Jennifer L. Gerner and W. Keith Bryant*
Cornell University

The Demand for Repair Service during Warranty

This paper examines consumer behavior within the warranty period. In the model the consumer recognizes that the use of an appliance is inherently risky, subject to some probability of failure. The consumer takes this into account when choosing a warranty and the amount of use of the appliance. Both the demand for the warranty comprehensiveness and the demand for use are estimated, using data on television use and repair. The estimates provide some evidence that use, and consequently repair, depends on warranty coverage.

Introduction

For many years appliance manufacturers have offered warranties with durations stated in chronological time (Gerner and Bryant 1976). Such warranties are designed to cover costs of repair in the event that the appliance fails while the warranty is in force. That appliance warranties are universally offered with chronological durations is strong evidence of the manufacturers' belief that reliability, at least during the first years of appliance life, is a technological property of the appliance. As such it is controlled by the manufacturer via product design and specification.

But this view ignores the role consumers play.

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An appliance can be viewed as a stock of services which are drawn as a service flow over time. Consumers have a demand for the service flow. If the appliance contains a fixed stock of services, then the rate at which the services are demanded will determine the chronological life of the appliance. If failures are viewed as a technologically determined constraint on the size of the service stock, then consumers who have a high demand for services will choose a high rate of use and experience more failures in a given time period than consumers who have a low demand for services and choose a low rate of use.[1]

Most economic literature dealing with product warranties or guarantees is concerned with the characteristics of optimal warranties (Heal 1977; Spence 1977; Courville and Hausman 1978). This paper deals with consumer behavior within the warranty period. The focus of the paper is on the derivation and estimation of the demand for repair service under the warranty. The demand for repair will be estimated using data on television set use and repair.

The Model

At the time the consumer purchases an appliance, he is faced with the choice of appliance characteristics, including reliability and warranty coverage, and expected use of the appliance. The consumer recognizes that use of the appliance is inherently risky. Each attempt at use is subject to some probability of successful use, β, and a probability of $1 - \beta$ of failure. The probability of successful use is a characteristic of the model and brand of the appliance. We assume it to be independent of the number of prior breakdowns. It is in essence the technical reliability of the appliance. The consumer cannot observe this probability with any certainty, but he can observe the warranty coverage, which he takes as a market signal of appliance reliability.[2] Since reliability is costly, firms offer more reliable appliances at a higher price.

The greater reliability of these appliances is signaled to the consumer by a longer and more comprehensive warranty. The consumer's problem can be conceived as one of simultaneously choosing expected

1. Consumers also determine the care with which the appliance is maintained and used. This, too, could have an important effect on the failure rate. The present paper does not address this source of consumer-induced failures.

2. An observable product characteristic can provide a market signal of an unobservable product characteristic if the cost of providing the signal is negatively correlated with the unobservable characteristic being signaled and if the observable characteristic can be controlled by the party wishing to provide the signal. In this case, the warranty coverage is the observable signal, reliability is the unobservable characteristic being signaled. See Spence (1974) for a discussion of market signaling and Courville and Hausman (1978) for an application to product warranties.

appliance use and appliance reliability in a situation where use and reliability interact to produce breakdowns.[3]

Specifically, consider the consumer who faces many periods over which he must maximize utility by choosing appliance use. He thus obtains many samples of attempts at appliance use. Let N be successful appliance use, V attempts at use, and B unsuccessful use, or breakdowns. Then

$$E(N) = \beta V \tag{1a}$$

$$E(B) = (1 - \beta)V. \tag{1b}$$

On any particular breakdown during the warranty period there are both unrecoverable and potentially recoverable costs. The time costs incurred by arranging for repair service and in waiting for it form an important component of unrecoverable costs. Any other unrecoverable costs are viewed as proportional to time costs. Such costs might include frustration and annoyance, which rises with time between breakdown and completion of service. The per unit value of the consumer's time, denoted by w, will be equal to the value of the consumer's time in the labor market—that is, the wage rate, or the value of the consumer's time in other activities. If the time spent arranging and waiting for service is T_b, then the unrecoverable time costs are wT_b.

