Determinants for the take-up of energy efficient household appliances in Germany

Draft Working Paper No. 2 within the project:

Soziale, ökologische und ökonomische Dimensionen eines nachhaltigen Energiekonsums in Wohngebäuden

Funded under the BMBF Programme
„Vom Wissen zum Handeln
- Neue Wege zum nachhaltigen Konsum“

Draft Version 1

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Authors: Joachim Schleich & Bradford Mills, Fraunhofer ISI

Karlsruhe, 30 June 2008

1 Introduction

Major household appliances account for 35 percent of total EU 15 residential end-use electricity consumption (Bertoldi and Atanasiu, 2007). Refrigerators and freezers alone account for 15 percent of residential electricity end-use, with washing machines accounting for 4 percent and dishwashers, electric ovens, and clothes dryers accounting for approximately 2 percent of total residential end-use, apiece. Increasing the energy efficiency of these appliances is crucial for realizing the European Council Action Plan for Energy Efficiency target of 27 percent residential energy-savings compared to expected baseline growth by 2020 using cost-effective technologies (European Council, 2006).

The EU appliance energy consumption labeling scheme has been a key component of past efforts to increase the diffusion of energy-efficient appliances (Bertoldi and Atanasiu, 2007). Labeling schemes are often promoted as a cost-effective measure to overcome barriers related to information and search costs, or to bounded rationality on the part of appliance purchasers (Sutherland, 1991; Howarth et al., 2000). In this case, the labeling scheme is designed to make consumers aware of the relative energy-efficiency of appliances and associated potential cost savings through the provision of observable, uniform, and credible standards. The generation of this consumer information is, in turn, expected to create market incentives for appliance manufactures to design more energy-efficient products, and may reinforce price-induced technological innovation. For example, Newell et al. (1998) find that the mean energy efficiency of water heaters and air conditioners offered in the US rose significantly once a labeling scheme was introduced in 1975.

The effectiveness of the energy labeling scheme in driving reductions in residential energy consumption depends on two outcomes. First, consumers have to be aware of the classification system. Second, the labeling system has to influence consumer purchase decisions. In this paper we examine the determinants for the choice of seven major kitchen and washing appliances based on a unique data set of more than 20.000 households in Germany. Specifically, we empirically explore both consumer knowledge of the EU Energy Consumption Labeling Framework for major kitchen and clothes washing appliances and the factors that influence consumer choice of class-A energy-efficient appliances. Since only households who are aware of the energy labeling scheme may respond to survey questions on the energy class of the appliance, the analysis of determinants of consumer choice of energy-efficient appliances may suffer from knowledge-based selection bias. Thus, we jointly estimate the determinants of knowledge of the energy labeling scheme with the determinants of class-A appliance choice.

The remainder of the paper is organized as follows. Section 2 provides an overview of the literature on the determinants for the take-up of energy efficient measures in general taking into account that the diffusion of such measures may be motivated by economic factors as well by attitudes towards the environment.

Then, Section 3 describes the EU Energy Labeling Framework and its implementation in Germany. Section 4 presents the statistical model and the specification of factors potentially associated with both knowledge of appliance energy class and choice of class-A appliances. Study data are outlined in Section 5 and estimation results are presented and discussed in Section 6. The paper then concludes by distilling implications for enhancing the adoption of energy-efficient appliances.

2 Determinants for the take-up of energy efficient appliances

Incentives for households' take-up of energy efficient appliances may be twofold. First, from an economic perspective, utility-maximizing households are assumed to aim at minimizing the costs for services like cooling of foods or drying of laundry. Hence, besides the initial purchasing expenditures, the energy performance and associated energy costs of appliances over time are expected to be relevant criteria for technology choice, along with other characteristics like size, design, reliability or other operating costs. Second, since purchasing energy efficient appliances results in lower resource use and lower emissions of local and global pollutants, environmental degradation is reduced. Thus, in economic terms, the adoption of an energy efficient appliance also creates a public good in terms of a cleaner environment.

Existing studies on the adoption of energy efficient measures in households are typically based on different, partially over-lapping, concepts form economics (including behavioural economics), psychology (including the marketing-related literature on consumer behaviour) and sociology. Preferences towards the environment are usually elicited via contingent valuation studies. Survey-based analyses on the diffusion of energy efficient activities typically include factors related to the following categories (e.g. Dillman et al. 1983, Olsen 1983, Walsh 1989, Long 1993, Scott 1997, Brandon and Lewis 1999, Dzioubinski and Chipman, 1999, Barr et al. 2005, Carlsson-Kanyama and Linden 2007, or, in particular, Sardianou 2007):

1. characteristics of the household (occupants)
2. characteristics of the residence
3. characteristics of the measure (technology)
4. economic factors
5. weather and climate factors
6. information diffusion
7. attitudes/preferences towards the environment

Household characteristics include disposable household income, age, gender, education, occupation, marital status, family size, number of children and home ownership. Information on residence is captured via age of the house, house type, number of rooms and size of residence (in m^2) and access to energy carriers (i.e. connection to electricity, distance heating or gas grids). Characteristics of the measure are, for example, size, design, reliability, service quality, energy performance, other operating performance (e.g. water use for dishwasher and washing machines), or suitability in existing technical infrastructure. Economic factors consist of energy (and other input) prices, purchasing/capital costs, and – if there are support mechanisms in place – also rebates, taxes/subsidies. Weather and climate factors are usually captured via cooling/heat degree days affecting the economic benefits associated with energy-efficient measures. Data on categories (1) to (5) - and possibly (6) - may be directly observed, while information on (7), i.e. attitudes/preferences towards the environment (including cultural factors like religion, or lifestyle) needs to be elicited in surveys either directly via appropriate questions related to the relevance of concerns for the environmental (stated preferences), or indirectly via observed or stated actions and behaviour like recycling activity, membership or support for environmental lobby groups, voting behaviour etc… . .

