4. Residential Energy Demand

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1. Introduction

This paper provides a concise review of the empirical literature on residential energy demand. It also discusses the findings in the reviewed literature and their implications for the choice of policy instruments. While there is a plethora of studies on the technical possibilities, *i.e.* the potential energy savings that new technologies allow, it is plain that energy consumption also depends on our attitudes, preferences and income as well as relative prices[1]. Therefore, this review is based on the idea that energy demand is essentially driven by human behaviour and our main task is then to explore a range of empirical evidence that sheds useful light on our limited objective. Indeed, the literature on energy demand is impressively rich; already in the early years of the 1980s there were more than 2 500 papers available on this topic (Joerges, 1988 cited in Weber, undated). This brief review will focus mainly on the economics domain, a limitation to be true, although pointers will be given to findings in related fields.

While our review targets insights from empirical studies within the economics domain, we must at the outset warn that the studies display substantial variations, so large that any firm conclusions about household behaviour must be cautioned beyond the usual caveats. For example, the estimated price and income elasticities show such large variance that it is hard to distil a pattern. Dahl (1993), in *a* comprehensive survey, compares these elasticities with snowflakes – no two are alike. Fortunately, there are a number of cogent explanations as to why there is such heterogeneity of results and we shall return to these in due course.

There are a number of idiosyncrasies that challenge the economic analysis of energy demand; empirics suggest informational failures, imperfect capital markets and certain other deviations between a perfectly functioning market and what we do observe in the real world. In addition, there are peculiarities that are difficult to grasp entirely; for example, not all new and improved technologies are adopted, even if adoption can save a

1. Energy per se is a good. Energy consumption does, however, lead to a number of negative side-effects. At any rate, whether or not saving energy is a sensible objective as such (rather than focusing upon the negative externalities) need not concern us here.

significant amount of money[2]. According to some observers, this is a good example of how limited standard economic theories are; others are quick to dismiss the apparent "paradox" on the grounds that the data do not stand up to close scrutiny. The literature on this "paradox" is substantial, and we can do no better here than to refer to the compact survey by Nyboer and Bataille (2000) for a review of the differing views.

The rest of the paper is structured as follows. Section 2 provides some background information on residential energy. Section 3 presents the framework that we will use to structure the empirical review. Section 4 is a review of selected studies. Finally, Section 5 discusses general policy implications as well as the choice of policy instruments, in light of the insights gained.

2. Residential energy use: a derived demand

Let us begin by defining terms: "Residential energy use" typically includes space heating, water heating and household electricity consumption. Heating/cooling is a major part of demand.

Space precludes discussion of how residential energy use in OECD countries has developed over time, but it will be useful to recall some salient trends. First, income has grown by more than 2% per year in the OECD area since 1970. Simultaneously, efficiency improvements have been secured throughout the period. Income has a positive effect on demand, while price increases tend to slow it down. The net impact of these factors is uncertain, because efficiency improvements might well be dwarfed by an increasing demand. To give a homely example; while we may have scrapped our old and inefficient refrigerator, we now have two efficient refrigerators and the floor is heated in the bathroom. Haas (2004) gives a useful summary of facts about residential energy demand.

Energy demand by the household is a derived demand – we do not demand energy *per se*; energy is combined with other goods, typically a capital good, in order to produce (or derive) the services we ultimately wish for. For example, we combine electricity and a TV set, oil and a heating system, gas and a stove and so on and so forth.

The close connection between energy demand and capital goods has a number of implications and we highlight three of these here. First, there is the technological component. As technology improves, we can enjoy the same stream of services but with a lower energy input. The literature on the so-called "rebound effect" holds that efficiency improvements can paradoxically lead to higher energy use. According to an often used example, if someone invests in more efficient air-conditioning, he keeps his energy bill constant by adjusting the thermostat on the new device.

Secondly, there is a distinctly dynamic component of energy demand that clearly separates the short run from the long run. Thus, in the short run, the capital stock is fixed; we may be locked in to our heating system with limited possibilities to escape from, say, price increases. The short-run response is therefore likely to be, sometimes significantly,

2. The literature on technology adoption in agriculture the last 50 years suggests a similar pattern; not all efficient technologies are employed.

smaller than the long-run response to price changes, an insight with substantial empirical support as we shall see. The important lesson is that it takes time before a policy has effect simply because it takes time for households to adjust their real capital stock.

Thirdly, because decisions to buy a capital good are affected by income, the ultimate reason why energy use changes may well be changes in prosperity. Thus, at one level, we can explain why energy demand is affected by the number of appliances in homes. A more satisfactory explanation starts by considering the decision to buy a capital good as endogenous. Dubin and McFadden (1984) are the authors of a classic study that rigorously handled this issue.

3. Framework

There are many different frameworks that can be used to organise a review, including, for example, the so-called A-J model[3] of psychology. The comprehensive review by Lutzenheiser (1993) on social and behavioural aspects of energy use provides yet another way of delineating the empirical insights. Our framework is based on an augmented version of the simplest energy demand model for the household. Our approach separates the variables of interest into two subsets: "economic variables" and "other variables". Unfortunately, this is not a clear-cut separation, for the simple reason that "preferences" and "attitudes" can be put in both categories. We will nevertheless stick to this separation here.

