Chapter 3

Consumer durables and energy and water use

3.1 Introduction

Household demand for energy and water are largely determined by the stock of consumer durables and the use of this stock.[1] As a consequence, analyzing consumer behavior with respect to durables is an important step towards understanding household energy and water demand.

This Chapter focuses on two issues concerning consumer durables. The first issue is the development of the durable appliances over the years (see section 3.2). We estimate hedonic regression equations in which we relate purchase prices to the characteristics of consumer durables, in particular capacity, and energy and water efficiency. This allows us to determine the changes in electricity and water use per service unit resulting from efficiency improvements, and it provides a picture of the changing costs of the use of domestic appliances to the consumer. We use data sets on refrigerators, freezers, washing machines and dishwashers.[2] The estimation results are used to construct quality-corrected prices and electricity and water uses. We find that while the quality and capacity of consumer durables enlarged over the years, purchase prices and electricity and water uses per service unit declined.

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[1] Figure 2.8 in Chapter 2 shows the development of the possession rate of some consumer durables.

[2] Our analyses focuses on these four consumer durables for two reasons. First of all, HOMES particularly focuses on these durables. Secondly, data availability for tumble dryers, for instance, is insufficient. The possession rates of the durables chosen are high, and the durables are present in households for a relatively long period of time.

In section 3.3 we consider a more specific choice problem: we analyze the choice between a high-efficiency and a low-efficiency version of a consumer durable. We focus on the role of the government providing subsidies on the purchase price of high-efficiency consumer durables in order to increase their penetration rate. We provide a theoretical analysis of the effectiveness of two subsidy schemes, the continuous and the instantaneous subsidy. In the first scheme, a household receives a subsidy each time it purchases an energy-efficient appliance, and in the second scheme a household only receives a subsidy at the first purchase. We consider two levels of aggregation, namely the purchase decision of households at micro-level and the penetration rate at macro-level. As to the first level, we use an intertemporal choice model comparing the costs of two purchase options. The cost comparison is based on minimum expected discounted costs, in which the preference of time for households, measured by the subjective discount rate, plays a central role. As to the macro level, all households have their own subjective discount rates, and we assume that the distribution of subjective discount rate values can be represented by a density function. Based on the distribution of the subjective discount rates, we construct a penetration rate. With this penetration rate we can analyze the effectiveness of two different subsidy schemes, the continuous subsidy scheme and the instantaneous subsidy. We also analyze the possibility of financing the subsidies by an energy tax. Finally, section 3.4 concludes.

3.2 Consumer durable prices, energy and water use, and the hedonic regression technique

3.2.1 Introduction

This section analyzes the development of energy and water uses of consumer durables. We estimate hedonic regressions analyzing purchase prices as well as energy uses and water uses of four different consumer durables, namely refrigerators, freezers, washing machines and dishwashers. In our analysis we use data gathered from comparative tests of domestic appliances conducted by the Dutch Corporation for Comparison Tests (Stichting Vergelijkend Warenonderzoek) between 1964 and 1992 which were published in the Consumer Reports (*Consumentengids*).[3]

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[3] Since 1956, the Consumer Report (*Consumentengids*) is the monthly magazine of the Dutch Consumer Union (*Consumentenbond*).

Hedonic regression technique

The hedonic regression technique originates from the sixties when Becker (1965) and Lancaster (1966) suggested more elaborate models for the theory of consumer demand. In particular, Lancaster (1966) suggested that the demand for goods depends on the characteristics of goods. From this point of view the hedonic regression technique provides a tool to compare heterogenous products, which slightly differ in characteristics and purchase prices (see Rosen, 1974). Over the years the hedonic regression technique has been applied to compare heterogeneous products and services. One main application is the comparison of purchase prices of durable goods, such as cars (see for instance Dhrymes, 1971, and Thompson, 1987), refrigerators (Dhrymes, 1971; and Gordon, 1990), and houses (see for instance Cropper *et al.*, 1988).

Gordon (1990) extensively reviewed the measurement of consumer durable prices including the hedonic regression technique. In particular, he applied the hedonic regression technique to the prices of several consumer durables, such as refrigerators, air conditioners, and cars. Gordon argued that adjustments for the improvements in energy efficiency should be included in analyses. However, due to the limitation of his data, Gordon included a dichotomous variable representing energy efficiency in only a few regressions. In the case of refrigerators, he found that the energy efficiency has a significant positive effect on the price of the consumer durable.[4] The inclusion of an energy efficiency measure introduces an additional complication in the price regression equation since energy efficiency is likely to be correlated with other explanatory variables in the price regression equation.

Wilcox (1984) was one of the first to estimate a hedonic-like regression equation for energy efficiency of consumer durables. Witt (1997) included a hedonic regression equation in his analysis of the fuel efficiency for cars. He also estimated a price regression equation, but he did not include the fuel efficiency as an explanatory variable in the purchase price regression equation.

3.2.2 Data

For our analysis we created separate data sets for each consumer durable, namely refrigerators, freezers, washing machines and dishwashers. Refrigerators and

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[4] In particular, Gordon (1990) estimated six different equations for purchase prices of refrigerators. He only included a dummy variable for high efficiency in one of the price regression equation.

Table 3.1: *Summary statistics of the refrigerator data set,* 1964 – 1991

Variable description	Mean	Standard deviation	Min	Max	N
Price in guilders (real)	1,107	480	291	3,132	662
Net volume in liters	163.3	40.5	81	315	665
Quality in freezing	2.58	1.53	0	4	636
Volume freezing compartment	40.2	37.7	0	137	665
Electricity use in kWh per day	1.23	0.52	0.37	4.10	601
Number of doors	1.46	0.50	1	2	665
Number of refrigerators in test	23.9	12.5	7	55	665
DUMMY VARIABLES					
Table-sized refrigerator	0.50	0.50	0	1	665
Combined refrigerator	0.21	0.41	0	1	665
Two-doors refrigerator	0.29	0.45	0	1	665
Freezing compartment present	0.87	0.34	0	1	665
Built-in version	0.06	0.23	0	1	418
Ambient temperature					
18°C	0.45	0.50	0	1	665
25°C	0.55	0.50	0	1	665

freezers almost continuously require electricity during the day, while washing machines and dishwashers require electricity and water when running.[5] The electricity requirements of refrigerators and freezers are measured per day and the electricity and water requirements of washing machines and dishwashers are measured per run. Below we subsequently discuss the data sets and their summary statistics where N is the number of observations.

Refrigerators

The results of the first comparative test of refrigerators were published in 1964. The data set contains information on 665 refrigerators for the period 1964–1991, see table 3.1. We distinguish three types: cabinet-sized, two-doors and combined refrigerators. The cabinet-sized model is the smallest refrigerator which consists of a refrigerating compartment which might include a freezing compartment.[6] Two-doors refrigerators and combined refrigerators are both wardrobe-sized refrigerators which have separate freezer and cooling compartments. The difference between the two-doors refrigerator and the combined refrigerator is the number of generators. The combined refrigerator has two separate genera-

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[5] More precisely, refrigerators and freezers are continuously turned on.

[6] Three two-doors refrigerators have freezing compartments inside the refrigerating compartment and do not have a separate freezing compartment.

Table 3.2: *Summary statistics of the freezer data set,* 1970 – 1992

Variable description	Mean	Standard deviation	Min	Max	N
Price in guilders (nominal)	1,117	473	377	3,284	350
Net volume in liters	198	88.6	19	495	350
Number of baskets	4.1	1.8	1	10	245
Freezing capacity in kilograms	17.7	6.6	3	34	339
Electricity use in kWh	1.25	0.5	1.0	4.0	346
Number of freezers in the test	23.7	6.1	11	31	350
DUMMY VARIABLES					
Wardrobe-sized freezer	0.27	0.45	0	1	350
Table-sized freezer	0.30	0.46	0	1	350
Chest-sized freezer	0.43	0.50	0	1	350
Thick-walled freezer	0.17	0.37	0	1	350
Test performance	5.79	1.24	1	7	285
Ambient temperature					
18°C	0.24	0.43	0	1	350
20°C	0.15	0.36	0	1	350
25°C	0.61	0.48	0	1	350

tors, one for the freezing compartment and one for the refrigerating compartment, while the two-doors refrigerator has one generator for both compartments. The cabinet-sized refrigerator has one generator.

