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Estimating customer utility of energy efficiency standards for refrigerators

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Abstract

A frequent argument against efficiency standards is that they prohibit products that represent optimal choices for customers and thus lead to reduced customer utility. In this paper we propose and test a method to estimate such losses. Conjoint analysis is used to estimate utility functions for individuals that have recently bought a refrigerator. The utility functions are used to calculate the individuals' utility of all the refrigerators available in the market. Revealed utility losses due to non-optimal choices by the customers seem consistent with other data on customer behaviour. The same utility estimates are used to find losses due to energy efficiency standards that remove products from the market. Contrary to previous claims, we find that efficiency standards can lead to increased utility for the average customer. This is possible because customers do not make perfect choices in the first place.

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1. Introduction

In recent years the use of energy efficiency standards has increased. Nadel (2002) reports standards to be used in 17 countries plus the European Union and to "have

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been set on more than 35 products, with refrigerators, air conditioners, ballasts, and freezers being the most common.'' There seems to be general agreement that these standards lead to reduced energy consumption, oil imports, and CO_2-emissions, Greene (1998), Koomey, Mahler, Webber, and McMahon (1999), and Nadel (2002). According to the same authors, there also seems to be evidence that standards are cost effective, reductions in energy expenditures typically exceed the costs of improving the energy efficiency, although the effectiveness is likely to vary considerably between products. Koomey et al. estimate the US cost savings to be 165 times larger than the costs incurred by the US government to set the standards.

Still the use of standards is controversial. According to Sutherland (1996): ''… there is no evidence that conservation programmes, such as energy efficiency standards for appliances, maximise net benefits as measured by consumer preferences.'' His arguments are that ''consumers have different preferences, and – consumer preferences cannot be determined by the state.'' It is not difficult to find products and standards for which this claim is self-evident, e.g. mandating that everybody should wear shoes of a given size. Since the individuals know best how the shoe fits, a standard would reduce utility for most people. On the other hand, examples also exist to the contrary, e.g. who would go to a brain surgeon who does not satisfy a minimum standard with respect to competence? In this case the quality of the surgeon is all that matters, individual differences between brains and lack of knowledge about these differences are of little or no importance for the choice of standard. From these two examples it should be clear that the question about net benefits of standards is an empirical one.

The purpose of this paper is to suggest and test an empirical method to measure if average customer utility is increased or decreased by product standards. The case is refrigerators and the standard regulates energy efficiency. To introduce the method, first note one particular condition that must always be satisfied for a standard to yield an increase in customer utility. All customers cannot make perfect choices. If they did, there is only potential for reduced utility by setting a standard. However, if people make imperfect choices in the first place, it is no longer self-evident that a standard reduces utility. If for instance the standard removes both the optimal product and some bad choices for an individual, the expected outcome of a somewhat random search process could be positive or negative.

A good reason to expect imperfect choices is that people tend to use highly simplified procedures when searching for durable products with many attributes. Since energy efficiency is often one of the less important attributes, it is paid limited attention in the search process. Previous studies indicate considerable losses due to non-optimal customer choices of energy consuming durables, see e.g. Fisher and Rothkopf (1989), Gately (1980), Ruderman, Levine, and McMahon (1987), and Sutherland (1991). Some of these losses are claimed to be caused by systematically biased decisions, e.g. customers using discount rates that by far exceed interest rates on loans. In this study, however, we accept and use revealed customer preferences as they are. To minimise biases we make an effort to lessen the cognitive burden for the respondents.

We suggest the following method: A conjoint analysis is used to estimate individual utility functions for customers that have recently bought a refrigerator. Using these utility functions, we identify each customer's utility for all the refrigerators in the market. By comparing the utility for the chosen product to the utilities of the products that yield the maximum and minimum utilities, we find the relative utility of the actual choice. A quite similar method to measure losses has been previously applied by Gupta and Ratchford (1992). Finally, we use the estimated utility functions to find customer losses (or gains) due to energy efficiency standards that remove refrigerators from the original choice set. We find that most efficiency standards lead to an increase in average customer utility.

Even though a standard has a positive effect on average customer utility, and it could be considered to be a public good, there is still an argument that is sometimes used to impede the implementation of standards. One may argue that any product is a potential candidate for standards, not only energy consuming equipment. Thus the question arises which standards should be prioritised. The general answer is that all welfare enhancing public goods should be provided. If forced to prioritise, energy consuming products should get high priority because of externalities such as climate change, local pollution, and vulnerability to supply shortages. We recognise that in this case the first best policy is to increase prices of energy by the use of taxes or quota limitations. However, there seems to be considerable political resistance towards taxing energy appropriately. This is why externalities provide another argument for the use of standards, as a second best policy. There is also a dynamic aspect of this argument. By using standards to reduce the dependence on energy, it will be easier to raise energy taxes to secure a first best policy in the future. In this paper we will base the reference case on current energy prices, however, we will also find the effect of standards in case the energy price is doubled.