Let us begin by discussing preferences and then turn to the various constraints that the household faces. Combining preferences and constraints with the assumption of utility maximisation will then lead to a demand function conveniently summarising a number of factors that ultimately affect demand. We proceed with comments of a more conceptual nature and try to pin down what various theories of choice and behaviour tell about what impact on energy use can be expected from different variables.

3.1 Preferences

Demand for energy depends on the household's preferences for goods and services. Preferences vary across populations; the elderly may well prefer an in-door temperature that does not suit the young and, as many parents of teenagers will testify, the number of showers varies with a household's demographic composition. Empirical research on residential energy demand shows how demand fluctuates between households of different sizes, composition and so on. What is more, demand differs between households of a given social class living in the same category of buildings. Importantly, even households with the same kind of equipment consume energy at different levels. Different preferences regarding, for example, the opportunity cost of time is one possible explanation of this fact.

Because preferences differ, it is obvious that two households with identical observable characteristics (income, education, sex and so on) may demand different baskets of goods, including energy goods. Detailed research by Lutzenheiser (1993, p. 249) shows

3. The A-J model of psychology examines the links between attitudes and behaviour (see Ajzen, 1991).

that similar households living in similar housing display widely varying energy consumption patterns. The conclusion is that if preferences are heterogeneous across the population, the response to price changes may well differ between otherwise identical households. We will come back to this point repeatedly.

While preferences are usually defined over goods that are sold in markets, it is reasonable to include non-market goods as well, when discussing demand for energy. Thus, energy demand will also depend on air quality or other non-market goods that relate to environmental quality. We know from the European Union's barometers that preferences over environmental issues vary substantially across the EU-25. This barometer provides some information about attitudinal variables, such as the households' view towards "green" consumption across the EU. There is abundant academic literature on the green consumer and the green firm. Whether or not consumers are willing to pay a premium for green goods remains unclear. Empirical results cut both ways and we cannot do justice to this large literature here, suffice it to say that the importance of the "green consumer" for energy consumption can hardly be neglected.

3.2 Income

Income is a key driver of residential energy demand and perhaps more important as such than what it would seem at first glance. Superficially, the link is straightforward. As we become richer, we can afford to use combinations of energy and capital goods as substitutes for, say, our input of time. For example, when buying a dish-washer, a washer or similar appliances, we can trade off some other private consumption goods to gain leisure time. Furthermore, as income increases, we might make intra-fuel substitutions and switch from one heating system to another that is likely to be more efficient. But perhaps the most useful insight we obtain from economic theory is that income encompasses many of the attitudinal variables that superficially appear to affect demand.

The concept of income seems to be rather important in this context. Indeed, it is reasonable to expect that energy demand is closely connected to future income, and perhaps more so than current income. Future income is uncertain and expectations about future income are notoriously difficult to model. In the review of empirical studies below, we give examples of how this problem has been handled.

3.3 Price

If the relative price of energy increases, we expect reductions of demand *ceteris paribus*. How strong the response to price is remains a subject of debate; economists are, perhaps, more optimistic than other researchers (Huntington, 1987). We will review insights from the literature on price elasticities below, but we will make some general comments before turning to the results.

The first point to make from a conceptual point of view is that we must consider two kinds of price elasticities, short run and long run. In a policy perspective, long-run elasticities might be considered more important, yet short-run elasticities will speak clearly about distributional consequences during a period of time when households have not fully adjusted their capital stock. Because time provides additional possibilities for adjustment, we expect long-term price elasticities to be larger, in absolute value. The empirical literature shows this pattern very clearly, notwithstanding significant variations from one study to another.

Secondly, it is known from basic economic theory that there is a close link between price elasticity and substitution possibilities. Hence, when substitution possibilities are limited, price elasticities will also be small. A household facing higher energy prices can typically use a whole array of different ways to lessen the impact of the price increase on their budget. For example, indoor temperature can be adjusted; washing schedules can be tweaked to reduce energy consumption and so forth. Ultimately, the household can move to a different house that uses another, less expensive, heating and cooling technology (in a general equilibrium setting, the relative price of such a house will have increased, however). Because these substitution possibilities vary across households (compare those living in apartments with metered consumption with those living in single-family homes), we expect price elasticities to vary across the population, a hypothesis that is given ample empirical support in the literature. It is also consistent with the general message here: households are heterogeneous as regards their consumption of energy and response to changing policies.

Thirdly, the bulk of the empirical literature on residential energy demand is based on a partial equilibrium view. In a general equilibrium analysis, one takes into account the fact that income depends on prices and that all markets interact, more or less directly. In such a setting, price responses are not as clear as in the partial equilibrium world, yet we still expect that higher prices will reduce demand.