The average real price was 1,107 guilders and the electricity use per day was 1.23 kWh. The electricity use was measured under different circumstances. In the first years of testing, the ambient temperature was 25°C, while in more recent tests it was 18°C. The capacity of the refrigerators is measured by their refrigerating and freezing volume. The average volume of the refrigerating compartment was 163 liters, while the average volume of the freezing compartment was 40 liters. We assume that the cooling performance per unit volume is constant across the refrigerators. In other words the refrigerating performance is determined by the net volume of the refrigerating compartment.

Freezers

The first comparative test of freezers appeared in 1970 and by 1992, 350 freezers had been analyzed. Three models are distinguished: cabinet-size, wardrobe-size, and chest-type. Note that the freezer compartments of refrigerators were not taken into account here, since these were accounted for in the data set of refrigerators. Table 3.2 summarizes statistics of the freezer data set. The freezer

Table 3.3: *Summary statistics of the washing machine data set,* 1965 – 1992

Variable description	Mean	Standard deviation	Min	Max	N
Price in guilders (real)	1,691	789	600	6,387	663
Dry load in kilogram	3.76	1.35	0.8	5.5	663
Water use in liters per run	106.6	28.0	32	215	647
Electricity use in kWh	1.66	0.88	0.3	4.9	662
Time per wash run in hours	1.68	0.75	0.75	3.25	662
Max. number of turns per minute	1,047	512.6	360	2,865	334
Number of washing machine in test	15.6	3.9	9	22	663
Overall Test performance	5.34	1.29	1	7	507
Cleaning performance	5.41	1.81	1	9	660
Performance of usage	5.66	1.51	1	9	661
DUMMY VARIABLES					
Top-load washing machine	0.15	0.35	0	1	663
Front-load washing machine	0.75	0.43	0	1	663
Combined washing machine	0.09	0.28	0	1	663
Program temperature					
40°C	0.12	0.32	0	1	663
60°C	0.52	0.50	0	1	663
95°C	0.36	0.48	0	1	663
Synthetic program	0.29	0.45	0	1	663
Prewash	0.28	0.45	0	1	663
Energy-saving program	0.09	0.29	0	1	663
Hallmark for safety device	0.62	0.49	0	1	569

volume varies considerably, depending on the model; the average was 198 liters. The freezing capacity is defined as the maximum weight of food that can be frozen in 24 hours. The average electricity use of freezers is 1.25 kWh per day. The electricity use was measured at different ambient temperatures, namely 18, 20, or 25°C.

In the case of freezers we included a variable reflecting an overall test performance and ranging from 1 to 9: the value 1 reflects a worse performance, and the value 9 reflects an excellent performance. Note that this variable is also published in the Consumer Reports.

Washing Machines

We used the results of comparative tests on 663 washing machines (published in 1965 – 1992) of three types: front-loaders, top-loaders without a spin dryer, and twin-tub models (separate top-loader and spin dryer). Table 3.3 summa-

Table 3.4: *Summary statistics of the dishwasher dataset,* 1968 − 1989

Variable description	Mean	Standard deviation	Min	Max	N
Price in guilders (real)	1,906	974	619	4,714	129
Number of baskets	10.9	2.1	4	14	129
Water use in liters per run	41.6	15.0	11	71	129
Electricity use in kWh	1.9	0.6	0.6	3.2	129
Time per run in hours	1.3	0.3	0.5	2	129
Program temperature in °C	62.4	5.3	35	70	125
Number of dishwashers in test	14.6	4.3	10	23	129
Overall test performance	5.7	1.4	1	4	129
Cleaning performance	5.9	1.5	1	9	129
Performance of usage	6.2	1.4	1	7	127
Noise performance	4.5	1.7	1	9	127
DUMMY VARIABLES					
Portable dishwasher	0.10	0.30	0	1	129
Top-load dishwasher	0.05	0.23	0	1	129
Front-loader	0.95	0.23	0	1	129
Cabinet-sized dishwasher	0.90	0.30	0	1	129
Built-in version	0.09	0.28	0	1	129
Energy-saving program	0.02	0.15	0	1	129
Softener	0.92	0.27	0	1	129
Hallmark for safety device	0.47	0.50	0	1	129

rizes their characteristics, prices and electricity and water consumption. On average, washing machines were the most expensive to buy of the four domestic appliances we analyzed. The weight of the dry loads varied from 0.5 to 5.5 kilograms. Some machines (28 percent) were tested during a washing program including a prewash. There were four different programs with four washing temperatures: washing programs at 40 and 60°C; a special washing program at 95°C; and a special program for synthetics at 60°C. Note that in the latter washing program the weight of dry load is approximately half of the weight of dry load in the other programs considered.

Similar to the freezer data set we included three performance variables, namely an overall test performance, cleaning performance and the performance for easy usage. The performance variables range from 1 to 9, where the value 9 reflects an excellent performance.

Dishwashers

We gathered information on 129 dishwashers tested in the period 1968 – 1989. In the first comparison test in 1968 three models were tested: a small portable dishwasher that could be installed near to the sink for waste water drainage, and two cabinet-sized models, one a top-loader and the other a front-loader. Table 3.4 summarizes the data set. Note that it is hard to measure the capacity of a dishwasher. In the data set the number of baskets is a proxy for the capacity.

In the dishwasher data set we included four performance variables measuring the performance on the overall test, cleaning, easy usage and noise. The performance variables range from 1 to 9, where 9 reflects an excellent performance. In the case of the noise variable the value 9 reflects an extremely silent dishwasher.

3.2.3 Econometric specification and estimation results

Specification

We assume that the electricity use, water use, and purchase prices are linear in the characteristics. The electricity use specification is

$$q_{ei} = \beta_e^{'} X_{ei} + \gamma_e t + \varepsilon_{ei}, \tag{3.1}$$

and the water use specification is

$$q_{wi} = \beta_w^{'} X_{wi} + \gamma_w t + \varepsilon_{wi}, \tag{3.2}$$

where q_{ji} is the input j of consumer durable i and X_{ji} is the vector of characteristics, including a constant term, of the consumer durable i with $j = e$ and w.[7] Here t is a trend and ε_{ji} is the error term which has zero expectation and covariance σ_j^2 for $j = e$ and w. The parameters to be estimated are γ_j, and the vector β_j ($j = e$ and w).

The purchase price specification is

$$p_i = \alpha^{'} X_i + \gamma t + \delta_e q_{ei} + \delta_w q_{wi} + \varepsilon_i, \tag{3.3}$$

where p_i is the purchase price of consumer durable i, and X_i is a vector of characteristics of the consumer durable i. We assume that the electricity use q_{ei} and water use q_{wi} are also determinants of the purchase price of durable appliance i. Here t is a trend and ε_i is the error term which has zero expectation

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[7] We actually used the double logarithmic specification in the estimations. Hence, the electricity use and water use coefficients can be interpreted as elasticities.

and covariance σ^2. The parameters to be estimated are the vector α, γ, δ_e, and δ_w. We expect that if a consumer durable is more electricity efficient or water efficient, the purchase price will be higher, i.e. both δ_e, and δ_w are negative. Since we assume that electricity use and water use are determined by the characteristics of a consumer durable, both q_{ei} and q_{wi} are endogenous. As a consequence, we cannot estimate (3.3) with Ordinary Least Squares, since the estimation results will be biased. Therefore, we estimate (3.3) with Two-Stage Least Squares (2SLS) in order to obtain consistent estimation results as well as corrected standard errors. First, we estimate (3.1) and (3.2) with Ordinary Least Squares and calculate the predicted values $\hat{q}_{ei}$ and $\hat{q}_{wi}$. Then, we use these predicted values as instruments for q_{ei} and q_{wi} in (3.3) and we estimate (3.3) with Least Squares correcting for the standard errors. Note that to identify all parameters in (3.3), X_{ei} should include at least one variable that is not in X_{wi} and X_i, and X_{wi} should include at least one variable that is not in X_{ei} and X_i.