The potentially recoverable costs are the out-of-pocket cost of the service rendered and the cost of the parts. These potentially recoverable costs, E, are actually recoverable only if the particular breakdown is covered by the warranty. Since some warranties have broader scope than others, whether E is recoverable depends on the scope of the warranty attached to the appliance. The scope, S, of the warranty can be measured in terms of the number and coverage of provisions. If the warranty is to act as a market signal for reliability, the scope of the warranty must be a function of reliability. Thus,

$$S = s(\beta) \frac{\partial S}{\partial \beta} > 0. \tag{2}$$

It is now possible to specify the expected total variable cost of obtaining N successful uses, R, as the expected total cost of unsuc-

3. An alternative model would have the consumer choose quantity of appliance use and performance quality. Failure of the appliance occurs when performance quality falls below some predetermined desired level. This model would be particularly appropriate when considering appliance life and the decision to replace the appliance. However, we are concerned only with the first year of ownership of an appliance whose life is long relative to the first year. In the data used to estimate the model there are no cases of abandonment during the first year of ownership. Furthermore, we are particularly concerned about the effect warranties have on appliance use. The model we have chosen allows us to deal directly with this issue.

cessful uses (breakdowns) plus the operating costs incurred during successful uses, P_e:

$$R = (wT_b + ES)B + p_eN. \tag{3}$$

By dividing R by N, an expected variable cost per successful use can be obtained:

$$R/N = \frac{[wT_b + ES(\beta)]}{N} B + p_e = p_n. \tag{4}$$

In view of (1a), and allowing the consumer to choose N,

$$V = \frac{I}{\beta} N + e \tag{5}$$

and

$$p_n = (wT_b + ES) \frac{(1 - \beta)}{\beta} + p_e, \tag{6a}$$

or, setting $\alpha = (1 - \beta)/\beta$,

$$p_n = (wT_b + ES)\alpha + p_e. \tag{6b}$$

The expected price of successful use, p_n, can be interpreted in much the same way as Oi interprets the "expected full price" of an unsafe product (Oi 1972). If an insurance company were to insure the appliance against breakdown, and if the insurance policy was priced fairly in the actuarial sense, then α would be the price per use of a policy which paid the consumer one dollar in the event of a breakdown. A policy fully covering the consumer's expected loss on any breakdown would have to return $(wT_b + ES)$ dollars and thus would have a price of $\alpha(wT_b + ES)$. Thus, the price per successful use, p_n, can be interpreted as the price the consumer would have to pay for operating costs plus an actuarially fair insurance policy fully covering the appliance against breakdowns.

Now, if the consumer maximizes utility in each time period, as postulated in the model above, the expected price of successful use is of little value. In such a world the expected price will not, in general, be the actual price. Indeed, the actual price takes on various values with known probability. It is the probability distribution of the actual price which is of concern to the consumer. But if the consumer has a time horizon of many periods, the expected price becomes the pertinent price. In such a situation the consumer is allowed to vary his demand for total use, V, such that in each period he obtains exactly N successful uses. Although over many periods he will on average make $V = (1/\beta)N$ attempts to obtain N successful uses in any given period, he may make $V \gtrless (1/\beta)N$ attempts to obtain N successful uses. When his luck is good, so that $V < (1/\beta)N$ and the actual cost of use is less than the expected cost, the consumer invests the excess of some interest rate i. When his luck is bad, so that $V > (1/\beta)N$ and the actual cost of use is greater than the expected cost, the consumer can borrow the deficit at the same rate of interest, i. It should be noted that by framing the price in this fashion the problem has been transformed from one involving uncertainty to one involving certainty. Furthermore, there need not actually exist a market for insurance, since the consumer can insure himself. For such a self-insurance scheme to work, the number of uses during the warranty period must be large enough so that the consumer can spread his risk and offset his losses.