2. Method

First we describe the conjoint technique which is used to estimate individual utility functions. Then we define optimal choices and describe how losses from non-optimal choices can be estimated. Finally we describe how to estimate losses or gains due to efficiency standards.

2.1. The conjoint technique

A conjoint technique is used to estimate individual utility functions, Green and Srinivasan (1990). The functional form of the utility function and the product attributes are determined a priori, while the technique is used to estimate the parameters of the utility function. According to Green and Srinivasan (1978): "The linear-compensatory model ... can approximate the outcomes of other kinds of decision rules quite closely". With this advice, and in order to save degrees of freedom, we apply a linear additive functional form with parameters or attribute coefficients a_j, $j = 0, 1, \dots, J$:

$$u(\boldsymbol{q}) = a_0 + a_1 q_1 + \cdots + a_J q_J \tag{1}$$

where q_j is the product's attribute j. We use a full profile conjoint design where respondents are asked to rank order a set of products, according to their probability of buying them. The products are described by a set of common attributes which differ in attribute levels. Rank numbers ρ_k for product k, are regressed against attribute values q_{jk} for each respondent:

$$\rho_k = a_0 + a_1 q_{1k} + \cdots + a_J q_{Jk} + \varepsilon_k \tag{2}$$

where ε_k is the random error. In accordance with current practice in conjoint analysis, OLS is used to estimate the $\boldsymbol{\alpha}$ vector.

At the outset it may seem overly optimistic to judge the utility of actual purchases by an utility function found by the conjoint technique. The motivation for doing this is one important difference between actual purchasing strategies and the conjoint technique. Actual purchasing involves costly search for information about the attributes of different products. Investigations show that customers tend to investigate only a few products and to be less than fully informed about their attribute values (see Table 4 for some numbers and references). The conjoint technique presents the customers with well organised and precise information about all the products that are to be ranked. Thus using the conjoint technique, customers are not constrained by the search problem, and they are stimulated by the organisation of attribute information on cards to apply efficient heuristics to rank the alternatives.

This is not to say that the conjoint technique produces perfect estimates of utility functions. We rely on assumptions about a linear additive functional form, about a given set of attributes, and about the ability of respondents to rank order the products without a common systematic bias. If there are checklist attributes that customers are not at all willing to trade off against others, the chosen conjoint technique will tend to underestimate the importance of these attributes. In such cases the method will underestimate the goodness of choices. Height is probably the most likely candidate as a checklist attribute. By using three different size classes, potential biases are reduced. If participants simplify the rank ordering of conjoint cards by using non-compensatory decision rules (while underlying customer preferences are compensatory), checklist attributes will get relative weights that are too high while others will get weights that are too low. In such cases the method will tend to overestimate the goodness of actual choices.

2.2. Definition of losses from non-optimal choices

Search costs, imperfect product information, and imperfect information treatment can cause customers to end up with non-optimal products. To measure an individual customer's loss, one could use compensating variation, i.e. estimate how much the customer is willing to pay to have her actual choice replaced with the optimal one. There is, however, one important practical problem with using compensating variation. It is very sensitive to estimation errors in the attribute coefficient for price, which enters in the denominator of the expression for compensating variation. For this reason we choose another measure of loss which is much more robust. We term this measure *relative utility*

$$r = \frac{u'(\boldsymbol{\alpha}) - u^{\mathrm{m}}(\boldsymbol{\alpha})}{u^{*}(\boldsymbol{\alpha}) - u^{\mathrm{m}}(\boldsymbol{\alpha})} \tag{3}$$

where $u^{*}(\boldsymbol{\alpha})$ and $u'(\boldsymbol{\alpha})$ denote respectively the utility of the optimal and the actual choice, while $u^{\mathrm{m}}(\boldsymbol{\alpha})$ denotes the utility of the product with the lowest utility for the individual. Thus to calculate the value of r one must identify the products that yield the optimal and the minimum utility. This is done by enumeration. As long as utilities differ among products, the denominator will be positive, and it will not be highly sensitive to estimation error. When the actual choice is equal to the optimal choice, r equals 1.0. When the actual choice is the product with the minimum utility, r equals 0.0. The weakness of this measure compared to compensating variation is that we get an index rather than a measure in currency units. Since our major concern is to find out if utility goes up or down due to efficiency standards, this is not a major concern. From Eq. (3) one can see that uncertainty in $\boldsymbol{\alpha}$ implies uncertainty in r. Uncertainty in $\boldsymbol{\alpha}$ can also lead to a certain bias in r. [1]

Finally, when using data for many individuals, we are interested in aggregate losses. Taking the average R of relative utilities is a measure that can be criticised. A simple average puts the same weight on all individuals not recognising that a given relative loss may be perceived differently among individuals. The aggregation problem is not avoided by using compensating variation.

Since our measure of relative utility is not the standard one, it is reassuring that the results obtained here are almost identical to the results obtained in Hatlebakk and Moxnes (1996) using compensating variation and a number of auxiliary assumptions.