Results

We used a sample of $N = 598$ refrigerators for our estimations.[8] Table 3.5 shows the estimation results of the price regression equation and the energy use regression equation for the refrigerator.[9] Electricity use has no significant effect on the purchase price of refrigerators. The purchase price is determined by the type of refrigerator, the net volume and a degree of competition in the market for refrigerators.[10] The market competition has a significant negative effect on the purchase price. Furthermore, on average the purchase prices annually decline with 1.7 percent.

The electricity use of refrigerators is determined by the net freezing volume and the type of refrigerator, the ambient temperature and a trend. Both the wardrobe-sized refrigerator and the combined refrigerator use more energy (31 and 32 percent respectively) excluding the effect of the freezing compartment. The presence of a freezing compartment has a positive effect on the energy use (37 percent), and additionally each cubic centimeter of the freezing compartment increases the energy use with 0.25 percent. If the ambient temperature is set

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[8] In this section k is the number of parameters in the regression equation.

[9] We did not find significant effects on the coefficients for the presence and the net volume of a freezing compartment. Therefore, we excluded those variables from our final price regression equation.

[10] Here, we interpret the number of refrigerators in the test as the number of refrigerators in the market at the time of the test. This provides us an indicator for market competition. The effect of this indicator is expected to be negative: increasing competition implies lower purchase prices.

Table 3.5: *Estimation results of hedonic price and electricity use regressions for refrigerators (absolute t-values in parentheses)*

Variables description	Logarithm of price	Logarithm of electricity use
Intercept	7.822 (30.72)	1.069 (5.154)
Logarithm of electricity use	0.153 (1.162)	–
Year	-0.017 (4.985)	-0.019 (9.840)
Number of refrigerators in test	-0.004 (3.605)	–
Net volume cooling compartment in liters	0.003 (7.372)	0.0008 (1.667)
Net volume freezing compartment in liters	–	0.003 (3.581)
Cabinet-sized refrigerator with freezing compartment	-0.151 (2.577)	–
Wardrobe-sized refrigerator	-0.061 (0.620)	0.271 (6.023)
Combined refrigerator	0.376 (3.253)	0.276 (4.065)
Presence of freezing compartment	–	0.312 (7.560)
Ambient temperature 25°C	–	0.091 (3.833)
R^2	0.64	0.61
$F_{N-1,k-1}$	148.1	133.8
N	598	598
k	8	8

to 25°C instead of 18°C, the energy use of a refrigerator increased with 10.5 percent. Finally, on average the energy use declined annually with 1.9 percent.

In the estimation procedure for freezers we used a sample of 335 freezers. Table 3.6 shows the result of the estimation of both the price regression equation and the energy use regression equation for freezers. The electricity use has a significantly negative effect on the purchase price. For instance, if a freezer uses one percent less electricity, the purchase price will be 0.3 percent higher.[11] Furthermore, the purchase price is determined by the type of freezer, the net volume, the overall test performance.[12] There is no significant effect of the indicator for the market competition.

The electricity use is determined by the type of freezer, the net volume, the ambient temperature, the freezing capacity and a trend. A cabinet-sized freezer uses 16.4 percent more energy than a chest-sized freezer, while a wardrobe-sized freezer uses 26.2 percent more energy. Thick-walled freezers use 26.6 percent less

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[11] Due to the double logarithmic specification, the coefficient can be interpreted as an elasticity.

[12] Here, the overall test performance variable is a dichotomous variable in the regression equation, which is equal to 1 if the value of the performance variable was 7 or higher and zero otherwise.

Table 3.6: *Estimation results of hedonic price and electricity regressions for freezers (absolute t-values in parentheses)*

Variables description	Logarithm of price	Logarithm of electricity use
Intercept	9.515 (36.27)	0.040 (0.190)
Logarithm of electricity use	-0.286 (3.177)	–
Year	-0.041 (11.87)	-0.013 (7.275)
Number of freezers in test	0.005 (1.686)	–
Net volume freezing compartment	0.003 (5.597)	0.003 (8.213)
Wardrobe-sized freezer	0.255 (4.978)	0.233 (7327)
Cabinet-sized freezer	0.185 (2.700)	0.152 (3.173)
Freezing capacity	0.005 (1.185)	-0.014 (5.254)
Thick-walled freezer	–	-0.309 (10.60)
Ambient temperature	–	0.038 (11.02)
Good quality performance	0.170 (5.232)	–
R^2	0.55	0.74
$F_{k-1,N-k}$	49.1	130.0
N	335	335
k	9	8

energy.[13] The net volume of a freezing compartment has a positive effect on the energy use. If the net volume is increased with one cubic centimeter, the energy use will increase with 0.3 percent. Additionally, freezers with a larger freezing capacity have less electricity use. The ambient temperature affects the energy use measured. On average, a freezer uses 3.9 percent more energy when the ambient temperature is increased with one degree Celsius. Finally, on average the energy use declined annually with 1.3 percent.

For the estimation of the washing machines specifications we used a sample of 646 washing machines. Table 3.7 shows the results of the price regression and both the energy use and water use regression equations. The electricity use has a significantly negative effect on the purchase price, -0.266, while the water use shows a significant positive effect, 0.837. This latter effect is opposite to what we expected. The large positive effect might be caused by the relatively high negative correlation coefficient between the instruments used for the electricity use and water use. Remarkably, we did not find differences in purchase prices for different types of washing machines. Washing machines that are convenient when using and have a good cleaning performance are somewhat more expen-

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[13] Note that we did not find a significant effect of the thick-wall characteristic on the purchase price.

Table 3.7: *Estimation results of hedonic price, electricity use and water use regressions for washing machines (absolute t-values in parentheses)*

Variables description	Logarithm of price	Logarithm of electricity use	Logarithm of water use
Intercept	5.521 (5.573)	0.739 (5.185)	5.409 (35.92)
Logarithm of electricity use	-0.266 (4.069)	–	–
Logarithm of water use	0.837 (4.248)	–	–
Year	-0.032 (11.21)	-0.024 (14.60)	-0.013 (6.963)
Number of washing machines in test	-0.004 (1.126)	–	–
Top loader	-0.008 (0.209)	-0.039 (1.605)	0.060 (2.489)
Washing machine with separate tumble dryer	-0.041 (0.750)	-0.098 (3.195)	0.105 (3.447)
Maximum load per run	–	–	0.073 (8.820)
Time per run	–	0.205 (8.411)	-0.007 (0.337)
Prewash	–	0.101 (3.568)	0.063 (2.166)
Program temperature in °C	–	0.017 (28.70)	0.001 (1.332)
Energy-saving program	–	0.003 (0.086)	-0.054 (1.642)
Good cleaning performance	0.095 (7.297)	–	-0.020 (3.379)
Easy usage performance	0.049 (4.939)	–	–
Electronic safety	-0.139 (4.290)	0.071 (3.914)	–
R^2	0.41	0.85	0.41
$F_{N-1,k-1}$	49.4	466.3	55.5
N	646	646	646
k	10	9	10

sive. The purchase price declined by 3.1 percent per year. We did not find a significant effect for the indicator of market competition (i.e. the number of washing machines in test).