In light of the interdependencies among those factors (and categories), the relevance of individual variables (or concepts) cannot always be clearly identified or distinguished. For example, the level of education is expected to affect the level of disposable income, or households' attitudes towards environmental degradation.[1] To the best of our knowledge, no studies exist which specifically explore the impact of those factors on the actual diffusion of energy-efficient household appliances based on survey data. Hence the findings for energy-saving measures in households in general may serve as proxies. Among others, Curtis et al. (1984) point out that energy-savings measures may be distinguished in (i) low-cost or no-cost measures which do not involve capital investment but rather behavioural change (e.g. switching off lights, substituting compact fluorescent lamps for incandescent light bulbs) and (ii) measures which require capital investment and involve technical changes in the house (thermal insulation of built environment, double- or triple-glazing windows). Purchasing a new appliance usually does not require technical changes in the house, but purchasing expenditures may be high.

As for the impact of income, results from most studies imply that higher income is positively related with energy-saving activities/expenditures, e.g. Dillman et al. (1983) and Long (1993) for the US, Walsh (1989) for Canada, Sardianou (2007) for Greece, and Mills and Schleich (2008) for Germany.[2] Thus, richer

[1] See Shen and Saijo (2007) for a recent econometric analysis of the impact of household socioeconomic characteristics on environmental concerns. Torgler and Garcia-Valinas (2007, Section 2) provide a recent overview of factors affecting individuals' attitudes towards preventing environmental damage. For an international comparison of the effects of gender, age and parental status, see Torgler et al. (2008).

[2] However, Curtis et al. (1984) find no statistically significant correlation of energy saving activities and income in Canada (Province of Saskatchewan).

households are less likely to face income or credit constraints for investments in energy efficiency. Further, environmental concerns may increase with income (Fransson and Garling, 1999). Similarly, income elasticity of willingness to pay for environmental benefits is found to be positive (Kriström and Riera, 1996). Empirical findings for Canada by Young (2008) suggest that richer households also tend to be associated with a higher turnover rate for household appliances, providing greater chances for energy-efficient appliances to replace older, less energy-efficient appliances.

With regard to the impact of education levels on energy saving activities, the empirical evidence is rather mixed. Among others, the econometric analyses by Hirst and Goeltz (1982) for the US, by Brechling and Smith (1994) for the UK and by Scott (1997) for Ireland confirm that higher levels of education are associated with greater energy-saving activities. Reasons include, for example, that a higher education level reduces the costs of information acquisition (Schultz, 1979). Likewise, education, as a long term investment, may be correlated with a low household discount rate and, thus, be positively associated with energy savings measures. Such measures often require higher up front cost for investment, while savings in energy costs materialize in the future. In addition, attitudes towards the environment as well as social status, lifestyle (Lutzenhiser 1992, 1993, Weber and Perrels 2000) or belonging to a particular social milieu group (Reusswig 2004) approving environmentally friendly behaviour tend to be positively related with education. Similarly, Torgler and Garcia-Valinas (2007, p. 538) cite several sources suggesting that higher education levels are associated with higher levels for environmental protection. In contrast, the analyses by Stead (2005) – based on a survey in the EU 15 Member States on appliances in general and lighting – and by Mills and Schleich (2008) for the diffusion of energy efficient light bulbs in Germany do not imply a statistically significant impact of education levels. Likewise, the recent survey on attitudes towards the environment in Germany, no longer finds a statistically significant impact of education (BMU 2006).

Most existing studies find that higher energy prices accelerate the diffusion of energy efficient technologies or are associated with higher expenditure for energy saving measures (e.g. Walsh 1983, Long 1993, Sardianou 2007, Mills and Schleich 2008). As suggested by economic theory, higher prices for energy services (such as heating and cooling) render energy efficient measures more profitable and should thus result in a higher take-up of these measures.

According to Walsh (1989), who finds that older household heads are less likely to carry out energy efficiency improvements, such investments yield a higher expected rate of return for younger investors. For household appliances (and light bulbs) this argument may be less relevant than for thermal insulation of the built environment. Further, as suggested by Carlsson-Kanyama et al. (2005), younger households tend to prefer up-to-date technology, which is usually also more energy efficient. Lower take-up of energy efficient technologies by elder households may also interact with older people’s fewer years of formal education, and lower information on energy savings measures. For example, survey results by Linden et al. (2006) for Sweden indicate that younger people have better knowledge about energy-efficient measures than older people. Clustering individuals into different types, findings by Barr et al. (2005) for the UK, and by Ritchie et al. (1981) and Painter et al. (1981) for the US suggest that “energy savers” are older. Addressing environmental concerns directly, the studies by Whitehead (1991) and by Carlsson and Johansson-Stenman (2000) – cited by Torgler and Garcia-Valinas (2007) – found that willingness to pay for environmental protection decreases with age, arguably, because a shorted expected remaining lifetime results in lower expected benefits from environmental preservation compared to younger people. Torgler and Garcia-Valinas (2007) for Spain and Torgler et al. (2008) for 33 Western European Countries also observe a negative correlation between age and environmental attitudes/preferences. Similarly, according to Howell and Laska (1992) – also cited by Torgler and Garcia-Valinas (2007) – younger people in the US are more concerned about the environment than older people. For Germany, the reverse appears to be hold (BMU 2006). However, as Torgler and Garcia-Valinas (2007) point out, age effects need to be decomposed into a life cycle effect which stems from being in a particular stage of life, and into a cohort effect which results from belonging to a particular generation with generation-specific experiences, socialization and economic conditions (e.g. “flower power generation” versus “baby boomers”). Thus, depending on the timing of the survey, age may turn out to have quite different effects on the take-up of energy efficient measures. Further, the relationship between age and the take up of energy savings measures, however, may not be linear and is likely to depend on the measures considered. Also, the impact may differ across countries.