2.3. Calculation of losses or gains due to efficiency standards

An energy efficiency standard reduces the choice set. Only refrigerators that have a yearly energy consumption less than the standard, $q_{\mathrm{e}} < q_{\mathrm{S}}$, will be allowed in the market. Again Eq. (3) can be used to calculate the relative utility for each individual:

$$r_{\mathrm{S}} = \frac{u'_{\mathrm{S}}(\boldsymbol{\alpha}) - u^{\mathrm{m}}(\boldsymbol{\alpha})}{u^{*}(\boldsymbol{\alpha}) - u^{\mathrm{m}}(\boldsymbol{\alpha})} \tag{4}$$

where $u^{\mathrm{m}}(\boldsymbol{\alpha})$ and $u^{*}(\boldsymbol{\alpha})$ are given by the original choice set. Thus the utility of the choice after the standard has been set $u'_{\mathrm{S}}(\boldsymbol{\alpha})$ is seen in light of the original range of

[1] To illustrate, assume that an individual has made a perfect choice such that the true loss is zero, $r = 1.0$. In this case an erroneous estimate of α can lead us to identify a wrong product as the one giving the optimal utility. Consequently we may estimate a value of r which is less than the true value of 1.0. Since we will never estimate a value of r greater than 1.0, we should expect a downward bias in this case. Similarly, if a customer has made the worst possible choice, identifying the wrong minimum choice could lead to an upward bias in the estimate of r. For a set of customers that have made a mix of good and bad choices, the bias in the average relative utility R could go in either direction. Moxnes (2003) uses Monte Carlo simulations to show that the bias is small given the data of the present study. He also indicates how the bias can be minimised by using a more complicated procedure.

utilities, i.e. the range from optimal to minimum utility before any product has been removed by the standard. We define the loss

$$l = r - r_{\mathrm{S}} = \frac{u'(\boldsymbol{\alpha}) - u'_{\mathrm{S}}(\boldsymbol{\alpha})}{u^{*}(\boldsymbol{\alpha}) - u^{\mathrm{m}}(\boldsymbol{\alpha})} \tag{5}$$

as the difference between r and r_{S}. Because the denominator is the same for r and r_{S} in Eqs. (3) and (4), we see from Eq. (5) that the loss is directly related to the difference between the utility of the actual choice $u'(\boldsymbol{\alpha})$ and the choice made after the standard is put in place $u'_{\mathrm{S}}(\boldsymbol{\alpha})$. Like Eq. (3), Eq. (4) may be biased. However, these two biases tend to cancel when r_{S} is subtracted from r to calculate the loss l. L will denote the average of individual losses.

When calculating r_{S}, an assumption has to be made about how customers choose within the restricted choice set. First note that customers typically buy refrigerators at very long time intervals, it is not such that they make a choice the day before the standard is implemented and then they revisit the same store the day after to make another choice. Thus when customers replace their refrigerators they will typically face a totally new collection of refrigerators and they will not be influenced by the data they gathered the last time they bought one. Thus we cannot assume that they will repeat their previous choice even if that choice is allowed by the standard. We can only speculate that they will use the same simplified search procedures that they used last time. This suggests that the expected quality of the choice they make will be the same. However, using even optimal search procedures there is a considerable random element. This implies that we cannot make reliable predictions of individual choices. We can only choose a procedure that maintains the average goodness of the choices made by all individuals. A simple, and probably best possible way to do this is to assume that each individual will make a choice that gives the same (closest possible) relative utility before and after the standard. Note that for this comparison the relative utility after the standard

$$r_{\mathrm{S}}^{\mathrm{S}} = \frac{u'_{\mathrm{S}}(\boldsymbol{\alpha}) - u^{\mathrm{m}}_{\mathrm{S}}(\boldsymbol{\alpha})}{u^{*}_{\mathrm{S}}(\boldsymbol{\alpha}) - u^{\mathrm{m}}_{\mathrm{S}}(\boldsymbol{\alpha})} \approx r \tag{6}$$

must be based on the choice set allowed by the standard, with optimal utility $u^{*}_{\mathrm{S}}(\boldsymbol{\alpha})$ and minimum utility $u^{\mathrm{m}}_{\mathrm{S}}(\boldsymbol{\alpha})$. The new choice is found by enumeration. The product that brings $r_{\mathrm{S}}^{\mathrm{S}}$ and r closest to each other is assumed to be chosen. Over a large sample of respondents, minor errors, due to a lack of products that ensure perfect equality, should be expected to cancel out. Hence this procedure should ensure that average estimated effects of standards are not explained by changes in the quality of the decisions. The expected effect on average utility is only due to the standard.

3. Design of the investigation

In order to estimate losses from non-optimal choices, we need to know both actual choices and the choice set available at the time of purchase. We obtained lists of customers who had recently bought a refrigerator from the "Bonus" chain, which has four stores in the district of Bergen, and which is the largest seller of refrigerators in the district. 180 customers, who bought a refrigerator in the period April 26th to June 24th 1995, received a letter with the conjoint cards. The customers were asked to rank order the cards, to write their rank ordering in an attached scheme, and to return the scheme in a pre addressed and stamped return envelope.