The electricity use is determined by the type of washing machine, the washing program (such as the time per run, prewash or not and the temperature), and a trend. The electricity use of top loaders did not differ from the front loaders, while washing machines combinations, with separate tumble dryers, use 10 percent less electricity. The washing programs characteristics are important in the electricity use. The electricity use increases with the time per run, the inclusion of a prewash and the program temperature. If the time per run is increased with one hour, the electricity use increases with 23 percent. If the washing program includes a prewash, the electricity use is increased by 10.6 percent. The exclusion of prewash itself reduces the electricity use and water use as well as time per run. The exact amount of time saved by exclud-

Table 3.8: *Estimation results of hedonic price, electricity use and water use regressions for dishwashers*

Variables description	Logarithm of price	Logarithm of electricity use	Logarithm of water use
Intercept	14.96 (10.10)	1.307 (5.410)	5.921 (15.01)
Logarithm of electricity use	-0.083 (0.371)	–	–
Logarithm of water use	-0.627 (2.188)	–	–
Year	-0.755 (6.802)	-0.022 (7.121)	-0.036 (10.54)
Volume	0.035 (1.202)	0.029 (1.952)	0.059 (3.645)
Time per run	–	0.627 (8.536)	0.586 (5.717)
Program temperature in °C	–	–	-0.016 (3.396)
Top-loader	0.354 (2.002)	-0.147 (1.439)	–
Portable dishwasher	-0.412 (2.286)	-0.168 (1.766)	-0.098 (1.095)
Energy-saving program	-0.245 (1.414)	–	-0.346 (2.656)
Softener	0.473 (3.871)	–	0.236 (2.655)
Performance: very dry	–	0.118 (3.586)	-
Good overall test performance	–	–	–
Bad overall test performance	0.106 (1.917)	–	–
Electric safety	-0.100 (0.888)	-0.073 (1.936)	–
R^2	0.70	0.76	0.72
$F_{N-1,k-1}$	25.20	52.1	41.6
N	121	121	121
k	11	8	8

ing the prewash option, however, is unknown. Furthermore, the electricity use increases with 1.7 percent per degree Celsius. If the 95 degrees program is used the electricity use increased by 60 percent. Finally, on average the electricity use declined by 2.4 percent per year.

The water use is determined by the type of washing machine, the weight of dry load, the inclusion of prewash, the cleaning performance and a trend. Both top loaders and washing machines combinations use more water (6.2 and 11.1 percent respectively). The weight of the dry load increases the water use as well, 7.6 percent per kilogram. Note that in the synthetic washing program the weight of the dry load is usually half the weight as compared to the other washing programs. Temperature is not affecting the water use. We found that the cleaning performance has a significantly negative effect on the water use. A particular energy saving option did not affect the water use of washing machines. Finally, the water use annually declined by 1.3 percent.

For our estimations we used a sample of 121 dishwashers. Table 3.8 shows the estimation results of the regression equations for the price, electricity use and water use. Water use has a significantly negative effect on the purchase price of dishwashers, -0.627, while electricity use does not significantly affect the purchase price. As in the case of washing machine, the correlation coefficient of the instruments for electricity use and water use is significantly negative. Furthermore, the purchase price is determined by the type of dishwasher and a trend. The purchase price of portable dishwashers, which were only available in the 1960s and early 1970s, are 34 percent less than the purchase price of front loader. Top loaders are more expensive. The purchase prices of dishwashers annually declined by 7.3 percent. Note that we did not include the indicator for market competition, because it is highly correlated with the trend.

The electricity use increases significantly at a 5 percent level with the net volume, the time per run and drying performance and a trend. In particular, if the time per run is increased with a quarter of an hour the electricity use increases with 22 percent. The dishwashers with good drying performances require 12.5 percent more electricity. On average, the electricity use declined by 2.2 percent per year. Note that the electricity use does not vary across the different types of dishwashers and the different program temperatures.

The water use is determined by net volume, the washing program and a trend. The time per run has a positive effect and the temperature a small negative effect. Furthermore, a particular energy-saving option reduces the water requirement with 29.2 percent.[14] The water use declined by 3.5 percent per year.

3.2.4 Discussion and conclusions

With the hedonic regression technique we estimated the effects of the determinants of the purchase price, the electricity use and water use of four consumer durables. For all electricity uses and water uses we found autonomous annual declines. The energy and water use per service unit declined over the years. As a consequence, the costs of producing service units with energy-using appliances declined.[15] The lower costs per service unit encourage consumers to use the appliances more.

In the case of the purchase price, we determined the effects of the electricity

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[14] We also included the energy saving option in the electricity use regression equation but we did not find a significant effect. As a result, the energy saving option only saves water.

[15] In the Netherlands the marginal electricity prices - in real terms - declined over the years, while for most consumers the marginal water prices increased slightly; see Chapter 2. For washing machines and dishwashers, the costs of the electricity inputs, however, are substantially higher than the costs of the water inputs.

use and water use on the purchase prices. Although the purchase prices of all four consumer durables annually declined, we found evidence that more electricity-efficient and water-efficient consumer durables in most cases have higher purchase prices.

According to standard neoclassical theory of consumer behavior, the declining purchase prices encourage consumers to buy more consumer durables (see figure 2.8 in Chapter 2) or replace them more frequently by new models. However, as a consequence of the relationship between the energy-efficiency and the purchase price, as found in our analyses, consumers might hesitate to purchase more energy-efficient consumer durables because of the higher purchase prices. In the next section we analyze the consumer decision with respect to the purchase of more energy-efficient consumer durables given the higher purchase price for more energy-efficient versions.

3.3 The consumer choice between a high- and low-efficiency consumer durable

3.3.1 Introduction

As we have shown in the previous section, the purchase prices of energy-saving alternatives are often substantially higher than the prices of less energy-efficient alternatives. These high purchase prices often discourage households to purchase these energy-efficient appliances, although the investments pay off in the long run. In fact, if the long-run rate of return on investments is the only criterion, this phenomenon contradicts with the rationality principle of neoclassical consumer behavior.[16] Probably, the time preference of consumers is rather high. Consumers consider a trade-off between higher costs of investment at the present and higher future revenues (the savings of energy costs) and they choose to invest if their time preference is low. This raises the question how the government can stimulate households to purchase high-efficiency versions. The government may provide subsidies on the purchase prices of high-efficiency alternatives which might be financed by energy taxes. The question then is whether or not these policy instruments are effective. Below, we analyze an intertemporal framework with a consumer decision with respect to a high-efficiency version and a low-efficiency version. Furthermore, we include the government that maximizes the penetration rate of high-efficiency versions.

In 1991, the Dutch governments started to provide a subsidy on the purchase price of high-efficiency central heating systems. The government's objective was to have placed over one million high-efficiency central heating systems in Dutch dwellings by the year 2000, i.e. on average one of every six dwellings should have a high-efficiency central heating system. Due to the subsidy the purchases of the high efficiency central heating systems increased steadily form 30,000 in 1988 to 200,000 in 1996, see ECN (1998) . The subsidy program was very successful and the government's objective was already achieved in 1995. For this reason, the Dutch government abolished the subsidy measure in 1996. Some energy supplying companies however continued the subsidy measure and they (partly) finance the subsidy program with the revenues of the so-called *ecotax* which has been implemented in 1996, see also Chapter 2.

Subsidies can be introduced on many different terms. Ideally, a subsidy

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[16] In the case of high-efficiency light bulbs Van der Meijde and Wunderink-Van Veen (1995) found a 27 percent rate of return. Despite this high rate, however, they also concluded that the participation of high-efficiency light bulbs is still less than expected.

regime is chosen on the basis of (expected) effectiveness, which is measured by the (expected) change in the penetration rate of an energy-efficient alternative. This section analyzes a general framework in which effects of implementing subsidies on the purchase price of high-efficiency versions of consumer durables are determined. In particular, we analyze the effects of two different subsidy regimes: the continuous subsidy and the instantaneous subsidy. The general framework includes two components. On the one hand we model the consumer choice with respect to the purchase of energy-efficient consumer durables within an intertemporal choice framework, and on the other hand we model the government objective as maximizing the penetration rate of high-efficiency consumer durables given a predetermined government's budget. Under certain conditions and assumptions this model yields analytical solutions for the amount of subsidy and the penetration rate.