Household size is expected be positively related to the adoption of energy efficient appliances because more intense use would lead to faster replacement (e.g. Young 2008). Similarly, the more persons there are in the household, the more profitable it is to acquire information on the energy performance of appliances and to purchase energy-cost saving appliances. The literature, however, appears to provide mixed results. For example, empirical results by Curtis (1983) imply higher energy saving activity for households with two to four members than for other household sizes, while the impact of household size on energy saving expenditures in the study by Long (1993) is negative. For similar reasons, the number of young children in the household is expected to increase diffusion of energy-efficient appliances like washing machines or dryers. In addition, since parents may be more concerned about short and long run local and global environmental effects, which also influence current and future wellbeing of their children (Dupont 2004), the number of children may be positively related to the take-up of energy-efficient technologies. However, the study by Torgler et al. (2008) does not find a positive relation of parental effect on preferences.

Renting, rather than owning a residence has been found in a number of previous studies (e.g. Curtis et al. 1983, Walsh 1983, Painter et al. 1983, Scott 1997 or Barr et al. 2005) to inhibit the adoption of energy-saving technologies, as it is difficult for residence owners to appropriate the savings from investments in energy-saving technologies from tenants (Jaffe and Stavins, 1994; Sutherland, 1996). As Black et al. (1985) emphasize this user-investor dilemma holds in particular for energy saving measures requiring large capital investment like thermal insulation of the outer walls, roofs, or attics.

Since households with larger residences have on average more appliances and higher levels of energy consumption, they are likely to have greater interest in, and knowledge of, household energy consumption and consumption saving technologies, particularly if the cost of information gathering is relatively fixed. Larger residences may also have greater economic incentives to invest in energy-saving technologies if appliance use is greater. Some studies like Walsh (1983) or Mills and Schleich (2008) find the expected positive relation between housing size and the take-up of energy-efficient measures, while others, such as Sardianou (2008) find no statistically significant correlation.

Unless recently refurbished, older houses should have higher potentials for (profitably) energy savings measures. Thus, the age of a dwelling is expected to be positively related to the diffusion of energy-efficient measures. This argument holds in particular for measures improving energy efficiency in the build environment. Because of shorter lifetimes it should be less relevant for household appliances, which typically last for around ten years or less (OECD 2002).

Location may also affect the take-up of energy efficient measures. In particular, urban households may have easier access and thus lower transaction costs than rural households. Likewise, larger cities (or utilities in larger cities) tend to be more active in terms of implementing and promoting environmental policies, including policies to raise awareness. On the other hand, citizens in smaller cities and hence more rural areas may have stronger preferences towards the environment. Thus, in general the sign of the relation is ambiguous. Among others, Loomis et al. (1993), Carson et al. (1994) for the US, and Veisten et al. for Norway (2004) report a positive relationship between urbanisation and willingness to pay for environmental amenities based on contingent valuation methods. Relying on survey data (for Spain) Torgler and Garcia-Valinas (2007) conclude that individuals in urban areas exhibit stronger attitudes towards preventing environmental damage. The econometric analyses by Scott (1997) for the observed diffusion of several energy efficient technologies in Ireland also suggests a positive relation.

In general, information diffusion relates to the level and quality of knowledge about (i) energy-efficiency measures, of (ii) energy consumption (patterns) and costs for existing and new technologies as well as (iii) knowledge about the environmental impact of the particular technology alternatives. From an economic perspective rational household behaviour presumes that households are well informed about the technological alternatives and their associated the costs (including energy costs). For example, information on energy operating costs is typically transmitted via energy bills, where frequency, design and other marketing elements may be relevant. For Norway, Wilhite and Ling (1995) report that more frequent and more informative billing, lead to energy savings of around 10% (cited by Sardianou 2007). Information on the energy performance of technologies (in particular appliances) is typically transferred via energy-consumption labels. Information about energy-efficient technologies is often transmitted via campaigns by local, regional, national and international administrations or institutions, by energy agencies, consumer associations, technology providers and their associations, or by utilities. Scott (1997) finds lack of adequate information on energy saving potentials to be a barrier for several energy efficiency technologies in Irish households.

From a behavioural and transaction cost perspective, what matters is not only the availability of information but also the *credibility* of the source (Stern, 1984, p. 43). For example, Craig and McCann (1978) find that New York households' response to information on energy savings measures was stronger if the information was provided by the state regulatory agency rather than by the utility. Along similar lines, Curtis et al. (1984) find that a greater variety of sources is positively correlated with energy efficient activities. Even if even households were perfectly informed and the incentive structures were appropriate, the concept of bounded rationality suggests, that cognitive limits on the ability to adequately process information may prevent optimizing behaviour (Simon, 1957, 1959). Consequently, some profitably opportunities for improving energy efficiency are neglected. For example, households may not be able to use the available information on specific energy consumption per time or load, utilization rate, energy cost savings for the useful lifetime of the technology, and initial purchasing costs for an appropriate lifecycle cost assessment (Schipper and Hawk 1991).

While information may improve the level and the quality of knowledge, improved information need not necessarily result in sustained energy savings. While energy savings resulting from technology choices tend to have long run effects, behaviour-related savings may only be transitory (e.g. Abrahamse et al. 2005). Likewise, for households' purchasing decisions to reflect their preferences towards the environment, they also need to be aware of the environmental consequences of the choice alternatives (e.g. Danielson et al. 1995).

Besides by economics factors, households' decisions for energy savings measures may be driven by social or psychological factors. For example, Barr et al. (2005, p. 1440) conclude in a more general context, that „environmental behaviours must be placed within a broader conceptual context, in which environmental action is not conceived in isolation, but in holistic terms that makes explicit the embedded relationships between lifestyles and specific behaviours." According to Sardianou (2007, p. 3783), empirical studies capture these social or psychological effects by exploring the impact of cognitive variables such as values, beliefs, or attitudes towards energy conservation (Gardner and Stern 1996). Social factors, in particular social norms (= expectations about appropriate behaviour) shared by relevant groups, may influence households' energy efficiency activities. Factors identified in the literature to have an impact on energy efficiency activities include the legitimacy of environmental problem, the seriousness (e.g. environmental pressure; resource scarcity), personal exposure, the believe that one's own action has an impact (public good character) and personal benefits from action (private good character).