To stimulate participation, the customers were told that they had a 1/100 chance to win 50 tickets in a state lottery with a purchasing price of NOK 1000 (Euro or USD 120). To take part in the lottery, respondents had to write their name and address on the mail back envelope, which all did. They were told that the mail back envelope would be separated from the survey scheme. About a week later a female student assistant phoned them, and asked if they needed some help, and also asked them to return the survey scheme. As a final strategy, she offered one or two tickets in the state lottery if they would return the scheme. Two weeks later a reminder was sent to the respondents who had agreed to return the survey scheme.

To increase reliability of the estimated parameters in a conjoint analysis, attribute levels should have a large range, and no correlations between attribute levels should exist. However, to ensure validity, the range should be within the actual range of attributes in existing products. This trade-off lead us to perform three separate studies of respectively small, medium and large refrigerators. Thus, the 180 customers were divided into three samples of 81, 44 and 55 customers, who bought respectively small (less than 200 l), medium (200–249 l) and large refrigerators (250 l and above). From these samples we got $17 + 14 + 15 = 46$ useful answers, which imply a response rate of 26%.

Unfortunately, 11 of the respondents who were registered as buyers of small refrigerators in the received name lists, turned out to have bought large refrigerators. Hence they were sent the wrong set of cards. They had all bought the same refrigerator with an interior volume of 251 l. Since 251 l is almost inside the range 200–249 l of the medium refrigerators, we group the buyers of this product together with the buyers of medium refrigerators when we investigate efficiency standards. Thus we end up with respectively $7 + 24 + 15 = 46$ respondents in the respective size classes.

The following attributes were included. Energy efficiency follows from the focus of the study. Attributes which are likely to be negatively correlated with energy efficiency were included to ensure that energy efficiency is not provided without costs. Price is an obvious candidate. In addition extra insulation either decreases interior volume or increases exterior volume. Since width and depth are standardised, exterior volume is measured by the height of the refrigerator. Thus we included inside volume and height in the design. To increase validity, the most important attributes should be included, because the remaining parameters can be biased if important attributes are excluded. After discussions with sales persons and some customers, we included quality as a fifth attribute in the conjoint task. If quality had not been included, some customers would probably use price as a proxy for quality. In that case, we could not have interpreted price as a pure cost variable. We divided the quality attribute into three different classes, low, medium and high quality. The models were classified into these groups by one sales manager in a Bonus store. A sales person in another (not Bonus) store (almost) agreed with this ranking. In the introduction to the conjoint task we described quality as including noise and durability. Furthermore, we used "a brand produced in Germany such as Siemens" as an example of high quality, and "a brand produced in Russia such as Atlas" as an example of low quality (in 1995). Attributes such as colour and equipment, with small or no variation between products, were not included. The discussions with customers were organised according to the rank ordering method, found to give good results with little bias in Breivik and Supphellen (2003).

To be able to identify the optimal choice for each individual, we made efforts to avoid individuals misinterpreting the attribute values in the conjoint design. To compare energy costs and prices, customers have to estimate the present value of future energy costs, utilising their real market interest rate. Such calculations are difficult, and one cannot expect correct results. We tried to reduce these problems by using energy costs per year as the attribute for energy efficiency, and by reminding respondents that a refrigerator will use energy during its entire lifetime, that interest costs imply decreasing value of money saved on energy, and that energy costs are reduced if the refrigerator diminishes the need for space heating.

Table 1 shows the range of all attribute values except quality for the real choice set and the attribute values for the products described on the conjoint cards. Energy costs per year were based on an electricity price of NOK 0.4/kWh (Euro or USD 0.05/kWh). In the experimental design the same attribute differences were used for all size classes. There exist $3^5 = 243$ different combinations of the attribute levels in the conjoint design. From these we chose an orthogonal design (no correlations between attributes) of 25 cards, using a commercial conjoint design algorithm.

The 46 respondents bought $4 + 6 + 8 = 18$ different models in respectively the small, medium and large size group. Nine different brands were represented. In the ensuing analysis of standards we also included models from Gram, which is a

Table 1
Real and experimental attribute values

Attributes	Real range	Conjoint range
Small refrigerators		
Inside volume (l)	109–197	110–150–190
Height (cm)	85–132	85–100–115
Energy cost (NOK)	43.8–189.8	43.8–131.4–219
Price (NOK)	1690–4890	1500–2250–3000
Medium refrigerators		
Inside volume (l)	197–251	190–230–270
Height (cm)	108.5–138.5	115–130–145
Energy cost (NOK)	43.8–219	43.8–131.4–219
Price (NOK)	1990–4890	3000–3750–4500
Large refrigerators		
Inside volume (l)	245–374	270–310–350
Height (cm)	125–187	145–160–175
Energy cost (NOK)	51.1–153.3	43.8–131.4–219
Price (NOK)	3590–6190	4500–5250–6000

high quality brand not sold by the Bonus stores. Two of these models were included both as small and medium models (volume of 197 l). One of the Gram models is a low energy refrigerator. We also included a low energy model from Electrolux.