So far, we have ignored the costs associated with reliability that are embedded in the purchase price of the appliance. Reliability is costly, so that as the reliability of the appliance increases so does the price of the appliance, *ceteris paribus*. However, reliability is not directly observed but is signaled by the comprehensiveness of the warranty. Thus, if p_t is the price of the appliance,

$$p_t = p_t\,(S; C) \quad \frac{\partial p_t}{\partial S} > 0, \tag{7}$$

where C is a vector of appliance characteristics exclusive of reliability.

With this addition we are prepared to look at the full model in which the consumer maximizes utility by choosing use, reliability, leisure, and other goods subject to his budget constraint:

$$\begin{aligned} &U = U(A, L, N) \\ &\text{s.t.} \\ &p_a A + p_n N + p_t\, wL - w\bar{T} - Z = 0, \end{aligned} \tag{8}$$

where $p_n = (wT_b + ES)\alpha + p_e$, L = leisure, A = all other goods, Z = nonwage income, T = total time available, p_a = price of all other goods, and other variables are as previously defined. The first-order conditions are:

$$\begin{aligned} &\frac{\partial U}{\partial A} - \lambda p_a = 0 \\ &\frac{\partial U}{\partial L} - \lambda w = 0 \\ &\frac{\partial U}{\partial N}\frac{\partial N}{\partial \beta} - \lambda\, \frac{\partial p_n}{\partial N}\,\frac{\partial N}{\partial \beta} + \frac{\partial p_t}{\partial S}\,\frac{\partial S}{\partial \beta} = 0 \\ &\frac{\partial U}{\partial N}\frac{\partial N}{\partial \beta} - \lambda\, \frac{\partial p_n}{\partial N}\,\frac{\partial N}{\partial V} = 0 \\ &wL + p_a A + p_n N = W\bar{T} - Z = 0. \end{aligned} \tag{9}$$

The Demand for Reliability, Use, and Repair

The first-order conditions can be solved for a demand use, V, and a demand for reliability, β:

$$\beta = \beta\,(p_n, p_a, w, Z; C) \tag{10a}$$

$$V = \nu\,(p_n, p_a, w, Z; C). \tag{10b}$$

The demand for use can be thought of as the demand for the average number of attempts necessary to obtain N successful uses from which the consumer actually derives satisfaction. Since reliability itself is never observed, but only signaled by the comprehensiveness of the warranty, the demand for β cannot directly be acted on. Instead the consumer chooses the warranty, S, and the demand for reliability becomes a demand for the warranty.

To this point it has been implicitly assumed that the appliance is the only one of its type owned by the consumer. In some cases, television sets, for example, a consumer may have more than one. Consider the consumer with two appliances, one new and under warranty, and one older and no longer under warranty. The price of use of the old appliance, p_o, like that of the new one contains time costs and out-of-pocket costs consequent upon breakdown. The time, T_0, the price, and expenditures on service, E_0, required for repair may differ from those required for the new appliance. In addition, the perceived probability of successful use for the old appliance, β_0, may also differ from that of the new television. Because the old appliance is not under warranty, the out-of-pocket costs, E_0, are certain if the set breaks down and not dependent on the warranty. Thus the price of successful use for the old set, P_0, is

$$P_0 = (wT_0 + E_0)\left(\frac{1-\beta_0}{\beta_0}\right) + P_e.$$

Clearly, when the consumer has two appliances the price of the use of the old appliance must be included in the demand for use of the new one.

Finally, the utility function, U, is undoubtedly conditioned on consumer characteristics, F. All of these modifications yield a demand-for-use equation:

$$V^d = n(p_n, p_0, p_a, w, Z; C, F). \tag{11}$$

Since it is the combination of reliability and attempts at use that determine successful use, there are a variety of combinations which will provide the same quantity of successful use. Which combination is chosen will depend on the trade-off between the price of reliability embodied in the purchase price and the price of repair embodied in the price of use.

