in reality for the (non-)adoption of efficient technologies in the household sector are complex and cannot be captured only by using parameters and decision rules associated with capital and operating costs. The relevance of different determinants of household choices is presented in the sections below. The examples presented cover the determinants of choice identified that relate to the building envelope, lighting and consumer appliances.

DETERMINANTS OF CHOICE REGARDING INVESTMENTS IN ENERGY-EFFICIENT BUILDINGS

Determinants of choice related to investments in the building are numerous. These involve investments in the building envelope, including loft and wall insulation, windows, heating and cooling equipment and air-conditioning systems. The literature review reveals that determinants of technology choices in these areas are indeed diverse.

Looking at investments related to space-heating or insulation, comfort is a very strong determinant (see e.g. Berry et al., 1997; Fuchs et al., 2004; Herring et al., 2007). Investment cost and operational cost (savings) are most often secondary considerations. It is also important to note the relatively strong determinant for non-adoption that relates to loft insulation and space constraints. The arguments against investing in loft insulation often involve the loss of storage space (see e.g. Herring et al., 2007). Another argument is timing. Investments in space-heating or insulation should coincide with home refurbishment or retrofitting (see e.g. Lutzenhiser, 1993; Jaffe and Stavins, 1994a Wilson and Dowlatabadi, 2007). Moreover, measures related to the building envelope are associated with aesthetic appearance. Gram-Hanssen et al. (2007) tracked aesthetic considerations in Belgium and Denmark, showing that tastes prevented some households from making energy efficiency improvements, such as installing roof insulation or double glazing. With regard to energy-efficient windows, reduced cold air inflow and expected noise reduction have been identified as key determinants (NUTEK, 1995). The degree of activity with regards to insulation also depends on age, education, and gender (see e.g. Stead, 2005).

Investments in heating, ventilation, and air-conditioning systems (HVAC) have been shown to be related less to operating cost than capital cost, technical performance, comfort and branding (see e.g. Lawrence and Jenkins, 2000; Mebane and Presutto, 2001; Bensch, 2005). On the other hand, investment in controls (timer/programmer) for central heating systems appear to be related more to operating cost (Herring et al., 2007).

Based on the reviewed literature, the type and age of a building have been shown to have a significant influence on choices of energy-efficient technologies and systems (see e.g. Vaage, 2000; Bartiaux et al., 2006; Herring et al., 2007). Moreover, it has been found that household mobility has a major effect on home improvement and investment strategies. According to Wilk and Wilhite (1984), households that move more frequently are "reluctant to invest in retrofits, though they may compensate by seeking to buy a home which is already energy efficient". In general, ownership has been shown to influence investments in energy efficiency. Consumers who own their homes are more likely to invest in energy-efficient technologies and systems compared to tenants (see e.g. Reid, 1982; Curtis et al., 1984; Black et al., 1985; Costanzo et al., 1986; Guerin et al., 2000; Rehdanz, 2007). In terms of the principal–agent issue (whereby those who pay the energy bills are not responsible for decisions on energy-efficient technologies), the literature extensively refers to ownership as a major barrier to energy efficiency investment decisions (see e.g. Blumstein 1980; Jaffe and Stavins, 1994a, 1994b; Murtishaw and Sathaye 2006). For instance, Meier and Eide (2007) found that 46-48 percent of investments in energy-efficient residential space heating systems in the US are hampered by the principal-agent problem.

DETERMINANTS OF CHOICE FOR INVESTMENTS IN ENERGY-EFFICIENT LIGHTING SYSTEMS

Energy-efficient lighting has attracted substantial attention in studies of consumer preferences. These studies attempt to understand (non-)adoption decisions. We focus on the case of compact fluorescent light (CFL) bulbs.

In general, the main determinants for lighting systems are design, style and aesthetics (Ashdown et al., 2002; Stokes et al., 2006). For outdoor lighting systems – safety, security and durability are the most important determinants. Contrary to common wisdom, one may argue, is the fact that energy efficiency as such is ranked low as a determinant (see Ecos Consulting, 2002; Oxera, 2006). However for those who have invested in CFL, low operating cost was found to be essential (see e.g. Palmer and Boardman, 1998; Herring et al., 2007). At the same time, barriers to choosing CFL technology are numerous and include design, style, aesthetics, high initial cost, unavailability, lack of awareness, incompatibility, performance problems (see e.g. Palmer and Boardman: 1998; The Northwest Energy Efficiency Alliance, 2000; Grover and French, 2004; Sathaye and Murtishaw, 2004; Herring et al., 2007; Hobart and Wilson, 2007). Uitdenbogerd (2007) shows that from a sample of 376 households, 38 percent did not buy CFL bulbs due to the high cost. Addressing the performance of CFL in the US, Rasmussen et al. (2007) show that the colour of light, brightness, and delayed lighting were critical issues preventing purchases. Once purchased, experience also shows that people replace CFLs due to perceived low performance (slow start-up, low light intensity) or compatibility dissatisfaction (e.g. "doesn't fit to existing fixtures") (Hobart and Wilson, 2007). Calwell et al. (2002) found that product size and ability to fit into existing fixtures were major barriers for CFLs in the US. According to Uitdenbogerd (2007), 62 percent of non-adopters refer to energy-saving bulbs being "not suitable for all fittings".