Finally, the respondents receiving the conjoint cards were also asked which attributes they considered most important.

4. Estimated attribute weights

From the rank orderings of products we estimate the α-parameters for each respondent. The quality attribute is modelled by two dummy variables, with medium quality as default. The other attributes are quantitative variables. Table 2 summarises the results. When not otherwise stated, the table refers to significant parameters at the 10% level.

As many as 37 of the 46 respondents had R^2 values above 0.79, indicating a high frequency of consistent rankings. The average R^2 was 0.80, while the average R^2 for respondents with $R^2 > 0.79$ was 0.94. The high R^2-values suggest that the fit cannot be improved much. Hence it would have been hard to discriminate between the current linear utility function and more elaborate utility models.

Counting significant parameters (row 1) low quality (36) comes out as the most important attribute, followed by high quality (31), energy costs (23), volume (19), price (17) and height (14). Most of the significant parameters have the expected signs (row 2). Hence, all averages of the significant parameters have the expected sign (row 3). The standard deviations of the average significant parameters (row 4) shows that all averages are highly significant with the exception of height.

Row 6 shows averages taken over all 46 respondents including significant and insignificant parameters. Similar to the case with significant parameters, standard deviations for the averages (row 7) show that all averages except the one for height, are significantly different from zero.

When the average parameter values are multiplied with the standard attribute differences used in the conjoint design (Table 1), we get a measure of attribute importance. In Table 2 this measure of importance is divided by the average parameter for price to get a willingness to pay (WTP) measure in NOK. Significant parameters (row 5) and all parameters (row 8) give nearly the same rankings: it is most important to avoid low quality (compared to medium quality), followed by the preference for high quality (compared to medium quality). The WTP-estimates are largely consistent with self-reported "most important attributes" in the questionnaire. Both methods indicate that we have included only important attributes. For details see Moxnes (2003).

There are some unimportant differences between the three groups (rows 9–14). The 24 early responders (row 16) produced more consistent rankings, having significantly higher R^2 values, than the 22 respondents who received reminders (row 15). Significant differences between average parameter values are all less than 25%.

Table 2
Results from the OLS estimation ($N = 46$)

	Const.	Height	Volume	Low quality	High quality	Energy costs	Price	R^2
1. No. of significant parameters	34	14	19	36	31	23	17	37[a]
2. No. of which with expected sign		10	16	36	31	22	16	0.94[b]
3. Average, significant parameters	28	−0.15	0.060	−7.9	6.0	−0.025	−0.0036	0.80
4. Std. dev., average significant parameters	5.8	0.092	0.015	0.55	0.45	0.0065	0.0009	0.04
5. Average WTP		−624	672	−2207	1680	−621	−750	
6. Average, all parameters	22	−0.037	0.023	−6.2	4.7	−0.014	−0.0014	
7. Std. dev., average all parameters	4.7	0.031	0.0081	0.65	0.45	0.0038	0.0004	0.04
8. Average WTP, all parameters		−397	676	−4511	3438	−873	−750	
9. Average, small refrigerators	16	−0.11	0.087	−8.1	4.8	−0.024	−0.0042	0.92
10. Average, medium refrigerators	44	−0.26	0.024	−7.4	6.2	−0.032	−0.0043	0.72
11. Average, large refrigerators	36	−0.11	0.023	−8.0	7.8	−0.022	−0.0019	0.76
12. Significant difference, small–medium?	Yes	No	No	No	No	No	No	Yes
13. Significant difference, small–large?	No	No	Yes	No	Yes	No	No	Yes
14. Significant difference, medium–large?	No	No	No	No	Yes	No	No	No
15. Average, reminded respondents	26	−0.09	0.041	−8.9	6.9	−0.017	−0.0036	0.68
16. Average, other respondents	29	−0.19	0.069	−7.1	5.5	−0.030	−0.0035	0.92
17. Significant difference?	No	No	No	Yes	Yes	No	No	Yes

[a] Number of subjects with $R^2 > 0.79$.
[b] Average R^2 for respondents with $R^2 > 0.79$.

5. Estimates of the relative utility of actual choices

The first row of Table 3 shows the estimates of average relative utilities R for the three size classes. The average relative utility is considerably below 1.0, which would follow if each and every one had chosen their optimal product. The second row shows the corresponding relative utilities when respondents with $R^2 < 0.79$

Table 3
Estimated relative utility compared to results of Monte Carlo simulations with random choice and to estimates based on a given search strategy

	Small	Medium	Large	All groups
Results all respondents				
Estimated average relative utility of actual choice	0.47	0.67	0.59	0.62
Results respondents with $R^2 > 0.79$				
Estimated average relative utility of actual choice	0.47	0.68	0.73	0.65
Random choice, respondents with $R^2 > 0.79$				
Average, average relative utility	0.56	0.63	0.49	0.57
Results based on search strategies				
Empirically based number of searches	0.64	0.64	0.64	0.64
Random choice	0.50	0.50	0.50	0.50

are excluded. The exclusion has an effect for large refrigerators, for small and medium refrigerators the effect is negligible. This means that also in the case where respondents rank order the conjoint cards systematically according to attribute values, relative utilities are far from optimal.