Fourthly, expectations about the future must be considered when examining responses to current price changes, not the least when policy packages of various kinds have a direct impact on relative prices. Thus, policies such as some subsidy packages certainly affect the time profile of energy investments within the household, as, for example, when the government is expected to subsidise conversion from electrical heating the following year. The response to a price increase of electricity today is not necessarily the same then as when the household expects no subsidy for conversion: without the subsidy, it might be worthwhile to make the adjustment much sooner.

3.4 Attitudinal and other "non-economic" variables

Attitudinal variables portray an individual's state of mind or feeling. A definition of "attitude" in social psychology is the valuation of a concept or an object (Sjöberg and Engelberg, 2005, p.3). Useful reviews of the literature linking attitudes to residential energy demand include those by Lutzenheiser (1993) and Sjöberg and Engelberg (2005) ; Fransson and Gärling (1999) summarise the literature related to environmental concerns, arguing that these concerns are only weakly correlated with socio-demographic and psychological factors.

Overall, the links between attitudes and energy demand are often found not to be strong. Yet, recent studies of the California energy crisis are shedding new light on the role of attitudes as we shall see below. Insofar as the impact of demographic variables on energy consumption can be detached from income influence, empirics suggest that energy consumption varies over the life cycle, between ethnic *groups* (Poyer *et al.*, 1997) and cultural practices.

4. Empirics of residential energy demand

Empirical studies of energy demand have cascaded in waves, being propelled by the oil crises of 1973 and 1979 and later by the climate change issue. Earlier surveys include those by Taylor (1975), Bohi (1981), Dahl (1973), Madlener (1996) and Ferrer-i-Carbonell *et al.* (2000). A recent meta-analysis (Espey and Espey, 2004) summarises 36 studies on residential electricity demand published between 1971 and 2000 and covering the years from 1947 to 1997.

A significant number of papers use microdata focusing on electricity. Demand functions are estimated through variables such as prices, heating technologies, house type and socio-economic characteristics. A substantial number of studies often appeared first in the grey literature (*e.g.* consulting reports that look at the California energy crisis) or as part of research report series (*e.g.* those from national statistical offices).

An important change in the empirical literature on residential energy demand has been the more frequent use of detailed microdata on households. The shift towards microdata has opened the scope for detailed assessments of household behaviour by tapping recent developments in economic and econometric theory. It has enriched our understanding by unraveling the significant heterogeneities that exist.

We will now consider the different factors in turn, beginning with income. In each of these sub-sections, the different explanatory variables examined in the studies are reviewed and their significance compared and discussed.

4.1 Income elasticity

A basic lesson from the empirical literature on residential energy demand is that the link between income and demand is difficult to pin down precisely; the estimates vary considerably across studies. There are a number of potential reasons for this and we shall consider them briefly, but first let us discuss some of the empirical results.

Dahl's (1993) extensive survey concluded that our understanding of the links between energy demand and income was quite limited, despite the impressive number of studies. In an earlier survey by Taylor *(*1975*),* the author suggested that the results were too tenuous to merit a summary.

Dahl found a significant difference between studies based on aggregate data and those based on disaggregate data, and that elasticities lowered over time. She argued that the larger elasticities found in studies using aggregate data are due to the fact that they capture demographic change better. Overall, the income elasticity might be less than 0.4 in the short run and higher, but less than one, in the long run (p.182).

Similar conclusions were obtained in later surveys, *e.g.* the meta-survey of household electricity use in Espey and Espey (2004). In that analysis of 36 studies, the short-run income elasticity is in the range 0.04 to 3.48 with a mean of 0.28, and the long-run income elasticity ranges between 0.02 to 5.74, with a mean of 0.97 (p. 66). The short-run estimates were on the average higher in studies using time-series data and covering countries other than the United States.

The classic study (earning its authors a prestigious academic prize) on residential energy demand is the one by Dubin and McFadden *(*1984*)*. It was the first study to rigorously take into account the fact that there is both a discrete choice (buying certain equipment) and a continuous choice (consuming electricity, say) prevalent in energy demand. We choose which durable good to buy and how much of its services to consume simultaneously, so that the characteristics of the durable goods are endogenous in the demand equation.

Dubin and McFadden allowed choice for space and water heating to be natural gas or electricity and found an income elasticity barely greater than zero. Their approach inspired a large literature and is standard in engineering models (for instance, the Residential End Use Energy Planning System). The low income elasticity they found could be due to a number of factors, including the restricted choice set, only two fuels (see McClung, 1993).

Recent studies also using microdata generally find small income elasticities. Baker and Blundell (1991*,* UK data), Poyer and Williams (1993, US data), Nesbakken (1999*,* Norwegian data) and Rehdanz (2005, German data) all report energy expenditure elasticities of about 0.1 to 0.2. Recent micro-studies on electricity demand, those by Damsgaard (2003, Swedish data), Leth-Petersen (2002, Danish data) and Berkhout *et al.* (2004, Netherlands data) display congruent results: income elasticities are found to be in about the same range as those covering household energy consumption in total. When energy demand is dominated by heating expenditures, this is not a surprising result. However, as Vaage (2000, p.663) notes, time-series analysis often gives much higher values on the income elasticity (around unity or more), because households increase their stock of energy-using appliances when they become richer (and thereby their energy consumption).