The demand for repair service can be easily derived from the demand for use. The consumer chooses a level of successful use, N, which maximized his utility as discussed above. But the total use, successful and unsuccessful, V, varies randomly as the number of unsuccessful uses, or breakdowns, varies. Although over many periods $V = 1/\beta\, N$, in any given period total use is:

$$V = \frac{1}{\beta} N + e, \tag{12}$$

where e is the random variation in total uses caused by breakdown. Assuming that each breakdown is repaired, the following identity holds:

$$B = V - N. \tag{13}$$

Substituting the relationship for total uses into the identity:

$$B = \left(\frac{1}{\beta}\right) N + e - N = \left(\frac{1-\beta}{\beta}\right) N + e, \tag{14a}$$

and, defining $\alpha = (1 - \beta)/\beta$ as before,

$$B = \alpha N + e. \tag{14b}$$

The focus of this paper is on the demand for repair service. But the demand for repair service is simply derived from the demands for use and reliability. Consequently, given reliability, anything which increases the demand for use will also increase the demand for repair. An increase in nonwage income, Z, will increase the demand for use and repair if television use is a normal good but decrease the demand for use and repair if television use is an inferior good. An exogenous increase in the price of service or the quantity of service per repair call; that is, E, the amount of time spent arranging and waiting for service, T_b, or the operating costs, p_e, all raise the price of successful use relative to the price of goods, thus reducing the demand for use and for repair. An increase in the wage rate will have two effects, one on the price of use and the other on income. Although the income increase will, *ceteris paribus,* increase the demand for use if television use is normal, the increase in the price of use will reduce the demand for use. Thus the effect of a wage change on the demand for use and repair is ambiguous. But if television use is inferior, the effect of wages or use will be unambiguously negative.

Reliability will also have an effect on the demand for repairs. As reliability increases, the price of use falls and the demand for use increases. At the same time, failures are determined in part by reliability. More reliable appliances will fail less often than less reliable ones. Thus, the effect of an increase in reliability on the demand for repairs is ambiguous.

Estimation

The demand relations identified in equations (10a) and (10b) are the demands for reliability and total use. However, neither reliability nor total use are observed in practice. Instead the comprehensiveness of the warranty, S, and successful use, N, are observable. The comprehensiveness of the warranty is the only information the consumer has about reliability. Thus the demand for reliability may only manifest itself as a demand for warranty comprehensiveness:

$$S = s(E, p_0, p_a, W, Z; C, F). \tag{15}$$

In addition, the demand for use, V, must be transformed into the demand for successful use, N:

$$N^d = \frac{1}{\beta} V^d(p_n, p_0, p_a, W, Z; C, F). \tag{16}$$

Equations (14b), (15), and (16) form a three-equation recursive system which can be estimated. This system is estimated using data on use and repair of television sets. The data used to estimate this system was collected in a survey of 483 households who purchased a television set between January and April of 1975. All households resided in Syracuse, New York. The survey was conducted in the spring of 1976, a full year after the television set purchase. The survey was designed to provide detailed data on the television set, its use, its repair record, and economic and demographic data on the households. The data collected constitutes a 2% sample of the 21,800 television sets purchased in Onondaga County in 1975.[4] Table 1 shows the means and standard deviations of relevant variables from the survey. Although there are 483 households for whom some data is available, removal of observations with missing data for relevant variables leaves 254 observations for use in estimation.

Although warranties on television sets vary in a number of details,[5] there were only two major variations in warranty coverage on new television sets in 1975. Some sets were covered for the cost of parts and labor involved in repair for a duration of 1 year after purchase. Others were covered for parts costs for 1 year but for labor costs for only 90 days. This leads to a binary measurement of the scope of the warranty, S, and the need to estimate the demand for warranty comprehensiveness using a probit technique. In this case consumers choose S^*, desired warranty comprehensiveness. Actual warranty comprehensiveness takes on only two values, however. If S^* equals or exceeds

4. For more discussion of the survey data, see Bryant and Gerner (1977).

5. For discussion of the variety of warranty provisions on television sets and other appliances, see Gerner and Bryant (1980). Most variation occurs in coverage of consequential damages, incidental damages, and similar items.