To put the estimated relative utilities in perspective, Table 3 also shows average utilities for the case that customers choose at random, i.e. all products are assumed to be chosen with the same probability. Thus the numbers reflect the average utility over all products and over all respondents in each group. Over all groups, random choices lead to lower average relative utilities than actual choices, as one should expect. However, in the small group, random choices lead to a higher relative utility than actual choices. This rather surprising result could be explained by the uncertainty of the method for small sample sizes (seven respondents). However, it may also indicate that the method is biased towards overestimating losses (for reasons that are not captured by the Monte Carlo analysis in Moxnes (2003)). Therefore, it is interesting to consider other sources of information to judge whether the results are reasonable or not.

A first indication of non-optimal choices is provided by customers who want to change newly bought refrigerators. My own experiences as well as reports by the retailers we were in contact with indicate that people at times want to change a newly bought product. Most probably, more customers than those that actually take an action are dissatisfied. Actions can be hampered by uncertainty about own preferences, fear of making another bad choice, considerations of sunk costs (Kogut, 1990), tendencies to postpone actions (Akerlof, 1991), and defensive actions to cover poor choices in the first place (Argyris, 1990).

Second, an investigation by Gately (1980) shows that customers miss out on dominating alternatives (equal to or better on all attributes). This happens even when the products are placed next to each other in the store.

Third, normative search theory predicts non-optimal choices when there are search and information processing costs. Hey (1981) finds quite similar losses for

Table 4
Empirical estimates of number of searches and of the percentage with one search only

	Average no. searches		% with only one search	
	Dealers	Brands	Dealers	Brands
Newman and Staelin (1972), automobiles and household appliances	2.3	–	49	–
Dommermuth (1965), refrigerators	–	2.3		41
Claxton, Fry, and Portis (1974), household appliances	2.4	–	–	–
Brottemsmo and Moxnes (1991), automobiles	2.1	2.7	43	41
Brottemsmo, Hatlebakk, Moxnes, and Nyhus (1992), lab. experiment automobiles	2.2	2.7	37	38

optimal search strategies and for simple, practical strategies. That the perceived information costs are considerable, or that the perceived gains of further search are small, is indicated by the fact that most customers investigate only a small number of options, see Table 4. In particular, note the high fraction of customers that make only one search. If there is no information search beyond what is reported, more than 40% of the customers choose at random. Probably, customers often possess some a priori information, and they are likely to get useful advice from salespersons. However, the fewer products they consider, the more likely it is that they come to ignore important attributes.

To quantify what the reported number of searches imply in terms of relative utility, we use a simple search strategy: investigate k products and choose the one with the highest utility. We assume that the products are uniformly distributed with a utility ranging from 0.0 to 1.0, i.e. the same range as our measure of relative utility. The expected utility of the search is simply given by $k/(k+1)$. [2] When only one product is searched, the expected utility will be 0.5. With infinitely many searches the expected utility will be 1.0. The average, expected utility for a group of customers with different number of searches is

$$R_{\text{Search}} = \sum_{k=1}^{7} w_k \frac{k}{k+1} \tag{7}$$

where w_k denotes the fraction of the population that makes k searches. We assume that 41% search only once, i.e. $w_1 = 0.41$. The other weights are set to obtain an average number of searches of 2.3, with a reasonably smooth distribution. [3] Thus the chosen distribution of searches is roughly consistent with the data in Table 4. With

[2] The probability that utility is greater than some value u is given by the joint probability that all searches result in a utility below u, $F(u) = u^k$, and $dF/du = f(u) = ku^{k-1}$. Then we find the expected value of $f(u)$ on the range from 0.0 to 1.0 and get $k/(k+1)$.

[3] The weights w_k for searches k from 1 to 7 are: 0.41, 0.26, 0.14, 0.09, 0.06, 0.03, and 0.01. The result is not very sensitive to likely variations in the distribution that maintain an average of 2.3. The distribution resembles the distributions reported in Brottemsmo and Moxnes (1991) and found in a laboratory experiment by Brottemsmo et al. (1992).

these assumptions we find a relative utility of 0.64, see Table 3. The result is very close to the estimated average relative utility over all groups.

However, this is not an ideal comparison. Rather we should compare how the search strategy and the respondents perform relative to the results of random choice. For "all groups", the differences between lines 4 and 5 (0.14) is larger than the difference between lines 2 and 3 (0.08). Apparently the search strategy performs better than the respondents. However, this should be expected because the search strategy does not involve any utility calculation, the utility of the different products is known exactly. Our respondents had a more difficult task when choosing refrigerators in the stores. Most likely they did not have full information about all attributes and they did not process this information perfectly. This may explain the difference.