Finally, it must be stressed that income elasticities are not necessarily constant. For example, they might be lower in the top deciles of the income distribution (Baker *et al.*, 1989*)*, they can be lower for newly established households (Halvorsen and Larsen, 2001); in general, they vary with socio-economic variables.

4.1.1 Measurement difficulties

Why is it so difficult to pin down the income elasticity, as Dahl's and Espey and Espey's surveys imply? First of all, income elasticities typically vary with type of data; as noted, time series often give higher elasticity estimates compared to cross-section data. Secondly, results might vary according to estimation technique, because each different technique typically entails different assumptions. Thirdly, in micro-econometric studies, it may be difficult to measure income precisely, if only because households can be reluctant to report their true income. Fourthly, the concept of income to be used could be of importance. Possible concepts include current income, expected future income and wealth.

4.2 Price elasticity

Economists have been quite optimistic regarding the price sensitivity of energy. As noted by Huntington (1987), by and large economists have been rightly optimistic. If nothing else, the oil crises OPEC I and II provided large natural experiments to verify the hypothesis; yes, over the longer term, households respond to price incentives. Even so, it might seem bold to suggest anything like a consensus estimate of price responsiveness. Yet, it seems as though a consensus estimate is 0.3 for the short run and 0.7 for the long run. But the variability is still substantial. Estimated elasticities vary across energy types, study types and regions. What is more, price elasticities vary according to household type, demographics and so on. We will come back to these points when discussing the non-economic variables in Section 4.3, but let us first return briefly to the results reported in previous surveys.

The extensive survey by Dahl (1993) provides a range of elasticities. For energy, the short-run price elasticity is often lower than 0.3. The NEMS (National Energy Modeling System, USA), uses Dahl's survey in its residential demand module and puts the short-run elasticity at 0.25 (EIA, 2005, p.24).

A selected sample of studies not focusing on electricity includes those by Baker *et al.* (1989) and Berkhout *et al.* (2004). They find price elasticities for gas ranging from 0.44 to 0.19. Turning to electricity, the survey by Taylor (1975) reports short-run and long-run price elasticities at 0.2 to 0.9 respectively. Bohi and Zimmerman's (1984) update of this survey presents rather similar results. In their meta-analysis, Espey and Espey (2004) suggest an average short-run (long-run) price elasticity for electricity of 0.35 (0.85). They find that short-run elasticities are generally higher in studies that include stocks, are based on time series and use average (rather than marginal) price, and lower in non-US studies. Long-run price elasticities are generally higher in studies that include stocks, substitutes, are based on time series and are undertaken outside the United States.

Reiss and White (2005) use detailed data on 1 300 Californian households to estimate price elasticities. They find that the response has a spike at zero; about 44 % of the households in the sample would not react to price changes in the short run. The distribution of elasticities is markedly skewed and about 13% of the households sample is estimated to have a price elasticity exceeding one. These results bring new light to the question of how households respond to energy price changes.

Price elasticities are not necessarily constant. For example, they might vary over time (Halvorsen and Larsen, 2001); over income groups (Rehdanz, 2005; Reiss and White, 2005a); across household sizes (Damsgaard, 2003); and also be different for price increases and decreases (Haas and Schipper, 1998). In general, they can vary across all variables that affect demand.

To summarise: empirical studies show that: *i)* households respond to price signals, and *ii)* residential energy consumption in the short term is one of the most inelastic goods in the economy.

Policies that affect the price of energy have impacts, but it will take some time before households adjust their capital stocks. Furthermore, the price responsiveness varies across households in a number of dimensions.

4.2.1 Measurement difficulties

After having established a significant variation of estimates, possible explanations of the variance remain to be explored. Beyond the methodological differences that are basically the same as already discussed for income, the key issue concerns variability of price within a given country. Before the deregulation of energy markets, there was little variation in *e.g.* the electricity price. If price does not vary, it is difficult to estimate the price elasticity precisely.

Furthermore, there may be limitations in the data; for example, electricity expenditures are not separated into fixed and variable costs. There is a literature on the difference between estimates based on average cost and those based on marginal cost (see Dahl, 1993 for a summary), and on the extent to which households understand the difference between these two concepts (see Lutzenheiser, 1993). It should be noted that price could vary in other ways. Reiss and White (2005, p.21, footnote 24) state that "An additional concern that has dogged this literature is that randomized pricing experiments are rare in energy demand research. Most rely upon voluntary participation and small samples, raising familiar attrition- and selection-bias concerns that impair generalization..."

We now turn to variables other than income and price that may affect energy demand. We will omit tenant/owner issues that have been dealt with by Levinson and Niemann (2004) and focus on a number of characteristics of individuals, households and more abstract items like information.