Most studies do not allow for a distinction between the relative contribution of factors related to the cost savings and attitudes towards the environment. Although Brandon and Lewis (1999) find that environmental attitudes and believes are relevant, but financial consideration are at least as important.

In any case, attitudes towards environment may lead to good intentions, but they do not necessarily translate into action. Social norms, lack of information about the implications of alternative actions on the environment, or institutional factors may act as barriers towards actual implementation (Van Raaij and Verhallen 1983).[3]

[3] Also note that because of a „hypothetical bias", willingness to act or pay may be overstated in contingent valuation studies, which would explain part of the presumed gap between intentions and the behaviour actually observed.

3 The Energy Labeling Framework

According to the EU Directive on Energy Labeling of Household Appliances ("Labeling Directive") (CEC, 1992) the retail trade is obliged to provide certain household appliances with energy labels at the point of sale. Among others, the label includes standardized information on electricity. Originally, the seven efficiency classes ranged from the green class-A label for the best performance to the red Class-G label for the worst performance. In Germany the Directive became national law effective in January 1998 for refrigerators, freezers and their combinations, for washing machines, for tumble driers and their combinations, in March 1999 for dishwashers, in July 1999 for lamps, and in January 2003 for electric ovens and air-conditioning appliances. After September 1999 new fridges with classes D to G and freezers with E to G were no longer allowed. The Directive (CEC 1992) also foresees a labeling scheme for water heaters and hot-water storage appliances, but the EU has (as of early 2008) not yet crafted a corresponding implementing directive which provides the technical details on how the labeling classes are being defined for water heaters and hot-water storage appliances. For the other household appliances such implementing directives were published by the EU in 1994 for refrigerators, freezers and their combinations, in 1995 for washing machines, dryers and their combinations, in 1997 for dishwashers, in 1998 for lamps, and in 2002 for electric ovens and air-conditioning appliances. Thus, while Germany was one of the last EU Member States where the "Labeling Directive" became national law, appliances with EU labels were present in the

German market prior to 1998, last but not least because appliance manufacturers had to comply with the provisions of the directives in other EU Member States. However, even in Member States where the EU appliance scheme became national law early on, evaluations for refrigerators and freezers suggest that compliance with the labeling obligation in the retail sector was rather poor, i.e. a large share of refrigerators and freezers were not correctly labeled (Winward et al., 1998). For Germany, Schlomann et al. (2001) find, that the highest share of completely and correctly labeled large household appliances are found in large scale specialist stores or hypermarkets while for retail stores specializing on kitchen or furniture, the level of compliance was generally poor.

EU-wide early evaluations on the effectiveness of the labeling scheme for refrigerators and freezers (Waide, 1998) and also for washing machines and wash-driers (Waide, 2001) conclude that the scheme has increased the market share of energy-efficient appliances. However, some portion of efficient appliance uptake occurred, independent of the incentives created by the labeling scheme. Since the counterfactual level of adoption cannot be determined, it is difficult to quantify the actual contribution of the scheme to the diffusion of energy-efficient appliance. However, the current paper does provide an important snap-shot of factors associated with knowledge of the labeling scheme and purchase of class-A appliances at the end of 2002, four years after official implementation of the labeling directive for most major appliances in Germany.

4 Study Framework

The analysis of determinants of consumer choice of energy-efficient appliances is potentially subject to serious knowledge-based selection bias when only households who are aware of the energy labeling scheme respond to survey questions on the energy class of the appliance (see Figure 1). Positive responders may have different observed and unobserved attributes, particularly with respect to awareness of energy use and concerns about environmental impacts that potentially bias parameter estimates of the determinants of class-A energy efficient appliances. However, such knowledge-based sample selection bias can be controlled for by jointly estimating the determinants of class-A appliance choice with the determinants of knowledge of the energy class of the appliance (e.g. van de Ven and van Praag, 1981).

4.1 Statistical model

Formally, the latent relationship between household attributes and choice of a class-A appliance is:

$$y_i^* = x_i B + u_{1i} \tag{1}$$

where y_i^* is a latent measure of household preferences for the class-A appliance, x_i is a row vector of household *i* characteristics, B is the parameter vector to be estimated, and u_{1i} is a residual term. The observed outcome is:

$$y_i = 1 \quad \text{if} \quad y_i^* > 0$$
$$y_i = 0 \quad \text{if} \quad y_i^* \leq 0 \qquad (2)$$

However the purchase decision is only observed if the energy-class of the appliance is known by the respondent. Respondent latent knowledge of appliance energy class is modeled as:

$$s_i^* = z_i \Gamma + u_{2i} \qquad (3)$$

where s_i^* is a latent measure of household knowledge of the appliance classification, z_i is a row vector of household *i* characteristics, Γ is the parameter vector to be estimated, and u_{2i} is a residual. Observed response to the survey question on energy-class on the appliance is:

$$s_i = 1 \quad \text{if} \quad s_i^* > 0$$
$$s_i = 0 \quad \text{if} \quad s_i^* \leq 0 \qquad (4)$$

Estimation of class-A energy-efficient appliance choice with the sub-sample of respondents who provide a response on appliance energy class is equivalent to:

$$E(y_i^*) = x_i B + E(u_{1i} \mid x_i, s^* \geq 0). \qquad (5)$$

Assume $u_1 \sim N(0,1)$, $u_2 \sim N(0,1)$, and $\rho = \text{corr}(u_1, u_2)$, then

$$E(u_{1i} \mid x_i, s^* \geq 0) = \rho\lambda_i \qquad (6)$$
$$\text{where } \lambda_i = \theta(z_i\Gamma)/\Theta(z_i\Gamma)$$

λ_i is the inverse of the Mills ratio, i.e. the ratio of the normal density function $\theta(.)$ over the cumulative distribution function $\Theta(.)$.