While we cannot rule out that there are still certain biases in our quantitative results, the available evidence clearly indicates that customers do not make perfect choices. Thus, there is a potential for efficiency standards to produce both losses and gains in customer utility.

6. The effect of energy efficiency standards

Standards for refrigerators used in the US are set as linear functions of interior volume (Turiel, McMahon, & Lebot, 1993). Here we simplify and assume one and the same efficiency standard for all size classes. Thus only refrigerators with an electricity consumption of less than q_S kWh/year are allowed to enter the market. This implies that we may underestimate the potential for standards somewhat, since we have only one rather than two parameters to adjust when searching for optimal standards.

Fig. 1 shows average losses L (or gains if losses are negative) as a function of the efficiency standard, q_S. First consider the average loss over all size classes. The standard starts to rule out the refrigerators with the highest electricity consumption at 547 kWh/year. Then for the entire range of standards from 547 to 209 kWh/year, the loss is negative. In other words, the average customer benefits in terms of utility. For standards below 209 kWh/year there is a loss, increasing to 0.073 relative utility units at the lowest possible standard of 128 kWh/year. This standard leaves only one refrigerator in each size class (this is also the situation at the lowest standard in the figure at 150 kWh/year). To put this loss in perspective, it is considerably lower than the average loss caused by non-optimal choices in the first place, $1.0 - 0.62 = 0.38$ relative utility units (Table 3).

For medium size refrigerators the finding is the same as for the overall average. For large refrigerators there is a loss in utility when the standard goes below 329 kWh/year, and it increases to 0.20 relative utility units towards the toughest standard. For small refrigerators the loss is always negative, being −0.18 relative utility units at the toughest standard. The results may suggest that the standard for electricity consumption should increase with the size of the refrigerators.

The effects of the standard are not sensitive to a removal of the nine respondents with $R^2 < 0.79$ or to the exclusion of all insignificant coefficients from the conjoint

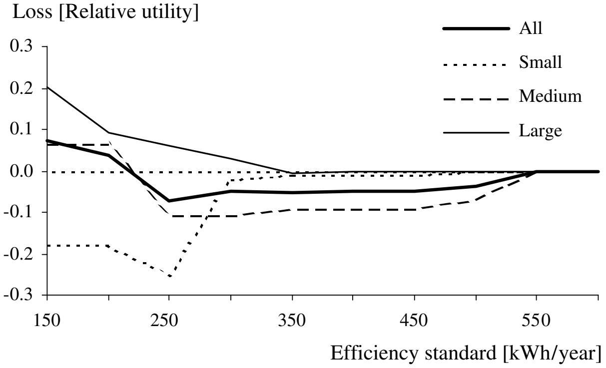

Fig. 1. Average losses as functions of the efficiency standard.

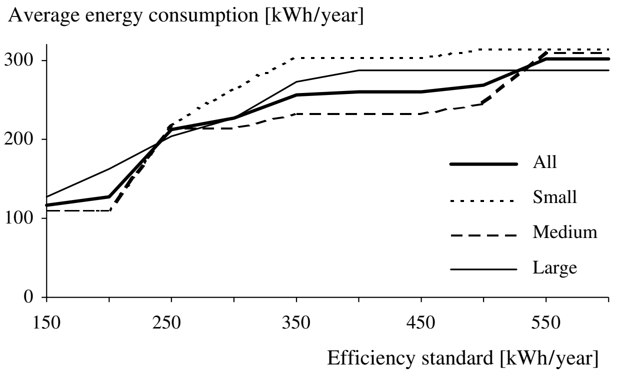

Fig. 2. Average energy consumption per year as functions of the efficiency standard.

analysis, see Moxnes (2003). Hence all the following results are from the case with all respondents and all coefficients.

Fig. 2 shows how the average energy consumption per refrigerator develops with the standard. We first consider the average over all size groups. By going from no standard to the toughest standard, energy consumption is reduced by 62%. The systematic effect of an increasingly tough standard is consistent with the empirical investigations showing that standards do have a significant effect on energy consumption. A standard of 200 kWh/year yields an energy saving of 58%, at a cost of 0.038 relative utility units. A standard of 209 kWh/year gives a saving of 43% at a gain of 0.046 utility units.

Looking at the separate size groups we see that the development is quite similar in all groups. This is related to the fact that the ranges for energy consumption are almost the same in all size groups, respectively 110–328, 110–548, and 128–383 kWh/year in the small, medium, and large group. This was the main reason for using the same standard in all size groups.