TABLE 1 Means and Standard Deviations

	Mean or % of Sample	Standard Deviation
Number of observations	254	...
Number of failures	.53	1.06
Use (hours/week)	43.28	25.03
p_n (warranty length)*	64.7	...
p_0 (number of additional sets)	.99	.90
Nonwage income	\$2,582	\$12,274
Value of nonmarket time:		
Females	\$12.71	\$8.87
Males	\$ 3.11	\$1.72
Technical characteristics:		
Color	78.3%	...
Screen size (inches)	19	4.5
Family characteristics:		
Number of children under age 6	.32	.60
Number of children 6–18	.87	1.27
Age of head (years)	40.86	14.64
Education of head (years)	13.11	2.78
Percent married	72.8	...

*Warranty length = percent of sample with a television set with a warranty covering parts and labor charges for 1 year. Remainder of sample have warranties covering parts charges for 1 year and labor charges for 90 days.

the longer warranty, the longer warranty is chosen. If S^* is less than the longer warranty, the shorter warranty must be chosen. Use must then adjust to compensate the lack of variation in warranty comprehensiveness. In the estimation, S will be defined such that a 1-year parts and labor warranty equals one and a 1-year parts, 90-day labor warranty equals zero.

The measure of successful use, N, used in the estimation is the number of hours the television set is on during the average week. The survey data also provide data on the number of hours the television set was on during the last day it was used. However, the number of hours the television set is on during the average week more closely conforms with the assumption that the consumer chooses N such that utility is maximized over many attempts at use. There are also detailed data on the use of the television by each family member. The utility function developed above should be viewed as a household utility function which aggregates individual family members' demand for use into household demand for use. We will assume that household demand for use and hours the television set is on are identical.

The demand equations are a function of E, expenditures on repair. No good measure of this is found in the data. Two alternatives arise. It is possible that, given failure, television sets do not vary in the cost of repair. In this case, omission of E in the cross-section data at hand is appropriate. If repair costs vary, the variation may be systematic with technical characteristics of the television set. Technical characteristics used in the estimation are a dummy variable defined as one if the television set is color and zero if it is black and white and by the screen size of the television set.

In addition to E, the price of use contains the term wT_b, the unrecoverable time and frustration costs associated with failure. The data provides no good measure or proxy for T_b. There are two possible assumptions that can be made: (1) $T_b = 0$, that is, the time and frustration associated with failure are unconsequential; (2) T_b is constant across all observations. The first assumption eliminates wT_b from p_n, while the second embeds the effect of wT_b in the coefficient estimated on the wage term.

If good measures of all the terms in p_n were available, the form in which these terms enter p_n would be dictated by the theoretical specification: $p_n = (wT_b + E)\ \alpha + p_e$. But since only proxies are available for any term in p_n, we have entered all variables linearly. Note that no proxy for p_e is used because the data are a cross-section from a single area facing a single price of electricity. Any variation in energy requirements across television set brands and models is assumed to be negligible.

The data provide little information about additional sets useful in measuring p_0. However, the number of additional sets present in the household is available and is used in the estimation. It is expected that use will decline as the number of additional sets increases.

The value of time, w, enters the price of use, p_n (under the assumption T_b is constant), and it is also the opportunity cost of television watching. The theoretical model suggests that the appropriate variable to use in estimation is the family opportunity cost of time. This concept is at best difficult to measure. It is possible, however, to estimate the value of time for male and female adult family members by exploiting the economic result that for those who participate in the labor market hours of work will be adjusted so that the marginal value of time is equated to the market wage rate. Heckman has outlined a procedure which fully exploits this information.[6] Consider first the females. The shadow price of time, w, can be implicitly defined as:

$$w = w(h, Z, F), \tag{17}$$

where h_i = hours of market work. Although w cannot be estimated directly, it can be calculated by recognizing that if hours of work can be adjusted

$$w = w^*, \tag{18}$$

6. See Heckman (1977, 1979) for a more complete discussion.

where w^* = market wage for those who work and

$$w \geqslant w^* \tag{19}$$

for those who do not work. Thus hours of work acts as a slack variable in a nonlinear programming problem and we have the basic condition (Heckman 1974):