If the error terms of the energy-class choice equation and the energy-class knowledge equation are correlated then $E(u_1) \neq 0$ and the regression results will be biased. Unbiased parameter estimates can be recovered either by including $\hat{\lambda}_i$ as a predicted variable in the Probit energy-class choice equation as suggested by Heckman (1976) or more efficiently by maximum likelihood estimation of the bivariate normal distribution $F_2(u_1, u_2)$ and the probability of sample exclusion $F(u_2)$ underlying the data generating process as:

$$\prod_{i=1}^{N_1} F_2(x_i B, z_i\Gamma; \rho) \prod_{i=N_1+1}^{N} F_2(-x_i B, z_i\Gamma; \rho) \prod_{i=N+1}^{M} F(-z_i\Gamma) \qquad (7)$$

where 1 to N_1 are observations for which the energy-class of the appliance is known and a class A appliance is chosen, N_1+1 to N are observations for which the energy-class of the appliance is known and a class A appliance is not chosen, and N_1+1 to M are observations for which the energy class of the appliance is not known. This maximum likelihood estimator is employed in the current application.

4.2 Model specification

Knowledge of the energy labeling scheme is measured by household responses on the question of the energy-efficiency class of their refrigerators, freezers, refrigerator and freezer combination units, dishwashers, and washing machines. Specifically, respondents who indicate that they own a certain type of appliance but do not provide a labeling scheme classification of between A and G on the questionnaire are categorized as unaware of the energy-rating of the appliance.

Residence characteristics

Residence characteristics may influence both the knowledge of labeling scheme and the choice of class-A appliances. In the empirical model, particular attention is paid to the age of the residence. Households living in residences built after 1997 are much more likely to have purchased a refrigerator, freezer, refrigerator-freezer combination unit, or a washing machine after the official implementation of the energy-labeling scheme for these appliances in the beginning of January 1998 and, thus, to have been exposed to the labeling scheme when purchasing the appliance. Similarly, households in residences built after 1998 are much more likely to have purchased a dishwasher after the official implementation of the energy-labeling scheme in March 1999. Discrete indicators for residences built in 2002, 2001, 2000, 1998-1999, 1996-1997, 1993-1995, 1990-1992, and 1985-1989 are included in the knowledge of energy-class specification. New detached residences may be especially likely to be equipped with new kitchen and laundry appliances, therefore a separate indicator for detached residences built after 1997 is also included in the knowledge of energy-class specification. The same set of indicators on the year of residence construction is also included in the class-A appliance choice specification. Households in more recently constructed residences may be more likely to purchase class-A appliances as the share of appliances sold that are class-A has trended upward over time at the market level (Europe Economics, 2007).

Renting, rather than owning, a residence has been found in a number of previous studies to inhibit the adoption of energy-saving technologies, as it is difficult for residence owners to appropriate the savings from investments in energy-saving technologies from tenants (Jaffe and Stavins, 1994; Sutherland, 1996). However, in Germany the vast majority of tenants supply their own appliances and pay for electricity usage. Thus, the influence of tenancy on benefit appropriation may be rather limited for class-A appliances. Further, renters change residence more frequently than owners and may have purchased appliances more recently as a result, which would increase the likelihood of tenants knowing the energy class of appliances relative to residence owners.

Households with larger residences have on average more appliances and higher levels of energy consumption. As a result, larger residences are likely to have greater interest in, and knowledge of, household energy consumption and consumption saving technologies, particularly if the cost of information gathering is relatively fixed. Larger residences may also have greater incentives to invest in energy-saving technologies if appliance use is greater. Thus residence size, as measured by floor space in square meters, is included as a variable in both the knowledge of energy class and choice of class-A appliance equation specifications.

Household characteristics

Characteristics of the household included in both the knowledge of energy class and class-A purchase equation specifications include family size and if children under six years of age are present. The intensity of use of major appliances increases with the number of persons in the household, making it more profitable to both acquire information on the energy class of appliances and to purchase class-A appliances. The use of washing machines may be especially high in households with children under six years of age because they have disproportionately high laundry needs. A quadratic specification of age of the main household income earner is also included in both equation specifications. Older household heads may find it more difficult to process information on new technologies. Elderly households may also be less likely to have recently purchased a new appliance, especially when compared to young families which have just established a household. An indicator for retired heads of households is also included in both specifications. Retirees may have more free-time for shopping and, therefore, potentially greater awareness of the attributes of appliances after controlling for age. Whether retirees are more or less likely to purchase class-A appliances after controlling for other factors is left as an empirical question.

Higher education reduces the costs of information acquisition (Schultz, 1979), making it more likely that a person understands the class of an appliance when exposed to sticker information. Education may also be positively related to the purchase of a class-A appliance. Cost-savings from the purchase of a class-A appliance occur over several years, but the additional purchase costs occur up front. Education, as a long term investment, may be correlated with a low household discount rate and, thus, be positively associated with class-A purchase. Unfortunately, the survey provides limited information on the education of the highest income earner and only a discrete indicator of secondary school attainment is included in the specifications.

An indicator for households headed by senior officials, senior managers, or highly skilled professionals is also included in both the knowledge of class and class-A purchase equations. The influence of job type on consumer knowledge of appliance energy classes is unclear a priori. On the one hand, senior managers and skilled professional may better understand information on appliance energy classes. On the other hand, the higher opportunity cost of time of this group of workers may reduce their willingness to invest in information. Class-A appliance choice may also be influenced by job type if senior managers and skilled professional are better able to calculate the potential profitability class-A appliances. Household income often has a major influence on the adoption of residential energy-efficient appliances. Environmental concerns and awareness may increase with income (Fransson and Garling, 1999), which would lead to greater knowledge of appliance energy classes. Similarly, the propensity to purchase class-A appliances may increase with income levels because the income elasticity of willingness to pay for environmental benefits is positive (Kriström and Riera, 1996). An indicator of whether the household resides in East Germany is also included in the specification, as that part of the county underwent rapid social change and residents may be disproportionately likely to have recently changed residence. East German residents have also been found to have generally lower levels of environmental awareness (BMU, 2004).