We also consider the case in which the government's budget is financed by an energy tax. With a simple model we calculate the level of the energy tax and the penetration rate of high-efficiency consumer durables given an amount of subsidy. The subsidy regimes are evaluated on basis of the penetration rates.

3.3.2 General framework

Consumer decision

We consider a consumer decision in which a consumer can choose between two alternatives of an energy-using durable, a high-efficiency ($i = H$) and a low-efficiency alternative ($i = L$). Both alternatives produce similar services, and they only differ in the amount of energy input. We assume that the lifetimes of the appliances, t_i for $i = H$ and L, are random, i.e. the precise moment of breaking down is unknown. The expected lifetime of the high-efficiency version, $T_{H,}$ is equal to, or larger than the expected lifetime of the low-efficiency version, T_L. The consumer decision is based upon the minimum expected discounted costs, $C_i(r)$, where the costs are a function of the discount rate r. The consumer considers an infinite period of time.

When comparing costs of the alternatives, the consumer considers two types of costs. Firstly, there are the annual operating costs of type i, denoted by τ_i, which may include energy as well as water costs. These costs are paid continuously, and future costs and benefits are discounted with a discount rate

r. The total discounted operating costs are

$$\int_0^\infty \tau_i \cdot e^{-rt} dt = \frac{\tau_i}{r}. \tag{3.4}$$

By definition, the operating costs of the high-efficiency version are less than the operating costs of the low-efficiency version: $\tau_H < \tau_L$.

Secondly, the consumer considers purchasing costs of type i, R_i. These are paid whenever the appliance is replaced, which occurs at random intervals. At each point in time, an appliance has a probability of still being in operation, which is represented by the survivor function, denoted by $1 - F_i(.)$, where $F_i(.)$ is the cumulative distribution function of the lifetime of type i, for $i = H, L$. The expected lifetime, T_i, can be calculated as

$$T_i = \int_0^\infty [1 - F_i(t)] dt. \tag{3.5}$$

As mentioned above, we assume higher expected lifetimes for the high-efficiency alternative, $T_H \geq T_L$.

Let s_{ik} denote the point in time of the k-th purchase of type i. So the sequence of replacements for type i is simply: $s_{i1}, s_{i2}, s_{i3}, ..., s_{ik}, ...$. Note that s_k's are unknown beforehand. Assuming that the purchase price R_i is constant over time, the expected discounted purchasing costs are

$$\begin{gathered} E[R_i(1 + e^{-rs_{i1}} + e^{-rs_{i2}} + ...) = \\ E[R_i(1 + e^{-rs_{i1}} + e^{-rs_{i1}} \cdot e^{-r(s_{i2}-s_{i1})} + ...) = \\ E[R_i \cdot \sum_{k=0}^{\infty} (e^{-rt_i})^k], \end{gathered}$$

using the fact that the time intervals $t_i = (s_{ik} - s_{i,k-1})$ are independent for all k and i and t_i is randomly drawn from the lifetime distribution. Since the expectation of the sum is equal to the sum of the expectations, the expected discounted purchasing costs are

$$R_i \cdot \sum_{k=0}^{\infty} (E[e^{-rt_i}])^k = \frac{R_i}{1 - E[e^{-rt_i}]}, \tag{3.6}$$

The total expected discounted costs for type i are

$$C_i^*(r) = \frac{R_i}{1 - E[e^{-rt_i}]} + \frac{\tau_i}{r}. \tag{3.7}$$

There are two modifications we will make for the cost function in (3.7). Firstly, we define the function $v_i(r)$ as

$$v_i(r) = \int_0^{\infty} (1 - F_i(t_i)) \cdot e^{-rt_i} dt_i = \frac{1 - Ee^{-rt_i}}{r}. \tag{3.8}$$

With this definition we can rewrite the Laplace transform $E[e^{-rt_i}]$ as $E[e^{-rt_i}] = 1 - r \cdot v_i(r)$. Then, we can rewrite (3.7) yielding (see e.g. Kooreman and Steerneman, 1998)

$$C_i^*(r) = \frac{R_i}{r \cdot v_i(r)} + \frac{\tau_i}{r}. \tag{3.9}$$

The relationship between the total expected discounted cost function, $C_i^*(r)$ and annual expected discounted cost function $C_i(r)$is given by:

$$C_i^*(r) = \int_0^{\infty} C_i(r) \cdot e^{-rt_i} dt_i = \frac{C_i(r)}{r}. \tag{3.10}$$

Thus, the annual expected discounted cost for type i are

$$C_i(r) = \frac{R_i}{v_i(r)} + \tau_i. \tag{3.11}$$

With this cost function we can compare the costs for both types. We define a function $h(r)$ which measures the difference of costs between the alternatives:

$$h(r) = C_H(r) - C_L(r). \tag{3.12}$$

In particular, the consumer chooses the high-efficiency version if the difference of costs is negative, i.e. $h(r)$ □ 0. Kooreman and Steerneman provided two sufficiency conditions under which $h(r) = 0$ has an odd number of roots.

Condition 1 *The purchase price of the more high-efficiency version is larger than the lower-efficiency version, i.e.*

$$R_H - R_L > 0. \tag{3.13}$$

Condition 2 *If the zero discount rate is zero, the consumer chooses the high-efficiency version, i.e.*

$$\frac{R_H}{T_H} - \frac{R_L}{T_L} + \tau_H - \tau_L < 0. \tag{3.14}$$

Note that $v_i(0) = T_i$. Furthermore, in their study they assumed that the replacement probability of a low-efficiency alternative is larger than the replacement probability of a high-efficiency alternative for each point in time. In other words, the hazard rate in case of the low-efficiency version is larger than the hazard rate in case of the high-efficiency version for all s, i.e.

$$\theta_L(s) \geq \theta_H(s). \tag{3.15}$$

This additional assumption immediately implies that the expected lifetime of the high-efficiency version is larger than the low-efficiency alternative: $T_H \geq T_L$. If the inequalities (3.13) to (3.15) hold, there is a unique root for $h(r) = 0$, see Kooreman and Steerneman, proposition 3. This unique root is also referred to as the *implicit discount rate* and it can be interpreted as the return rate of the investment. If we assume that consumers behave rationally, they choose the high-efficiency alternative if their subjective discount rates are smaller than this implicit discount rate.

There are two remarks on this model. First, this consumer decision model implies that the optimal strategy is that when the appliance breaks down, the alternative chosen is successively replaced by identical alternatives. Furthermore, we assume perfect credit markets in the economy, which implies that there are no borrowing constraints for consumers.

Penetration rate and the government's objective

In the second part of the general framework we construct a penetration rate for high-efficiency alternatives based upon the consumers' subjective discount rates. The subjective discount rates vary across consumers. The distribution of discount rates across consumers is represented by a density function $z(r)$. When a consumer's subjective discount rate is lower than the implicit discount rate, r^*, a consumer chooses the high-efficiency version. For convenience, we assume that there is a unique implicit discount rate. Then, the penetration rate is simply

$$Z(r^*) = \int_0^{r^*} z(r)dr. \tag{3.16}$$

By definition, the penetration rate is monotonically increasing in the implicit discount rate, r^*.

Suppose that a consumer receives an individual subsidy, S, if he purchases the high-efficiency alternative. As a consequence, the implicit discount rate depends on the subsidy: $r^*(S)$.