$$h(w - w^*) = 0. \tag{20}$$

Assuming there exists a monotonic transformation of the dependent variables so that each equation may be expressed in linear form, this leads to the following system:

$$\begin{cases} g(w_i) = \gamma_0 + \gamma_1 h_i + \gamma_2 Z_i + \gamma_3 F_i + \epsilon_i \\ g(w_i^*) = \delta_0 + \delta_1 S_i + \delta_2 O_i + \mu_i \\ h_1\,(w_i - w_i^*) = 0, \end{cases} \tag{21a}$$

where S = education and O = age. This can be solved for w^* and h:

$$\begin{cases} g(w_i^*) = \delta_0 + \delta_1 S_i + \delta_2 O_i + \mu_i \\ h_i = \dfrac{1}{\gamma_1}\,(\delta_0 - \gamma_0 + \delta_1 S_i + \delta_2 O_i - \gamma_2 Z_i - \gamma_3 F_i) + \dfrac{\mu_i - \epsilon_i}{\gamma_1}. \end{cases} \tag{21b}$$

Both w^* and h are observed only for those who work. Heckman (1977) has shown that consistent estimations can easily be obtained for such a system, when the sample selection rule can be specified and estimated, by using the inverse of the Mill's ratio as a regressor in (21b). Once this system is estimated, the value of time can be obtained. This can be done for both males and females (Gerner and Bryant 1979). It is this procedure that yields the value of time used in the estimation of the demand for warranty comprehensiveness and the demand for television use.

Households in the survey were asked both total income and wage earnings. Nonwage income is contructed by subtraction. There may be substantial measurement error in the nonwage income variable. The question asking households to provide total family income suggested that adjusted gross income from the 1974 income tax form be used. This figure excludes certain types of income. Reported earnings may be either after-tax earnings or gross wage earnings. Thus it is likely that in some cases these two income figures are not consistent and the nonwage income is measured with error.

Finally, the survey data provide several possible family characteristic variables. The number of children in the household, the age, and the education of adult family members may influence preferences. These are used in the estimation.

Table 2 shows the results from the probit estimation of the demand for warranty comprehensiveness. The probit coefficients are not di-

TABLE 2 Probit Results from Demand for Warranty Comprehensiveness Estimation

	Coefficient (SE in Parentheses)	Marginal Effect*
Female value of time	.053 (.035)	.008
Male value of time	−.102 (.074)	−.016
Marital status†	.067 (.247)	−.011
Color†	.644 (.292)	−.102
Screen size	.058 (.026)	.009
Nonwage income (thousands $)	.002 (.041)	.0003
Number of additional sets	−.247 (.105)	−.039
Head's age	.019 (.008)	.003
Head's education	.023 (.036)	.004
Number of children	−.042 (.075)	−.007
Constant	−3.031 (.99)	. . .
χ^2	36.96	. . .
Pseudo R^2	.203	. . .

*The probit coefficients can be interpreted as (∂ probit index)/(∂x_i). The marginal effect is (∂ probability of owning long warranty)/(∂x_i) calculated at the mean values of the independent variables. It is calculated $[(1/\partial\pi)/e(-I^2/2)]\ \beta_i$ where I is the probit index.

†Marital status and color take on the model value, 1 in both cases, for calculation of the marginal effects.

rectly interpretable as probabilities. Table 2 also provides the marginal change in the probability of owning the more comprehensive warranty when the independent variable changes by one unit for each of the independent variables. The χ^2 test that the variables account for none of the variance in the dependent variable must be rejected.

Of the independent variables, the female's value of time, the male's value of time, whether the set is color, screen size, the number of additional sets, and the head's age are significantly different from zero at the 10% level or better.

Table 3 shows the regression results from the estimation of the demand for use. In this estimation marital status, the probit index, the female's value of time, nonwage income, head's age, head's education, number of children under age 6, and number of children between 6 and 18 are significantly different from zero at the 10% level or better.