Owning more than one of the same type of appliance may also be an indicator for more recent purchase of that appliance type and, thus, positively associated with knowledge of energy class. Similarly, the market in Germany has trended away from the purchase of separate refrigerators and freezers toward combination units, implying refrigerators and freezers in households that also own a combination unit may be older. For refrigerators and freezers an indicator is included for concurrent ownership of a combination unit, while for combination refrigerator-freezer units, an indicator is included for concurrent ownership of a refrigerator or freezer. An indicator of household personal computer ownership is also included in both the knowledge of energy class and class-A choice specifications, as a proxy for ease of information access and receptivity to new technology. Also, an indicator of ownership of a class-A appliance of another type is included in the class-A choice equation specification, but not the knowledge of class specification, as the propensity to purchase class-A appliances may be strongly correlated across appliance types.

Two variables with expected positive correlations with awareness of appliance energy class are included in the knowledge of class specification, but not in the class-A choice equation. The first variable is an indicator for household provision of information on annual electricity consumption that proxies for household awareness of energy use. The second variable is the share of other households in the same region with knowledge of the appliance energy class as a proxy for potential regional spillovers in energy class awareness resulting, for example, from regional information campaigns by state energy agencies, retailers, or consumer groups. Finally, regional power prices are included in both the knowledge of class and class-A choice specifications, as higher electricity prices may increase energy awareness and the value of investing in information on energy-saving technologies and also generate greater incentives for the purchase of class-A appliances.[4]

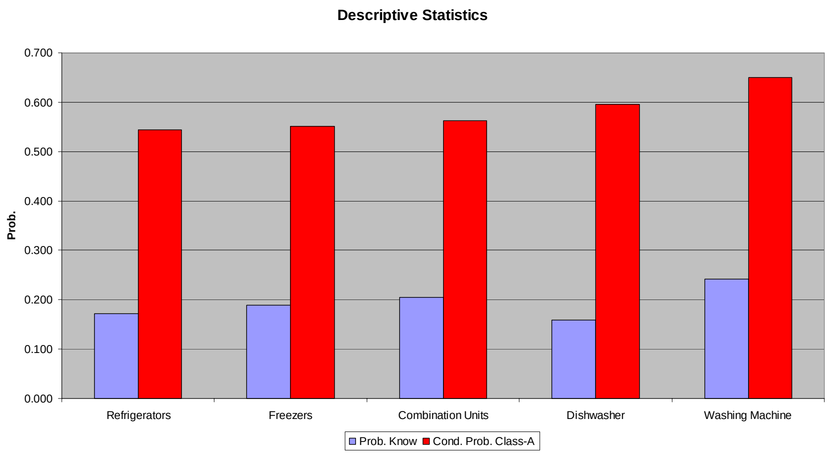
[4] Regional power prices are based on the average prices for other survey households in the same Federal State. Calculations produced infeasible prices for some households and Federal State averages are based on households with calculated prices in the Euro 0.10 to Euro 0.20 per kWh range.

5 Data

The dataset comes from a mail survey of private sector household energy consumption conducted in December of 2002 as part of a multi-topic survey of an existing representative panel of German households (Schlomann et al., 2004). Overall, 20,235 households (75 percent) responded to the mailed questionnaire. Survey responses were generally of high quality and the sample sizes for households that own the appliance being analyzed and supply information on all covariates are 15,526 households for refrigerators, 12,943 households for freezers, 6,993 households for refrigerator – freezer combination units, 12,814 households for dishwashers, and 19,014 households with washing machines.

Figure 1 displays the share of households that were able to provide information on energy class for each appliance type, as well as the share of appliances which were of energy-class A. Knowledge of appliance energy class is low for all appliance types, ranging from 24 percent for households with a washing machine to 16 percent for households with a dishwasher. It is worth noting that the level of knowledge generally increases with the length of time since the EU implementation directive on the energy-efficiency classification scheme for the appliance, with the implementation directive for washing machines put in place in 1995 and the directive for dishwashers put in place in 1999. Lack of purchase of an appliance after the implementation of the energy classification scheme is obviously an important factor in the observed low-levels of knowledge of the energy-class of household appliances. Specifically, the lifespan of appliances in general ranges from 10 years for dishwashers to 17 years for electric ovens (NAHB, 1998). Thus, approximately one-third to one-half of households can be expected to replace an appliance due to the end of its lifespan in the period from the beginning of 1998 when energy-efficiency classification schemes were officially implemented for most appliances in German and the time of the survey at the end of 2002.[5]

Fig. 1. Knowledge of energy label and conditional probability of class-A appliance choice



Among those households who know the energy class of the appliance, washing machines show the highest rate of class-A purchases at 65 percent, while refrigerators have the lowest rate of class-A purchases at 54 percent. As discussed, observed and unobserved heterogeneity between those who know and those who do not know the appliance energy class suggests that these rates of class-A purchase may not be representative of expected rates of purchase for the whole sample.

[5] Formation of new households and purchases for reasons other than replacement of an existing unit will, however, also increase the share of appliances purchased in the 1998

Descriptive statistics (not reported here in detail) indicate that combination refrigerator-freezer unit tend to be more prevalent in recently built residences than are separate refrigerator and freezer units, confirming the recent market trend towards combination units. However, residences with combination units also tend to be smaller than those with separate refrigerator and freezer units, suggesting combination unit purchase decisions may be partly motivated by space considerations. Second, dishwashers appear to be luxury items, as they are disproportionately present in more educated and higher income households relative to other appliances in the study.

to 2002 period.

6 Results

Estimation results for the knowledge of energy class equation and class-A choice equation are presented in Table 1 and for the choice of class-A appliances equation in Table 2. To improve readability we only report results in terms of statistical significance and signs. We now turn to the discussion of the findings for the individual appliances.