4.3 "Non-economic" variables

The extensive literature on energy demand includes, as noted, contributions from many fields. In what follows, we provide a glimpse of sociological, psychological and similar research. As stated in the introduction, this paper is essentially examining residential energy demand from an economic point of view; the summaries below are, indeed, incomplete. Our objective here, at any rate, is to distil some insights into the importance of the "non-economic variables".[4] We begin with some brief remarks on key conclusions from sociological and psychological research and then go on to look more closely at specific "non-economic" variables that may affect energy demand.

4.3.1 General findings

Lutzenheiser (1993), in perhaps the most comprehensive review available of social and behavioural aspects of energy use, details more than 200 studies that have observed household energy behaviour by means of a wide range of methods. The analysis supports the general argument presented here, namely that households are heterogeneous in many dimensions. Lutzenheiser also argues that a limit of economic studies is that they are based on tenuous assumptions, such as the assumption that fully-informed and rational consumers take decisions without regard to social contexts: "There seems to be a consensus in the literature, however, that adequate models of energy and behavior must be more directly concerned with the social contexts of individual action." (p. 262).

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4. Some studies suggest that attitudinal variables are important for deliberate behaviour (intent-oriented), while socio-economic variables are more important for understanding impact-oriented use of, say, energy. For example, there are studies showing that household energy use is mostly explained by socio-economic, rather than attitudinal, variables. But it is not difficult at all to find exceptions. For example, Carlsson-Kanyama *et al.* (2003) found, in their analysis of 600 Swedish households, that environmental attitudes and attitudes to energy are important for the use of appliances in households.

Shove (2003) has developed sociological models that look at evolutionary aspects; how do social norms regarding comfort and cleanliness develop over time? The importance of such variables for residential energy demand is commented upon below.

Sjöberg and Engelberg (2005, p.8) argue, from a psychological research angle, that "Research on energy consumption and conservation shows that attitudes are rarely much affected by campaigns, that attitudes have moderate predictive value, and that behavior is frequently not in line with expressed attitudes." Furthermore, they also claim that the largest share of the variance of energy consumption can be explained by differences in social habits. In a similar vein, Viklund (2002) concludes his review of the literature with "[there is] no room for psychological factors to explain energy savings behavior".

Finally, Aune *et al.* (2002, p. 10) summarise earlier research (from a socio-technic point of view) on household energy demand by claiming that "Among the results that still hold interest from this period [1973 to 1990], is that information campaigns are less effective than expected, that the link between attitudes and behavior concerning energy is weak..."

4.3.2 Specific findings I: Individual characteristics

Energy demand varies with the age of the individual, but the direction is not clear according to empirical evidence. For example, some studies suggest that older households are less likely to invest in conservation measures, for various reasons (lack of know-how, lower expected rate of return and so on). It has also been argued that elderly people live in sub-standard houses, raising the value of conservation measures. Liao and Chang (2002) report that an ageing population in the United States increases space-heating demand. Yamasaki and Tominaga (1997) present a detailed macro-analysis arguing that an ageing population pushes demand upwards in the Western world in general, and in Japan in particular. All the same, *a priori* there seems to be no particular reason to expect that age is positively or negatively correlated with demand, not the least because of the delicate issues of separating age from income. Some studies report that energy demand also varies across ethnic groups, a point we will return to below.

In a more comprehensive survey than this, *i.e.* one that included "non-stationary" energy demand (such as travelling), it would have been of interest to discuss "life style" variables. But we move on to household characteristics.

4.3.3 Specific findings II: Household characteristics

A number of studies point to household characteristics as key determinants But here again, results vary. The number of children has been found to affect demand: *i)* positively (*e.g.* Baker *et al.,* 1989); *ii)* insignificantly (Nesbakken, 1999; Vaage, 2000; Leth-Petersen, 2002); and *iii)* negatively (Rehdanz, 2005).

4.3.4 Specific findings III: Information

Whether or not information is an important driver of energy demand is a subject of seemingly never-ending debate between different researchers. Why, an economist might argue, is consumption of energy special? Why are the informational failures more attenuated in this area? At any rate, policies are often based on providing consumers with information and the question is whether targeted information affects residential energy demand.

Perhaps the most constructive piece of evidence is the recommendations that come out in Lutzenheiser's (1993) survey. Research has shown that mass information (via, say, labels) is "easily ignored", while more directed information seems more effective. Thus, a potentially useful line of attack is to use structured information through, say, "role models".[5] There seems much to be gained by tapping the experience and insights gleaned from the many experiments conducted in psychology on the role of information. What is more, fresh insights obtained via recent scrutiny of the California energy crisis provide food for thought. There, the message is rather more optimistic regarding the role of information campaigns (see Section 4.4.4 for additional details).

4.3.5 Miscellaneous findings: Weather

Demand is strongly correlated with the deviation from comfortable indoor temperatures. The recent years of unusually hot (and cold) weather in Europe have mapped into price increases on the market for carbon dioxide emission permits. These price changes are partly a reflection of residential energy demand. Almost all studies on the matter display a correlation between deviations from comfortable temperatures and energy demand. Indeed, rather than lowering indoor temperature to something like 16°C, indoor temperature is more in the neighbourhood of 20°C or more in Western Europe during the cold season. There is some evidence that cold weather affects demand more than hot weather (Henley and Peirson, 1998).