The government maximizes the penetration rate subject to a budget restriction. Suppose that the government reserves a given total discounted subsidy budget per household, S_0. The total demand for subsidy is the product of the expected discounted individual subsidies per household conditional on purchasing the high-efficiency version H, represented by $G(S;g)$, and the penetration rate $Z(.)$. Here, g is the government's discount rate. The subsidy scheme applied partly determines the functional form of $G(.)$. Then, the government considers

$$\max_S Z(r^*(S)) \tag{3.17}$$

subject to

$$G(S) \cdot Z(r^*(S)) \square S_0. \tag{3.18}$$

Below, we consider two different subsidy regimes namely the continuous subsidy scheme and the instantaneous subsidy scheme.

3.3.3 Two subsidy schemes

Specification of the model

Before we discuss the effects of the subsidy schemes on the consumer choice and the government's objective, we make assumptions about the distributions of the lifetimes and the subjective discount rates. These assumptions make the derivations more convenient but will not affect the outcomes of the general framework very much. We suppose that the lifetimes of the appliances are exponentially distributed with parameter λ_i $(i = H, L)$. Then, the expected lifetimes are $E[t_i] = 1/\lambda_i$. As a consequence $v_i(r) = 1/(\lambda_i + r)$. Moreover, suppose that the conditions in (3.13) to (3.15) are satisfied. Then, the cost function in (3.11) is

$$C_i(r) = R_i \cdot (\lambda_i + r) + \tau_i \qquad \text{for} \quad i = H, L, \tag{3.19}$$

and the implicit discount rate is

$$\begin{aligned} r^* &= -\frac{C}{B} \qquad \text{with} && (3.20)\\ B &= R_H - R_L && (3.21)\\ C &= R_H\lambda_H - R_L\lambda_L + \Delta\tau, && (3.22) \end{aligned}$$

where $\Delta\tau = \tau_H - \tau_L$. Furthermore, we assume that the subjective discount rates are uniformly distributed over the consumers on the interval $(0, r_{\max})$. Then, the penetration rate is

$$Z(r^*) = \begin{cases} \frac{r^*}{r_{\max}}, & \text{if } 0 \square r^* < r_{\max} \\ 0, & \text{if. } r^* \geq r_{\max} \end{cases} \tag{3.23}$$

So, if the implicit discount rate exceeds a particular value, $r_{\max}$, all consumers choose the energy-saving option. With these assumptions we compare the effectiveness of the continuous subsidy regime and the instantaneous subsidy regime.

Continuous subsidy scheme

In the continuous subsidy scheme (I) the consumer has only two options; the consumer always purchases either the high-efficiency version or the low-efficiency version. For both options, H and L, the consumer considers the cost function in (3.19). However, the purchase price for the high-efficiency version is continuously lowered by the individual subsidy: $R_H - S$. The cost functions are

$$\begin{aligned} C_H^I(r) &= (R_H - S) \cdot (\lambda_H + r) + \tau_H \text{ and} && (3.24) \\ C_L(r) &= R_L \cdot (\lambda_L + r) + \tau_L. && (3.25) \end{aligned}$$

We assume that the conditions in (3.13) and (3.14) are satisfied for $R_H - S$ instead of R_H. This implies that $S < R_L - R_H$. Then the unique implicit discount rate is

$$r_I^* = -\frac{C - S\lambda_H}{B - S} \tag{3.26}$$

with B and C defined as in (3.21) and (3.22) respectively. Note, that the implicit discount rate is monotonically increasing in the individual subsidy, because the first derivative of r^* with respect to S is positive. Furthermore, $r_I^* \geq r^*$ if $S \geq 0$.

The government provides a subsidy whenever a consumer replaces his high-efficiency version. The expected discounted subsidy costs per consumer for the government are analogous to the expected discounted purchasing costs for the consumer as in (3.6). Given the exponentially distributed lifetimes, the expected discounted subsidy costs in annualized terms is

$$G(S) = S(\lambda_H + g). \tag{3.27}$$

Then the budget restriction is obtained by substituting (3.27) into (3.18)

$$S(\lambda_H + g) \cdot Z(r_I^*(S)) = S_0. \tag{3.28}$$

Knowing the new implicit discount rate, $r_I^*(S)$, as a monotonically increasing function in S, we determine the optimal individual subsidy by substituting (3.26) into (3.28) and solving the equation with respect to S. For $r_I^*(S) < r_{\max}$, the optimal individual subsidy for the continuous subsidy scheme, S_I^*, is

$$S_I^* = \frac{-[S_0 \cdot r_{\max} - C(\lambda_H + g)] + \sqrt{D_I}}{2\lambda_H \cdot (\lambda_H + g)} \tag{3.29}$$

with

$$\begin{aligned} D_I &= [S_0 \cdot r_{\max} - C(\lambda_H + g)]^2 + \\ &\quad +4\lambda_H(\lambda_H + g) \cdot S_0 \cdot r_{\max} \cdot B, \end{aligned} \tag{3.30}$$

where C and B are defined as in (3.21) and (3.22) respectively. Note that $S_I^* = 0$ if $S_0 = 0$ and the optimal subsidy lies within the range $(0, B)$ which can be shown by straightforward algebra. If $r_I^*(S) \geq r_{\max}$, the optimal subsidy S_I^* is

$$S = \frac{S_0}{(\lambda_H + g)}. \tag{3.31}$$

We illustrate the continuous subsidy regime with an example in which the optimal subsidy is determined.

Example 1 *Let* $R_H = 2500$*,* $R_L = 1750$*,* $\tau_H = \tau_L - 150$*,* $\lambda_i = 0.1$ *for* $i = H, L$ *(i.e. the expected lifetime of both versions is ten years), and* $r_{\max} = 1.0$*. Then,* $r^* = 0.10$ *and hence the penetration rate of the high-efficiency version is* 10 *percent. Let the government provide an individual subsidy given the government's discount rate* $g = 0.05$ *and the subsidy budget* $S_0 = 1.5$*. The optimal individual subsidy then is* 80.59*. As a result, the implicit discount rate is* $r_I^* = 0.124$*, and the penetration rate is* 12.4 *percent.*

Instantaneous Subsidy

In the instantaneous subsidy scheme (II) the consumer receives a subsidy at a single point in time; particularly, the first time he replaces a consumer durable by a high-efficiency version. The consumer considers three options: he continuously chooses the high-efficiency version (H), he continuously chooses the low-efficiency version (L) or he chooses the high-efficiency version the first time and the low-efficiency version afterwards (HL). The latter option is also referred to as the switch option. Before we can analyze the effects of the single subsidy we briefly discuss the general derivation of the cost function of the switch option. The expected discounted purchasing costs are:

$$\begin{aligned} &E[R_H - S + R_L \cdot e^{-r \cdot s_{1H}} + R_L \cdot e^{-r(s_{1H}+s_{1L})} \\ &\quad +R_L \cdot e^{-r(s_{1H}+s_{2L})} + ...] = \\ &\quad R_H - S + R_L \cdot \frac{E[e^{-r \cdot t_H}]}{1 - E[e^{-r \cdot t_L}]} \end{aligned}$$

And the expected discounted operating costs are:

$$\begin{aligned} & E[\int_0^{t_H} \tau_H e^{-r \cdot s} ds + \int_{t_H}^{\infty} \tau_L e^{-r \cdot s} ds] \\ = & \frac{1 - E[e^{-r \cdot t_H}]}{r} \tau_H + \frac{E[e^{-r \cdot t_H}]}{r} \tau_L. \end{aligned}$$

Therefore, the total expected discounted costs in annualized terms are:

$$C_{HL}(r) = r(R_H - S) + \frac{r R_L E[e^{-r \cdot t_H}]}{1 - E[e^{-r \cdot t_L}]} + \tau_H - E[e^{-r \cdot t_H}] \Delta \tau. \tag{3.32}$$

Substituting the exponential distributions of the lifetimes in the general cost functions, we yield three cost functions written in annualized terms:

$$\begin{aligned} C_H^{II}(r) &= R_H(\lambda_H + r) - rS + \tau_H, & (3.33) \\ C_L(r) &= R_L(\lambda_L + r) + \tau_L, \text{ and} & (3.34) \\ C_{HL}(r) &= \frac{r}{\lambda_H + r} \left[(R_H - S)(\lambda_H + r) + \tau_H \right] \\ &\quad + \frac{\lambda_H}{\lambda_H + r} \left[R_L(\lambda_L + r) + \tau_L \right]. & (3.35) \end{aligned}$$

The first term of the C_{HL} cost function are related to the high-efficiency alternative including the subsidy, and the second term represents the delayed costs of the low-efficiency alternative.