Table 1. Estimation results for the knowledge of energy class equation

Know Class of Appliance	Refrigerator	Freezer	Frig-Freezer Combination	Dishwasher	Washing Machine
Rent residence	+		++	++	++
Floor space	+				
Residence built:					
2002	++	++		++	++
2001	++		+	+	++
2000	++	++	++	++	++
1998-1999		++		+	
1996-1997					
1993-1995				--	
1990-1992	--	--	--	--	--
1985-1989					
Post-1997 detached house					
Retiree	++	++	++	++	++
Number of persons	++	+		+	++
Children in household					
Age					
Age2	--	--	-	--	--
Secondary school	+	++	++		++
Management position	-	-			
Income class	++	+			++
East Germany			++	+	
Regional power price	++	++		++	++
Own a PC	++	++	++	++	++
Know power consumption	++	++	++	++	++
Region class knowledge	++	++		+	+
Rho	++				+

Note: -- = negative *p=0.05* , - = negative *p=0.10* , ++ = positive *p=0.05* , + = positive *p=0.10*

Table 2 Estimation results for class-A choice equation

Purchase Class-A Appliance	Refrigerator	Freezer	Frig-Freezer Combination	Dishwasher	Washing Machine
Rent residence	+			++	
Floor space	+	++		+	
Residence built:					
2002			+		
2001					
2000	++				
1998-1999					
1996-1997					
1993-1995					
1990-1992					
1985-1989					
Post-1997 detached house					
Retiree	+				
Number of persons					+
Children in household					
Age	++				
Age2	--				
Secondary school	++				
Management position					
Income class					++
East Germany					-
Regional power price				+	++
Own a PC					
Own other class-A	++	++	++	++	++

Note: -- = negative *p=0.05* , - = negative *p=0.10* , ++ = positive *p=0.05* , + = positive *p=0.10*

Refrigerators

As expected, a household’s knowledge of the refrigerator’s energy class is associated with several residence characteristics that proxy for recent purchase of an appliance. Specifically, renters and households living in residences built in 2002, 2001, or 2000 are more likely to know the energy class of the household’s refrigerator.[6] The likelihood of knowing the energy class of the refrigerator also higher for larger and rented residences (both at the *p=0.10* level).

A number of household characteristics also influence knowledge of refrigerator energy class. Specifically, the likelihood of knowing the energy class increases with household size and with household income level. Knowledge of refrigerator energy class is also higher for households headed by a retiree and by a person with a secondary school or higher level of education (*p=0.10* level). Younger households are also more likely to know the energy class of the refrigerator, as results from the quadratic specification of age of the household head imply the likelihood of knowing the appliance energy class declines exponentially after 18 years of age. The result, again, suggests that recent purchase during new household formation plays a key role in awareness of the energy classification scheme. Somewhat surprisingly, households with heads in senior management positions are less likely to know the energy class of the appliance (*p=0.10*).

Household knowledge of refrigerator energy class shows a strong positive response to higher regional energy prices. Ease of access to information and energy-use awareness also appear to be important. Knowledge of energy class is more likely when the household owns a personal computer, when the household knows its annual electric bill, and when the regional share of other households with knowledge of the energy class of their refrigerator is high. Knowledge of the energy class of the refrigerator is lower, however, if the household also owns a com-

6 Discussed relationships are statistically significant at the p=0.05 level unless specifically noted.

bination refrigerator – freezer unit. Again, as the market has trended towards combination units, concurrent ownership of a combination unit may imply the refrigerator is older. Finally, the estimated correlation coefficient between the knowledge of refrigerator energy class and class-A choice equation error terms is positive and significant, implying parameter estimates generated from separate estimation of the class-A choice equation are likely to be biased.

Overall, there are fewer statistically significant associations in the class-A choice equation for refrigerators than in the knowledge of energy class equation. Renting rather than owning the residence increases the probability of class-A refrigerator purchase ($p=0.10$). The probability of class-A purchase also increases with the size of the residence ($p=0.10$). Parameter estimates for residences built in 2002, 2001, and 2000 are all positive, however only the year 2000 estimate is significant at conventional levels.

Turning to personal characteristics, households headed by retirees ($p=0.10$) and individuals with secondary school education are more likely to purchase class-A refrigerators. Households with middle-aged heads are also most likely to purchase class-A refrigerators, as in the quadratic specification of household head age the propensity for class-A purchase increases up to 48 years of age and then declines. Concurrent ownership of a combination refrigerator – freezer unit decreases the propensity for class-A refrigerator purchase. However, the propensity for class-A purchase increases strongly with the purchase of a class-A appliance of another type by the household. The significant influence of purchase of other class-A appliance likely implies that there are factors influencing the general propensity to purchase class-A appliances that are not fully captured in the current specification.

Freezers

The estimation results for knowledge of energy class of freezers are, for the most part, the same as for refrigerators; with recently built residences, retirees, size of household (*p=0.10*), age, schooling, income, regional electricity prices, knowledge of household electric bill, and regional rates of knowledge of freezer energy class playing important roles in freezer energy class awareness. Two differences in the freezer and refrigerator results are worth noting. First, tenancy status of residence and residence size do not influence knowledge of energy class for freezers. Second, the correlation coefficient for the knowledge of energy class and class-A appliance choice equations is not statistically different from zero for freezers, implying unobserved heterogeneity in knowledge of appliance energy class may not be an important source of bias in the estimation of class-A appliance choice for freezers. Only two parameter estimates are significant in the class-A freezer choice equation. These are residence sizes and ownership of other types of class-A appliances, both of which show significant positive associations with the choice of class-A freezers.