4.4 A sample of studies

This section summarises a few studies, selected essentially because they illustrate the new wave of micro-econometric demand analysis and because they include unique information about energy price fluctuations (the California energy crisis). There exist many other interesting studies, not reviewed here, such as those by Akmal and Stern (2001a and 2001b), Lins *et al.* (2002), Ryan *et al.* (1996). We also add a summary of a recent paper on the energy efficiency literature, because it has, *inter alia,* bearing on policy implications Rosenfeld *et al.* (2004).

4.4.1 Study of energy consumption in Germany by Rehdanz

Rehdanz (2005) studies residential energy demand in Germany, using extensive data on energy use by a large sample of German households (more than 12 000) in 1998 and 2003. The analysis focuses on conditional demand (the capital stock is given). She includes a substantial number of socio-economic background variables in her regressions and provides some interesting insights into factors such as age and the number of children in the household. The economic key variables, income and price, significantly affect energy expenditures; the expenditure elasticity is about 0.1. She reports a gas-price elasticity at 0.43 (p. 16), where expenditures are limited to those for space heating and water heating. Thus, the price elasticity is equal to -0.57, which is in line with other studies on gas demand by households. As noted, she finds that the number of children is

5. For instance via commercials that feature well-known individuals.

negatively correlated with energy expenditure. Overall, she finds that a set of socio-economic variables and descriptors of the building is correlated with household energy demand.

4.4.2 Study of energy consumption in Sweden by Damsgaard

Damsgaard (2003) collected a microdata set for Sweden with the explicit purpose of examining the relative importance of different explanatory variables driving electricity demand. He collected household survey data (household characteristics, size of dwelling, heating system, insulation and other energy conservation measures, the stock and use of appliances, and awareness about and interest in energy conservation issues) and he combined them with public and company register data on income, prices, consumption and local weather conditions. In all, the data set comprises 1 225 observations. He finds that the price elasticity is highest in households without direct electrical heating, a result which is not congenial to intuition. One would expect that, if the budget share for electricity is low (which it would tend to be in households that do not use electrical heating), the price elasticity would also be small (in absolute value). The income elasticity is generally found to be low, even zero, for households having electrical heating. This result is, on the other hand, intuitively plausible. When we become richer, we do not spend the extra money on heating the house even further (but over the long run, more appliances will be bought and will be driving consumption). Damsgaard further finds that advice on energy conservation has little or no effect on consumption. He concludes (p. 23) that "Overall the introduction of the attitude and interest variables has a small, if any, effect on the explanatory power of the regressions."

4.4.3 Study of household electricity demand in Norway by Halvorsen and Larsen

Halvorsen and Larsen (2001) use panel data to shed some useful light on price elasticity changes over time. They use the Norwegian Consumer Expenditure Survey from 1975 to 1994 within a discrete-continuous framework (see McFadden *et al.*, 1977). The pooled data provide information about 23 284 households, including detailed data on household characteristics, price and temperature. Their model relates electricity consumption to appliances (freezers, refrigerators, washing-machines, dishwashers and kitchen stoves), prices of electricity, alternative heating fuels (kerosene and heating oil), socio-economic household characteristics and heating days. The key contribution is the study of the price elasticity for electricity over time; it turns out to be roughly -0.8 at the beginning of the study period (1976) and at the end (1993). Demand became price-elastic over a short spell (1981/82). The most curious finding is that the long- and short-run elasticities are virtually the same. The explanation is, according to the authors, that there are no substitutes, even in the long run. As the authors explain, they only had information about household appliances. With more information about heating alternatives, it is likely that the results would have been different. The income elasticity is found to be rather low, around 0.1, but with a slight upward trend (the maximum is around 0.2). Interestingly, the income elasticity is lowest for newly established households.

4.4.4 Studies on the energy crisis in California

Studies of the California energy crisis in 2000 are now becoming increasingly available. Many of them shed new light on how consumers react to dramatic price fluctuations and information campaigns. Consumers experienced a significant electricity price increase in 2000, which was followed by price caps on residential electricity prices and public energy saving campaigns. Data therefore allow an assessment of how households respond to price incentives and public appeals. Reiss and White (2005b) find that consumers are surprisingly price-responsive; households are found to have cut consumption by about 12 % in roughly two months. However, when prices were capped, consumption rebounded. What seems more surprising is that public appeal to conserve energy "worked"; the average household reduced consumption even though it faced no pecuniary incentive to do so. In short, this study suggests that consumers may be reacting much quicker to pecuniary and non-pecuniary incentives than previously believed.

Bushnell and Mansur (2005) analyse the price variations faced by San Diego households during 2000. A key result is that consumers seem to be lagging behind in their response to price changes; their responses are primarily based on previous rather than current information.