Comparing the three cost functions, we determine three *implicit discount rates*:

(i) the H- and HL-curve intersect at

$$r^*_{II,a} = -\frac{C}{B} = r^*; \tag{3.36}$$

(ii) the H- and the L-curve intersect at

$$r^*_{II,b} = -\frac{C}{B - S}. \tag{3.37}$$

This implicit discount rate, however, is not relevant, because consumers with subjective discount rates equal to $r^*_{II,b}$ will choose the switching option, since this option provide least expected discounted costs.[17] Finally

(iii) the HL- and L-curve intersect at $r^*_{II,c} = 0$, and

$$r^*_{II,c} = -\frac{C - S\lambda_H}{B - S}. \tag{3.38}$$

Note, however, that the case of zero discount rate is irrelevant, because the H-cost function provides least costs for zero discount rate. We can easily show that $r^*_{II,c} \geq r^*_{II,b} \geq r^*_{II,a}$ for a non-negative individual subsidy S. We can distinguish three types of consumers. First, consumers with subjective discount rate smaller than $r^*_{II,a}(= r^*)$ choose the high-efficiency alternative continuously, regardless the presence of a subsidy. Secondly, consumers with subjective discount rate within the range $(r^*_{II,a}, r^*_{II,c})$ choose the high-efficiency alternative only the first time, and consumers with high discount rates, larger than $r^*_{II,c}$, choose the low-efficiency alternative continuously. This implies that the penetration rate of the high-efficiency version temporarily increases from $r^*/r_{\max}$ to $r_{II,c}/r_{\max}$. When the first generation of high-efficiency appliances are replaced, the 'switch option' consumers choose the low-efficiency version again. With time, the penetration rate converges to its initial level, $r^*/r_{\max}$.[18]

As to the instantaneous subsidy scheme, the government subsidy cost function, $G(S)$, is rather simple $G(S) = gS$ in annualized terms. The relevant implicit discount rate is $r^*_{II,c}$ as it determines the temporary increase in the penetration rate. The government's budget constraint in annualized terms is

$$gS \cdot Z(r^*_{II,c}) \, \square \, S_0. \tag{3.39}$$

Note that in $G(S)$ is monotonically increasing in S and as a consequence the maximum penetration rate is achieved when the budget constraint in (3.17) is binding. Substituting (3.38) in (3.39) yields a second-order polynomial which has one feasible solution for $r^*_{II,c} < r_{\max}$. The optimal individual subsidy, S^*_{II}, in case of the instantaneous subsidy is

$$\begin{aligned} S^*_{II} &= \frac{-[S_0 r_{\max}/g - C] + \sqrt{D_{II}}}{2\lambda_H} && (3.40) \\ \text{with } D_{II} &= [(S_0 r_{\max} B/g - C)^2 + 4\lambda_H S_0 r_{\max}/g]. && (3.41) \end{aligned}$$

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[17] It is easily shown that the switching option provides least costs by comparing the costs of the three options given the subjective discount rate $r^*_{II,b}$ as given in (4.38).

[18] We implicitly assumed that the consumers' subjective discount rates do not change over time.

If $r^*_{II,c} \geq r_{\max}$, $S^*_{II} = S_0$. To illustrate the instantaneous subsidy regime we provide an example.

Example 2 *Let us reconsider example 1 with* $R_H = 2500$, $R_L = 1750$, $\tau_H = \tau_L - 150$, *and* $\lambda_i = 0.1$ *for* $i = H, L$, *and* $r_{\max} = 1.0$. *Hence,* $r^* = 0.100$, *and the penetration rate is* 10 *percent. The government provides an individual subsidy once only. Given the discount rate* $g = 0.05$ *and the subsidy budget* $S_0 = 0.5$, *the optimal individual subsidy is* 80.59, *the new implicit discount rate is* $r^*_{IIc} = 0.124$, *and the penetration rate is* 12.4 *percent. With time, however, the penetration rate converges to the initial level of* 10 *percent.*

Comparison

If we compare the examples of both subsidy regimes, we find a similar increase in the penetration rate. However, we also consider three major differences between the regimes. First, the effect of the continuous subsidy scheme on the penetration rate is permanent, while the effect of the instantaneous subsidy regime disappears with time. Secondly, from the comparison of the examples we can conclude that in the case of the continuous subsidy scheme the discounted subsidy budget of the government should be much larger than in the case of the instantaneous subsidy regime in order to achieve a similar penetration rate. Note that all other factor were equal. Finally, in the case that the life times are large the differences between both regimes becomes less important. In the case of central heating systems (with long expected lifetimes) the particular subsidy regime is less important than in the case of high-efficiency light bulbs with relatively short lifetimes.

The results from our general framework as presented in this section are based on the implicit assumption that the distribution of subjective discount rates over consumers remains constant over time. In other words, consumers choosing the switch option in the case of the instantaneous regime experience no *learning effect* from purchasing the high-efficiency version the first time, as these learning effects are not included in the model. Similarly, *reference group effects* are not included in the model as well. In the case of the instantaneous subsidy the initial group choosing the high-efficiency alternative will be larger than without the subsidy. As a result the consumer preferences may shift towards the high-efficiency alternative. In other words, the subjective discount rates of a consumer choosing the switch option might decrease over time.[19] More

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[19] In general, a consumer is more willing to invest if he considers a lower subjective discount

elaborated models should be developed to include both effects which is a subject for future research.

3.3.4 Energy tax

So far, we assumed that the government has a subsidy budget which is predetermined. However, one way to finance the subsidy budget is to implement an energy tax on the energy prices. Both instruments – the subsidy and the energy tax – stimulate the reduction of energy consumption. In this section we analyze the effect of imposing an energy tax on the energy prices in order to finance the subsidy budget based on the specification used in the previous subsection. First, we show that the energy tax has a positive effect on the penetration rate. Then, assuming the continuous subsidy scheme, we determine the optimal energy tax and optimal the subsidy simultaneously.

Suppose that the government only introduces an energy tax, μ. Then the operating costs in the cost function in (3.19) increase. The cost function of alternative i becomes

$$C_i(r) = R_i \cdot (\lambda_i + r) + \tau_i(1+\mu) \quad \text{for } i = H, L. \tag{3.42}$$

If $\mu \geq 0$, the conditions in 1 and 2 are satisfied and the *implicit discount rate* r_e^* is

$$r_e^* = -\frac{C + \Delta\tau\mu}{B}, \tag{3.43}$$

where B and C as in (3.21) and (3.22) respectively. Under the conditions in (3.13) to (3.15), the implicit discount rate (3.43) is monotonically increasing in μ. If $\mu = 0$, then $r_e^* = r^*$, where r^* is defined as in (3.20). As a consequence, the penetration rate is increasing in the energy tax for $r_{\max} \geq r_e^*$. If $r_e^* \geq r_{\max}$, the energy tax rate no longer affects the penetration rate.