Studies show that the use of CFLs decreases with age (Bartiaux et al., 2006). Some authors argue that ownership of CFLs is higher in households with higher levels of income and education (Ürge-Vorsatz and Hauff, 2001). Others state that there is no difference (Bartiaux et al., 2006). An interesting study by Rasmussen et al. (2007) showed that awareness of CFLs is important for adoption. The study analysed a residential lighting programme in California and the Pacific North-West. It showed that the awareness of CFLs was 58 percent when the programme was launched, and increased to 94 percent as a result of increased information resources. Consequently, the purchase rate increased from 17 percent in 1998 to 69 percent in 2006.

DETERMINANTS OF CHOICE FOR INVESTMENTS IN ENERGY-EFFICIENT CONSUMER APPLIANCES

Numerous determinants of choice regarding consumer appliances, such as refrigerators/freezers, dishwashers, washing machines and air-conditioners have been identified and their impacts estimated (see e.g. Shorey and Eckman 2000; Fuchs et al., 2004). In the case of refrigerators/freezers, key determinants of technology choice include price, technology efficiency and brand (see e.g. Boardman et al., 1995; Oxera, 2006). Brand is often seen as a guarantee for quality of appliances and is therefore an important determinant of technology choice (see e.g. Nowlis and Simonson 1997; Brucks et al., 2000; Ashdown et al., 2004; Oxera 2006; Uitdenbogerd 2007). Based on observable product characteristics, the literature stresses that the efficiency or performance of a given energy-efficient technology is another determinant of great importance for consumers (Sanstad and Howarth, 1994).

As for washing machines and dryers, important determinants identified are price, product performance and size (see e.g. Turiel et al., 1997; Grover and Babiuch, 2000). In general, the studies show that the operating cost has a very week effect on the investment. On the other hand, energy labels reflecting annual energy savings for refrigerators/freezers have been shown to have a considerable influence on choice in EU countries. The share of consumers who stated that energy labels on refrigerators/freezers influenced their purchase choices was as high as 56 percent in Denmark, 45 percent in the Netherlands, and 39 percent in Austria and Sweden (see Schiellerup et al., 1998).

In the case of entertainment, information and leisure products, operating cost has a very weak effect on technology choices. Drivers of choice are usually brand (including design), performance and investment cost (see e.g. Oxera, 2006).

Discount rates and technology choice

Within the economic/engineering paradigm that dominates bottom-up energy modelling tools, we explore the extent to which findings on empirically estimated economic behavioural parameters correlate with decision-making parameters applied for energy-efficient technologies. Within this context, the study focuses on the relevant issue of discounting to assess and simulate household preferences for the (non-)adoption of energy-efficient technologies.

In general, bottom-up modelling tools are based on engineering economics and forecast technology futures, corresponding energy use and environmental impacts as a function of (among other things) changes in technology efficiency, capital, operation and maintenance costs, fuel consumption, and abatement control equipment. Once the future costs of these factors are calculated and translated into present values using real (financial) discount rates, many energy-efficient technologies emerge as profitable and attainable under different policy scenarios. In other words, penetration rates for technologies are forecasted using the discount rates applied by consumers' in converting projected lifecycle costs into the current value for each technology. The literature review indicates that real (or normal/private) discount rates applied in bottom-up energy models are in the range of 3-20 percent. For instance, the PRIMES[1] model uses a discount rate of 17.5 percent for the household sector and the National Impact Tool (NIA)[2] uses discount rates of 3 and 7 percent to assess minimum energy efficiency performance standards.

Contrary to the range of discount rates mentioned above, there is extensive literature showing that consumers use high implicit discount rates for the (non-)adoption of energy-efficient technologies. In fact, there is compelling evidence that consumers use high implicit discount rates (e.g. up to 90 percent and even much higher), hindering the adoption of efficient technologies (see e.g. Hausman, 1979; Gately, 1980; Train, 1985; Ruderman et al., 1987; Lutzenhiser, 1992; Jaffe and Stavins, 1994a, 1994b; Metcalf, 1994; Howarth and Sanstad, 1995). Consequently, high implicit discount rates cause greater financial hurdles to be set for efficient technologies than for conventional ones. Numerous studies have analysed implicit discount rates in relation to income class. Discount rates are often estimated based on capital costs versus savings in operating costs from alternative projects (see e.g. Hausman 1979; Train 1985). Table 1 below summarises the key findings.