Lutzenheiser (2002) presents a detailed exploratory analysis of the same crisis, combining in-depth telephone interviews with billing data. Given income and a number of other variables, conservation behaviour differs according to: ethnicity (African Americans are more likely to report turning off their lights and television set); age (the older the respondents, the smaller the probability that they shift use to off-peak hours); household composition (single parents are more likely to turn off equipments than couples with children for a given income); dwelling type (mobile home-owners are more frugal regarding energy) and square footage (the larger the house, the more likely appliances are turned off).

4.4.5 Rosenfeld et al. on energy efficiency

A useful summary of the developments and importance of energy efficiency appears in Rosenfeld *et al.* (2004). The authors argue that "The most effective path toward energy efficiency has been standards for autos, buildings, appliances, and equipment." (p.374)

They provide a striking illustration of how refrigerators have improved energy efficiency by about 5% per year since the late 1970s. The difference between 1974 and 2001 energy efficiency levels (assuming 150 million refrigerators) is the equivalent "of avoiding 40 GW of power plant". They go on to cite similar impressive energy efficiency improvements for other appliances, also pointing the lacklustre performance for cars. The main argument is that building and appliance standards, not the least when combined, can contribute to significant energy savings.

Of course, we do not know what the level of residential energy consumption would have been in the United States without the standards. Furthermore, imposing standards is not necessarily the most cost-effective way of reaching an energy saving goal, even though the authors promote energy standards as a key ingredient of energy policy.

5. Conclusion and policy implications

Empirical analysis of residential energy demand teaches two general lessons of significant policy importance. First, that human behaviour matters decisively for energy consumption; when shaping a more efficient energy policy, it is not enough to consider the various energy-saving technologies that exist. Secondly, that human behaviour varies considerably with regard to energy demand; thus, looking only at the averages can be misleading.

The rich literature on residential energy demand includes contributions by, *inter alia*, engineers, economists and researchers from other social sciences. Economists tend to stress the importance of economic variables such as price and income, engineers the existence of technological solutions (and the tardiness of adoption, the so-called energy paradox), while the force of attitudinal factors are focal points in studies by other social scientists. The relative importance of the factors thought to affect residential energy demand remains debated. Even so, empirical evidence strongly suggests that energy prices and income affect demand; the role of attitudinal variables is more uncertain.

Many empirical studies focus on electricity demand and use data from the United States. There are studies on other energy sources, notably petrol and natural gas, but a majority of those that concern us here (residential demand) deals with electricity. Furthermore, the empirical studies have been using a smorgasbord of different estimation methods, data sets and levels of aggregation (macro-economic *vs.* micro-econometric, state *vs.* country, and so on). Thus, it is not so surprising if results vary and are not straightforward to summarise. Let us, nevertheless, present a digest of some empirical insights:

- Demand for energy is generally quite price-inelastic. There is some consensus on the short-run price elasticity being about 0.3. The long-run price elasticity could be 0.7. The important point is that energy demand responds to price in a non-negligible manner over the long run. Economists have been more optimistic than many other researchers about the price response.
- Demand for energy responds to income, but the response varies substantially across studies. The income elasticity is likely to be lower than unity, even in the longer run. It is much lower in the short run. More recent estimates tend to suggest rather low income elasticities.
- According to the mainstream economic view, income encompasses a large number of factors that superficially seem to affect demand. For example, while additional appliances increase energy demand, they were bought because of income increases.
- Empirical studies are yet to converge on the relationship between socio-economic variables like age and number of children. In some studies the relationship is negative, in others non-significant; yet there are studies that find positive relationships.
- Attitudes have been found to correlate with energy conservation behaviour. Psychology-based studies show mixed results. Mass information has limited success. Targeted information campaigns can be more effective.
- Demand for energy depends on a host of exogenous factors, most importantly temperature. Insofar as the impact of demographic variables on energy consumption can be detached from the impact of income, empirics suggest that energy consumption varies over the life cycle, between ethnic groups and cultural practices.

General policy conclusions include the following:

1. Households respond to economic incentives and economists have basically been correct in their optimistic view on households' response to higher energy prices over the longer term. When structuring policy packages, it is important to keep in mind that the short-run response is much smaller; during the period when households are adjusting their capital stocks, consumption does not change much.
2. Because price and income elasticities vary across data types (times series, cross-section, panel), methodology, time period and short-run *vs.* long-run, it might be dangerous to use average elasticities when trying to judge a demand elasticity in a particular case.
3. Policies based on non-pecuniary incentives are widely used and widely debated. Recent analysis of the California energy crisis brings fresh and somewhat more positive results on the value of information programmes to curb energy consumption. Information campaigns can make a difference, at least in the short run, and all the more so if they are structured effectively.
4. Energy policy must be analysed broadly and holistically, given that many different factors influenced by other policies affect residential energy demand.