Both the subsidy and the energy tax have a positive effect on the penetration rate of high-efficiency consumer durables. If we consider the continuous subsidy scheme and an energy tax simultaneously (E), the consumer now considers the identical options with two adjusted cost functions:

$$C_H^E(r) = (R_H - S) \cdot (\lambda_H + r) + \tau_H(1+\mu) \text{ and} \tag{3.44}$$

$$C_L^E(r) = R_L \cdot (\lambda_L + r) + \tau_L(1+\mu). \tag{3.45}$$

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rate. In particular, the consumer is more willing to invest in high-effiiciency versions of consumer durables.

The optimal implicit discount rate, r_E^*, is

$$r_E^* = -\frac{C - S\lambda_H + \Delta\tau\mu}{B - S}. \tag{3.46}$$

Note that the implicit discount rate in (3.46) is monotonically increasing in S, and μ under the conditions in (3.13) to (3.15).

By introducing both instruments the government can increase the penetration rate of high-efficiency consumer durables and with the revenues of the energy tax the subsidies can be financed. The government considers

$$\max_S Z(r_E^*(S, \mu)) \tag{3.47}$$

subject to

$$G(S) \cdot Z(r_E^*) \Box \mu \cdot [\tau_H \cdot Z(r_{Ie}^*) + \tau_L \cdot (1 - Z(r_{Ie}^*))]. \tag{3.48}$$

where $Z(.)$ and $G(.)$are similar to (3.23) and (3.27) respectively. Since r_E^* is monotonically increasing in S as well as in μ, and $Z(.)$ is monotonically increasing in r_E^*, the budget restriction is binding in the optimum. The optimal subsidy given the tax rate μ is

$$S_E^* = \frac{[-(C_\mu + \mu\Delta)(\lambda_H + g) - \lambda_H\mu\Delta + \mu\tau_l r_m] + \sqrt{D_{Ie}}}{2\lambda_H(\lambda_H + g)} \tag{3.49}$$

$$\text{with } D_E = [(-(C_\mu + \mu\Delta)(\lambda_H + g) - \lambda_H\mu\Delta + \mu\tau_l r_m)^2 + \tag{3.50}$$

$$+4\lambda_H(\lambda_H + g)(C_\mu + \mu\Delta)\mu\Delta - \mu\tau_l B r_m. \tag{3.51}$$

If the energy tax rate is zero, $S_E^* = 0$. It is easy to show that the subsidy is monotonically increasing in μ.

Example 3 *Let* $R_H = 5000$*,* $R_L = 2500$*,* $\tau_H = 400$*,* $\tau_L = 550$*,* $\lambda_i = 0.1$ *(the expected lifetimes of both version is equal to ten years), and* $g = 0.05$*. Given the individual subsidy we calculate the energy tax rate in which case the government's budget restriction is binding, i.e. the government's cost – the subsidies – are equal to the energy tax revenues. Without subsidy,* $r^* = 0.1$*. If* $S = 100$*, for instance, then* $r_{Ie}^* = 13.2$ *percent and the energy tax rate is* $\mu = 0.4$ *percent. Hence, the new penetration rate is* 13.2 *percent, and the government subsidy budget is* 2.0.

Based on the example, we can calculate the optimal energy tax rate and the optimal penetration rate for a range of individual subsidies. Note that

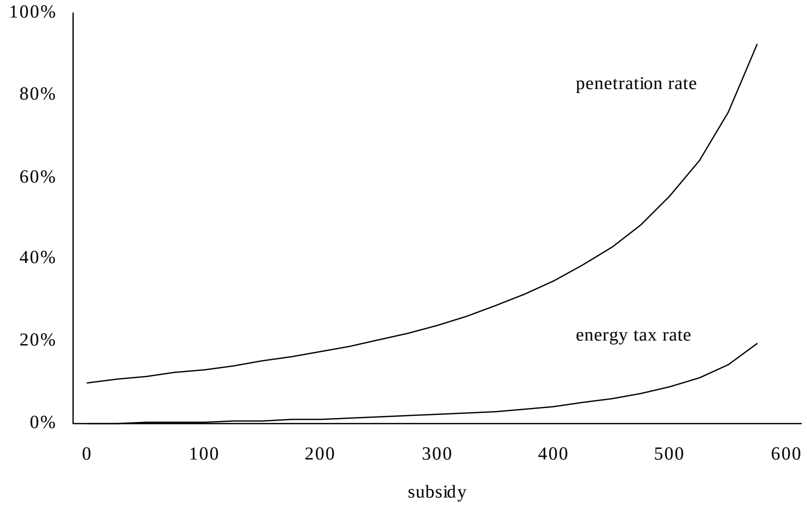

Figure 3.1: *Energy tax rate and penetration rate as a function of individual subsidy*

$S < R_L - R_H$. Figure 3.1 shows the results of the energy tax rate μ and the penetration rate Z given the individual subsidy S.

As the individual subsidy increases, the energy tax increases as well. As mentioned earlier, the penetration rate is increasing in both the energy tax and the subsidy. Comparing these results to those from the example with a fixed subsidy budget we now find that the individual subsidy and the government's budget are smaller given a particular penetration rate. This, of course, is due to the effect of the energy tax on the penetration rate. The individual subsidy needed to reach a 100 percent penetration rate is 583.8. The energy tax rate then is 21.9 percent.

3.3.5 Take-back effect

Switching from a low-efficiency version to a high-efficiency version might entail a *take-back effect.* The *take-back effect* is caused by a lower marginal price per unit of output produced by the consumer durable. This lower marginal price has a positive effect on the usage of the consumer durable. Let us reconsider example 3 in the previous subsection. To fix ideas, assume that it applies to central heating systems and its natural gas requirement. In example 3 we calculate a 27.3 percent decline from 550 to 400 in the marginal price of output for households switching from the high-efficiency to the low-efficiency version. For convenience, we assume that the energy input is a fixed proportion of the output, so that the price elasticity of output (heat equivalents) is equivalent to the price elasticity of energy. In Chapter 4 we found a -0.324 price elasticity of natural gas. With this elasticity, the demand for output as well as the demand for natural gas would increase with 9 percent if a household switches from a low-efficiency version to a high-efficiency version. Thus, the net reduction of the natural gas consumption is 18.0 percent.[20]

Another kind of take-back effect is entailed by households already choosing a high-efficiency version. With the subsidy, households save on there energy costs as well as on their total annual costs. Through an income effect the consumer durable usage will increase and so will the demand for energy. The income effect of the take-back effect will be small for two reasons: the income elasticities for electricity and water consumption are rather low, (see Chapter 4) and the savings are usually only a small fraction of total household income (less than 5 percent as shown in table 2.5 in Chapter 2).

3.4 Conclusions

This Chapter analyzed two aspects with respect to the consumer durables. First, we analyzed purchase prices and electricity uses and water uses of consumer durables. We estimated hedonic regression equations using data on refrigerators, freezers, washing machines and dishwashers from comparison tests published in Consumer Reports. We found that the purchase prices of consumer durables declined over the years, which provides one explanation for the increasing penetration rates; see figure 2.8 in Chapter 2. Furthermore, we found empirical evidence that – in general – the purchase prices of energy-using consumer durables increase significantly within in the range of -0.6 to -0.1 percent due to one percent less energy use or water use.

The purchase prices of more energy-efficient versions are higher, and the penetration rates are rather low. Although the rate of return on energy-efficient consumer durables is relatively high, consumers appear to hesitate to buy more energy-efficient appliances, possibly because they have high time preferences. Therefore, we analyzed the consumer decision and the penetration rate of energy-

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[20] In fact, if the absolute value of the price elasticity of output is larger than unity, the total demand for energy will even increase.

efficient versions within an intertemporal framework. In particular we analyzed the effect of a continuous subsidy regime and an instantaneous subsidy regime. The effect of the continuous subsidy is permanent, while the effect of the instantaneous subsidy vanishes with time. If the subsidy is financed by an energy tax, the effect is even stronger since both subsidy and energy tax have a positive effect on the penetration rate.