Refrigerator-freezer combination units

Estimation results for knowledge of the combination refrigerator – freezer unit energy class are also similar to those for refrigerators. Renters, recently built residences, retirees, younger households (*p=0.10*), and households headed by someone with a secondary school or higher level of education are more likely to know the energy class of the combination unit. Owning a PC and knowing the household annual electrical bill also increases the probability of knowing the energy class of the combination unit. Several differences in the results when compared to refrigerators are worth noting. In the case of combination units, residence size, regional rates of household knowledge of energy class, and regional electricity prices do not influence knowledge of energy class. On the other hand, the probability of knowing the energy class of combination units is significantly higher in East Germany. The correlation coefficient for the error terms is also not significantly different from zero in the combination unit case. As with freezers, few parameter estimates are significant in the class-A choice equation for combination units. Households in residences built in 2002 are more likely to choose class-A units (*p=0.10*), as are those households who own more than one combination unit and who own another type of class-A appliance. Ownership of a separate refrigerator or freezer as well as a combination unit reduces the likelihood of owning a class-A combination unit.

Dishwashers

Covariates in the knowledge of dishwasher energy class equation largely show the same relationships as in the refrigerator model, with the following groups more likely to know the energy class of the dishwasher; renters, households in recently built residences, larger households (*p=0.10*), younger households, households headed by a retiree, households living in East Germany (*p=0.10*), and households owning a PC. High regional energy prices also increase knowledge of dishwasher energy class, as do household knowledge of its energy bill and high regional rates of knowledge of appliance energy class (*p=0.10*). The correlation coefficient for the model error terms is not statistically significant in this case.

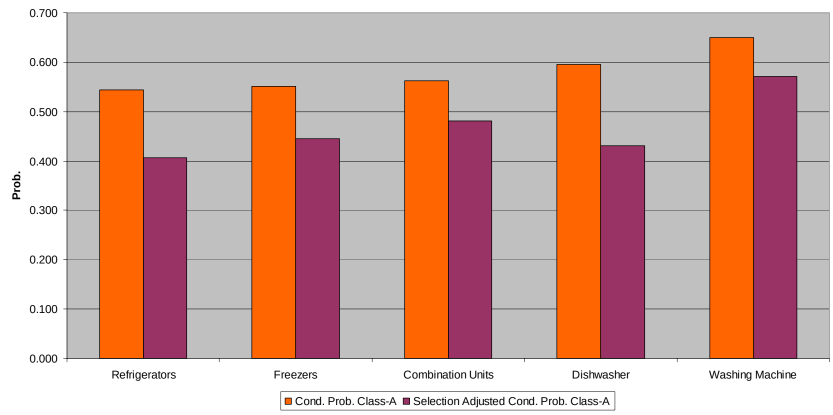
Few parameter estimates in the choice of class-A dishwasher equation are statistically significant. The propensity to purchase class-A dishwashers is higher in rented residences and larger residences (*p=0.10*). High electricity prices also increase the propensity to purchase class-A dishwashers at the *p=0.10* level and, as usual, the propensity to purchase class-A dishwashers increases when the household owns another class-A appliance.

Washing machines

The results for the knowledge of the energy class of washing machines are largely consistent with those for other appliances. Households that rent the residence and households in more recently built residences are more likely to know the energy class of the washing machine, as are larger households, households headed by a retired individual, households headed by an individual with secondary school education, younger households, and households with higher levels of income. The likelihood of knowing the energy class of the washing machine also increases with higher regional electric prices, knowledge of annual electric bill by the household, and the regional share of households with knowledge of the energy class of their washing machine. The error terms' correlation coefficient estimate is also significant at the *p=0.10* level. Again, there are considerably fewer significant covariates in the choice of class-A dishwasher equation. Household income, regional power prices, and ownership of other class-A appliances are positively related to choice of a class-A washing machine. While the size of the household and residence in East German show a weak (*p=0.10*) positive relationship with class-A washing machine purchase.

Finally, the conditional probabilities of purchasing a class-A appliance with and without correcting for the selection bias are displayed in Figure 2. Clearly, without correcting for the knowledge bias, the conditional probability of purchasing a class-A appliance would be overestimated.

Figure 2: Conditional probability of class-A appliance choice with and without selection correction **Selection Adjusted Conditional Class-A Purchase Rates**



6 Conclusions

The results generate a number of implications for the refinement of energy-efficiency labeling schemes and other policies to promote the take up of energy efficient household appliances. Perhaps most obvious, given the relatively long average life of most major household appliance, the information provided in energy labels will diffuse very slowly into consumer purchase decisions. This long lag period must be accounted for in the formulation and evaluation of energy-efficiency labeling schemes. While proxies for recent appliance purchase are arguably noisy, the data provide evidence that for most appliances that conditional propensities to purchase class-A appliances increased rapidly between mandatory implementation for most appliances in the beginning of 1998 and the survey at the end of 2002. The portion of this shift motivated by increased supply of class-A appliance due to energy efficiency technology advances on the part of manufactures can not be separated from the portion due to increased demand for class-A appliances due to the EU labeling scheme with the current cross-sectional dataset.

The results do suggest that consumers respond to economic incentives, as knowledge of energy classes increases with regional energy prices for most appliances. This finding suggests that policies that internalize the social costs of energy consumption will spur awareness and, therefore, adoption of energy efficient appliances. The finding also suggests that provision of economic information on the likely economic benefits of energy efficient appliances as currently discussed in the context of the revision of the labeling Directive can further influence purchase decisions. Increased awareness of household energy use and access to information though personal computers are also likely to influence consumer purchase decisions and should be incorporated into future energy classification scheme information awareness campaigns. Greater awareness of the potential contributions of energy-efficient appliances to household energy conservation will also increase the efficiency of tax and other policies to align marginal energy consumption decisions with marginal social costs. On the other hand, household characteristics in the current dataset have surprisingly little impact on the purchase of energy efficient appliances. Yet, within households, the propensity to purchase class-A appliances is strongly correlated across appliance types. Further research is needed to identify the currently unobserved factors underlying these common purchase propensities, with particular attention paid to environmental attitudes, psychological factors and social norms (Kahn, 2007; Gilg and Barr, 2006; Barr et al., 2005). Incorporating these aspects would delineate the role of perceived environmental benefits in household energy-efficient appliance purchase decisions, and thus complement the economics-based approach presented in this paper.

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