A comparative analysis of policy instruments cannot be undertaken without specifying the underlying policy objectives. In energy policy, objectives traditionally include safety, security, affordability and environment-friendliness. There may also be quite specific objectives such as reducing the use of electricity for heating (Sweden), improving energy efficiency in the residential sector (the Netherlands), promoting district heating (Denmark) and fighting fuel poverty (United Kingdom).[6] At any rate, we cannot go much further than the standard efficiency criteria in this paper.[7]

A wide range of policy instruments is currently being used in the OECD countries to address energy policy objectives.[8] These instruments include, among others:

1. Energy taxes
2. Energy efficiency standards for appliances
3. Energy labels
4. Energy conservation grants
5. Thermal efficiency standards

6. See *e.g*. the UK Government White Paper on Energy (DTI, 2003).

7. In the environmental economics literature, policy instruments are compared on issues such as *i)* precision (regarding reaching the policy target), *ii)* cost-efficiency, *iii)* incentives to develop new technologies, *iv)* revenue generation and *v)* equity properties. Usually no instrument dominates in all these dimensions.

8. A recent review of energy policy instruments covering more than 50 countries has been undertaken by the World Energy Council. Beyond the instruments considered here, it also includes energy audits; see www.worldenergy.org.

Comparative analysis of such instruments for *e.g.* residential space heating in certain countries is available in projects such as EPISODE[9]. We consider each instrument in turn:

Energy taxes. An overwhelming amount of empirical evidence, some of it included in this paper, shows that higher energy taxes reduce energy consumption. An impressive body of evidence also shows that energy taxes are regressive. From an efficiency point of view, they stand out as the most useful instruments.

*Energy efficiency standards for appliance*s. These are regulations that specify energy efficiency requirements that products must meet. They have been adopted in several countries for several products (*e.g.* refrigerators, air-conditioners and freezers). According to recent reviews, they have reduced energy use cost-efficiently (Nadel, 2002) and significantly (Rosenfeld *et al.*, 2004), creating only "minimal adverse impacts" on producers (Nadel). On the negative side, such standards could be considered (and used as) non-tariff barriers to trade, as several international disputes suggest (fuel efficiency standards have generated several international disputes reviewed in Zhang and Assuncao (2001). At least at a conceptual level, cost efficiency is in doubt.

Energy labels. Most, if not all, industrialised countries use energy efficiency labels for home appliances (Newman, 2000). As we have seen, their effect on behaviour is unclear. Priddle (in the Foreword to Newman, p.3) enthusiastically kicks off a recent IEA review of energy labels with the statement "Policy makers cannot afford to neglect them". True, labels could be inexpensive instruments and, if they deliver, remain a very attractive policy instrument. Yet, the links to non-tariff trade barriers are important from an efficiency point of view and the impact of labels on choice remains unclear.

Energy conservation grants. These grants come in various forms and are sometimes motivated by the well-established fact, as we have seen, that consumers (and firms) often use a high implicit discount rate for energy conservation investments. Despite substantial empirical evidence, debate still continues on whether or not there exists a market failure of import in this case. Subsidies that are not connected to an underlying market failure are socially costly and should be avoided from an efficiency perspective.

Thermal efficiency standards. Empirical evidence suggests that they have been important as building standards seem to have reduced the demand for space heating in certain countries, as is asserted in Rosenfeld *et al.* (2004). From an efficiency point of view, the usual argument applies: in a perfect market these standards are hardly needed.

Which policy instrument is the most suitable? Again, the answer to this question depends on the objectives: what is the policy trying to achieve? Furthermore, we need to define exactly the reason why policy A is preferable to policy B. That is not easy to pin down, as centuries of debates in various studies show. For the most part, many economists are satisfied with an efficiency criterion; A is better than B if the goal is reached at least cost. This depends on the possibility of separating efficiency and equity, so that distributional concerns can be mitigated in the usual ways (via parameters in the tax system, for example). Theory and empirics strongly suggest that incentive-based

9. EPISODE is a project funded by the EU on "effective policy instruments for energy efficiency in residential space heating-an international empirical analysis".

instruments are the most cost-effective in meeting an energy-saving objective. It is equally well-known that taxes on energy, for example, have a regressive impact. Much less is known about the distributional impacts of other instruments, but they can certainly have regressive impacts as well. (see Serret and Johnstone, 2006).

From an efficiency viewpoint, there is little to conclude beyond the fact that incentive-based instruments have an advantage. As noted, the other instruments have affected energy use, save the unclear impact of labels. From an equity point of view, no clear conclusion emerges, because each case will be unique. If an energy tax is increased, for example, equity impacts depend on how revenues are returned. Reducing labour taxes (as per the "double dividend" argument) maps into a different, and typically more regressive, distributional profile compared to a lump-sum return (see Serret and Johnstone, 2006). The next stage of this project will be tailored to provide additional information about the effects of different policy instruments across different populations.

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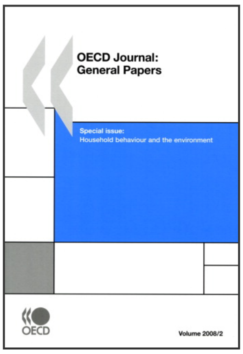

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