Although not exhaustive, various causes can explain the identification/use of high implicit discount rates by consumers. Overall, it is argued that energy-efficient technologies entail longer payback periods and greater risks and uncertainties than conventional technologies. According to the reviewed literature, more specific causes may include a lack of information about cost and benefits of efficiency improvements, a lack of knowledge about how to use available information, uncertainties about the technical performance of investments, a lack of sufficient capital to purchase efficient products (or capital market imperfections), income level, high transaction costs for obtaining reliable information, risks associated with investments, etc. (e.g. Ruderman et al., 1987; Train, 1985; Suttherland, 1991; Gates, 1993; Metcalf, 1994). Ownership status is regarded as a relevant socio-economic explanation for high implicit discount rates (Train, 1985). Hausmann (1979) and Train (1985) also argue that implicit discount rates vary inversely with income category. Train (1985) argues that the relationship between low income category and high implicit discount rates can be explained partly by low-income households having less access to capital markets and less liquid capital to invest than higher-income households. As a result, even given adequate information on investment returns, lower-income households will still be unable to invest in efficient technologies unless complementary economic instruments are in place.

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1. The PRIMES Energy System Model has been developed by the National Technical University of Athens, Greece, since 1993. PRIMES simulates a market equilibrium solution for energy supply and demand within each of the 27 EU Member States and another seven European countries. See E3Mlab – ICCS/NTUA (2000) for further details.

2. The National Impact Analysis (NIA) is one the different analytical spreadsheet tools used by the DOE-EIA to develop and asses minimum energy efficiency performance standards for specific product types (e.g. residential appliances) in the US. For further information visit http://www1.eere.energy.gov/buildings/appliance_standards/

Table 1: Summary of estimated implicit discount rates used by consumers for household energy-efficient technology choice

Reference	Method(s)	Results
Hausmann (1979)	Model addressing individual behaviour for the purchase and utilisation of energy-using durables (air conditioners), with a purchase equation based on a discrete choice model.	The study found average implicit discount rate of 25% for air conditioners (ranging between 5 to 89%)
Gately (1980)	Similar to Hausmann (1979)	The study estimated rather high implicit discount rates for efficient refrigerators, ranging from 45% up to 300%
Dubin and McFaden (1984)	Econometric analysis with an introduced discrete appliance choice model	The study estimated an average discount rate of 20% for water- and space-heating efficient technologies
Train (1985)	Literature review addressing, for instance, (i) logit/probit models, (ii) stated preferences, (iii) observed points along a continuum, and (iv) hedonic price analysis	The study found that average implicit discount rates in household purchase decisions for efficient equipments range between: i) 10 to 32% for insulation; ii) 4 to 36% for space heating, iii) 3 to 29% for air conditioning, and iv) 18 to 67% for other appliances (e.g. water heating, cooking)
Sutherland (1991)	Literature review confronted with a capital asset pricing model (to test the validity of consumers using higher rates of return)	The study notes that energy efficiency appliances appear to entail very high discount rates, say 50% or higher

The use of high implicit discount rates has been labelled as another form, or restatement, of the 'energy efficiency gap', that is, the slow diffusion of profitable and efficient technologies and their failure to achieve market success (see Jaffe and Stavins, 1994a, 1994b). The reviewed studies show that the implicit discount rates related to investments in different technologies differ. For example, investments in the building envelope show relatively high rates, approximately 10-30 percent, and implicit discount rates related to appliances are even higher, approximately 20-300 percent. This is to be compared to the real or normal discount rates used in the modelling exercises mentioned early in this section. On the one hand, 'real' or 'normal' discount rates are usually applied in modelling studies through assumptions of 'well-defined consumer preferences' and 'unbounded rationality'. Consequently, their use generates optimistic penetration rates for efficient technologies. On the other hand, it is argued that household investments in energy-efficient appliances might correctly imply high discount rates because these investments are illiquid, risky, represent high transaction costs and have long payback periods (see e.g. Sutherland, 1991; Andersson and Newell, 2002). Furthermore, high (implicit) discount rates used to set baselines are often then lowered to 'real' rate levels to simulate or mimic household preferences for energy-efficient technologies in response to policy instruments (such as information campaigns and certification programmes). This modelling approach has been also criticised (see e.g. Anderson and Newell, 2002; Worrell et al., 2004).

Note that the results presented in this section attempt by no means to suggest the idea that the determinants of choice previously mentioned should be incorporated into a set of implicit high discount rates. The results simply show (and attempt to illustrate) that even if purely economic parameters are examined, there is still a gap between what ex-post analyses reveal and the discount rates used in ex-ante modelling exercises. At the risk of oversimplifying, even though high implicit discount rates and related causes have been the most common and frequently mentioned evidence for the non-adoption of efficient technologies by consumers (see Huntington, 1994), the debate regarding the use of appropriate discount rates in modelling exercises continues (see Anderson and Newell, 2002).