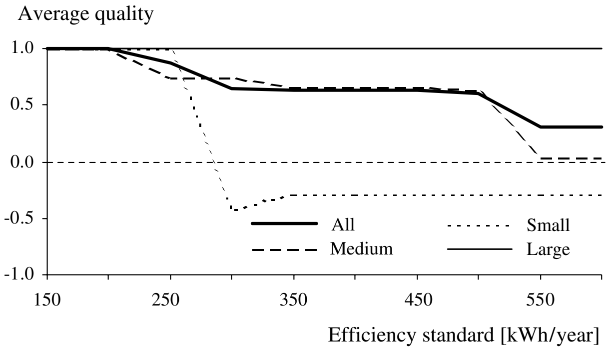

Fig. 3. Average quality as a function of the efficiency standard.

Then we consider the effect of the standard on the most important of the attributes, quality. To investigate this effect we construct a linear measure of quality, where low quality has the value −1.0, medium quality has the value 0.0, and high quality has the value 1.0. Fig. 3 shows that the overall average quality increases as the efficiency standard is reduced. The reason must be that the general quality attribute is correlated with energy efficiency. This seems natural since energy efficiency could be seen as one of several elements contributing to the overall quality of refrigerators. Thus, the energy efficiency standard drives low quality models out of the market.

On average there is only a minor effect of standards on the interior volume. At tough standards the interior volume of small refrigerators increase considerably and it decreases somewhat for medium sized ones.

As quality and energy efficiency improves one should expect the price to rise. Fig. 4 shows that this is what happens. It is interesting to note that there is hardly any increase in the average price of refrigerators as the standard is reduced from 500 to 250 kWh/year. Going from 250 to the toughest standard, the average price

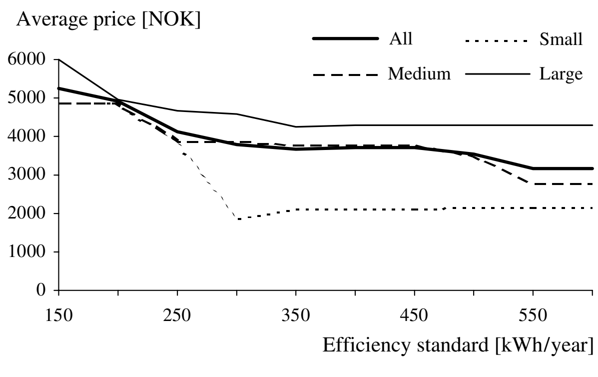

Fig. 4. Average price over all size classes as a function of the efficiency standard.

increases by 27%. From Fig. 1 we see that this reduction in the standard turns a utility gain into a loss. The price increase is particularly strong for the small class. When this strong price increase does not lead to a similarly strong reduction in utility, it is because at the same time quality and interior volume both increase and energy consumption decreases.

Finally we consider the sensitivity of our findings to the price of electricity. We have assumed an electricity price of NOK 0.4/kWh (Euro and USD 0.05/kWh). The effect of doubling this electricity price (to the level of most neighbouring countries) is not very strong. At the most the average loss for all groups is reduced by around 0.023 relative utility units.

7. Concluding discussion

We have proposed and tested a method to estimate customer losses due to energy efficiency standards. The main finding is that for most standards there is a gain in utility rather than a loss. Only for standards below 209 kWh/year is there a reduction in utility. When only the most efficient refrigerators are allowed in the market, average customer utility is reduced by 7% points. This loss is small relative to our estimate of normal customer losses due to limited search and imperfect information processing. While our estimate of normal losses is uncertain, there is much evidence to the fact that customers do (and should) make imperfect choices. It is these imperfections that make it possible for standards to have a positive effect on customer utility.

The above results are confined to a static context. The following dynamic factors should also be considered. First, standards should be announced ahead of the implementation time such that producers get a chance to adjust their models and such that customers with particular requirements do not end up with large utility losses. Not only does this seem fair to both the producers and customers, it will also help maintain sufficient competition in the market. Second, models that are produced in large quantities are cheaper per unit because of the effects of scale in production, advertisement, distribution, sales efforts and maintenance. Thus, an energy standard will lead to increased demand and reduced costs and prices of future low energy refrigerators. In our case the price of the most efficient refrigerators must drop by 15% to prevent reductions in average utility at the toughest standard. Third, adaptations of other attributes than energy efficiency by producers could but does not have to contribute to further increases in utility given the toughest efficiency standard. Altogether this indicates that an efficiency standard of 128 kWh/year, giving a reduction in energy consumption of 63% could be both socially and privately preferable in the near future.

Our study should be considered a first rough test of a rather complicated empirical issue. Further studies should aim for higher response rates. They should consider distributional effects, for instance investigate the effect of standards on second-hand refrigerators, yielding a combination of low energy consumption and a low purchasing price. Further studies should investigate the extent to which non-compensatory decision rules are used by customers and by respondents in conjoint tests, and analyse the implications for the choice of methodology when studying standards. It may also be interesting to consider efficiency standards that depend on some other attribute, e.g. the volume of refrigerators, and to consider standards for other attributes than energy, e.g. certain aspects of quality. Finally, it is important to study other products for which energy efficiency standards seem appropriate. The question about the effect of standards on utility is an empirical one, and one should be careful not to generalise the quantitative findings presented here.

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