Concluding remarks

This paper aimed to identify and summarise determinants of choice influencing the (non-)adoption of energy-efficient technologies in the household sector. The question that laid the basis for this paper appeared to concern various dimensions. Among the determinants of choice, we find those supporting rational economic explanations, as well as benefits not related to energy efficiency. Undoubtedly, the number of factors influencing households' choices regarding energy efficiency technologies is extensive. At the same time, the role and influence of the determinants can be quite case and context specific. Whereas economic factors are used as key determinants for technology choice in energy modelling tools, the review shows a variety of determinants that need to be taken into account when analysing the process of (non-)adoption of energy-efficient technologies and those different determinants can be relevant to different types of technologies.

The results also highlight households' low preference for decreased operating costs. This result could be interpreted as reflecting a market barrier regarding energy efficiency. This may involve a lack of information and knowledge and may reflect the principal-agent problem. However, it may also reflect preferences for determinants related to co-benefits or non-energy benefits, such as improved housing comfort level, functionality, performance, quality, reliability and design. However, the study demonstrates a continued challenge in assessing the specific influence of certain parameter. Furthermore, some contradictions were found when confronting outcomes from various studies, so findings are likely to be case-specific and should be viewed with caution.

The literature review on discount rates surely indicates that more research is needed on behavioural aspects driving choices about energy-efficient technologies. It is shown that even if economic criteria alone are scrutinised, there is still a gap between what ex-post analyses reveal and the discount rates used in ex-ante estimates of technology lifecycle costs and related market penetration rates. Among others, this aspect stresses the difficulties of relying purely on economic factors to represent complex socio-economic household behaviour in energy modes when dealing with energy-efficient technologies. It is found that high implicit discount rates attempt to capture or characterise the low preferences of consumers towards energy-efficient technologies. However, the literature review also shows that much more research is needed to understand consumers' decision-making processes. In turn, implicit discount rates also illustrate that the "economic rationality" applied by householders is different for different types of measures and technologies. As for technology choice in the building itself, the implicit discount rates seems to be lower than for appliances. These results are supported by the analyses of choice determinants used by households. The results indicate a higher relevance of capital and operating costs in the case of investments in the building envelope and heating system, whereas the review of choice determinants indicate a lower relevance of capital and operating cost when investing in appliances. Again, findings suggest that results are likely to be case-specific.

At the risk of stating the obvious, these days, market barriers need to be reduced or eliminated by the use of different policy instruments in order to increase the adoption of energy-efficient technologies. There is extensive literature about the effects of different policy instruments (e.g. tax, rebates, soft loans, subsidies, information and regulation) and their effects in terms of the adoption of energy-efficient technologies in the household sector. The review in this paper indicates radical improvements due to information programmes such as labelling and efficiency standards. Another strategy for increasing energy efficiency is to design energy-efficient products that meet households' requirements and preferences in terms of performance, price, brand/design, etc. On the whole, we argue that modelling studies do provide useful policy insights and they should be complemented with other methods using a variety of evaluation criteria for policy design and instrument choice. Several modelling tools have contributed extensively to improving our understanding of policy instruments – provided that the right models are chosen to answer appropriate policy questions.

To further enhance the realism of bottom-up energy modelling tools and their usefulness for policy design and evaluation in addressing the household sector, the reviewed literature clearly suggest that such tools need an extended representation of determinants. The key question now is to what extent a better representation of empirically estimated determinants of choice is actually feasible in energy modelling tools (i.e. improvements of decision-making rules embedded in such models). Which determinants are more workable than others in improving such tools in practice? In addition, what can be done in order to bridge the gap in the debate regarding real and implicit discount rates? Undoubtedly, these aspects pose a challenging but necessary research task, as a more realistic portrayal of decentralised and dynamic microeconomic decision-making frameworks is crucial in improving the design and evaluation of policies.[3] Although not covered in this paper, it is important to take into account the fact that technology choice will be strongly affected by intermediaries such as developers, construction companies, installation companies and vendors (see e.g. Lutzenhiser, 1993; Wilhite and Shove, 1998). These actors take many important and strategic (business) decisions – sometimes on behalf of end-users – influencing subsequent household energy use. Several studies show that intermediaries' incentives to pursue energy efficiency are few, while their disincentives are many (see e.g. Blumstein et al., 1980; Stern and Aronson, 1984; Gordon and Dethman, 1990; Brown, 2001).

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3. The second phase of the project will review numerous bottom-up energy (efficiency) models and examine the decision-making rules to determine technology choice and associated energy use in the household sector. It will analyse the approaches undertaken to evaluate energy efficiency policy instruments using the models reviewed to date. It is expected to address key issues in advancing energy (efficiency) models and their policy usefulness for the household sector.

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