It is interesting to consider these two estimations together. Increases in the female's value of time have a positive effect on the probability of

TABLE 3 Regression Results from Demand-for-Use Estimation

	Coefficient (SE in Parentheses)	Elasticity
Female value of time	−1.499 (.639)	−5.664
Male value of time	.349 (1.219)	5.389
Marital status*	11.114 (.198)	. . .
Color*	−2.062 (5.502)	. . .
Screen size	.362 (.581)	. . .
Nonwage income (thousands $)	.645 (.380)	.00001
Head's age	−.373 (.161)	. . .
Head's education	−1.120 (.564)	. . .
Number of children < 6 years	13.940 (2.811)	. . .
Number of children 6–18	4.482 (1.255)	. . .
Probit index	11.579 (6.709)	. . .
Constant	67.458	. . .
F-statistic	8.42713	. . .
R^*	.277	. . .

*Marital status and color take on the model value, 1 in both cases, for calculation of the marginal effects.

owning a comprehensive warranty but a negative effect on the use of the set. This is consistent with the predictions of the theory. As her time increases in value, the cost of repair rises, causing the household to demand both more reliability and less use. A similar relationship is expected for males. However, this expectation is not met. Instead, the demand for reliability decreases as his value of time rises and the demand for use appears to be unaffected by the value of his time.

Nonwage income positively affects the demand for warranty comprehensiveness, although the coefficient is not significantly different from zero. In the demand for use the effect of nonwage income is also positive. This suggests that both reliability and use are normal goods.

The probit index enters the demand for use because it affects the price of use. The greater the probit index, the more likely the household is to own the more comprehensive warranty and the lower the price of use. The positive sign on the estimated coefficient for the probit index indicates that the demand for use rises with increased likelihood of ownership of comprehensive warranty. This is consistent with our expectations.

Households with older and better-educated heads appear to demand more reliability but less use. Households with more children demand less reliability but less use.

Estimation of the Demand for Repair

The final equation in the system is the demand for repair service during the first year of ownership of the television set. This equation is estimated using the reported number of breakdowns on the television set as the measure of breakdowns. It is assumed that each breakdown generates a repair call and no breakdown remains unrepaired. The predicted number of average hours of television watching per week is calculated using each of the estimated demand for use equation reported in table 3. Since repairs are in terms of repairs per year the average number of hours of use per week must be multiplied by 52 to give average number of hours of use per year. In addition, there are enough observations to estimate the demand for repair service separately for each of five brands of television sets. The results of these estimations are shown in table 4.

The demand for repairs can be envisioned as the result of a series of attempts at obtaining successful hours of television watching. Exactly N hours of successful use are demanded. The number of failures, B, which occur during these trials is stochastic and distributed as a negative binomial. A maximum likelihood estimator of the demand for repairs can easily be derived. However, since the negative binomial distribution approaches the normal distribution as sample size in-

TABLE 4 **Demand for Repair Regression Results**

Brand*	Constant (α_0)	Annual Hours of Use $\left[\alpha_1 = \frac{(1-\beta)}{\beta}\right]$ (SEs in Parentheses)	R^2	Estimated Probability of Successful Use $\left[\beta = \frac{1}{(\alpha_1 + 1)}\right]$
A	.2508	.000089 (.000155)	.004	.99991
B	−.6837	.000500 (.000164)	.156	.99950
C	.6501	−.000143 (.000251)	.013	.99986
D	.8628	−.000067 (.000213)	.001	.99993
E	.7866	−.00001	.005	.9999
Total	.1174	.000176 (.000102)	.012	.99982

*Data were collected with the cooperation of television manufacturers with the assurance of anonymity.

creases, ordinary least squares (OLS) seems to be an appropriate estimation technique in this case. The OLS estimation done here allows for a constant term. Statistically, the negative binomial is defined only for nonzero values of N. This, then, requires that the estimation allow for a constant term. Intuitively, this is because exactly N successful uses can occur if, and only if, exactly $V-N$ attempts at use precede the Bth failure. Further, the probability that a failure will occur on any given use, B, is expected to be extremely small. Thus, some positive number of successful uses will occur before the first breakdown. The constant term assures that this will be the case (Feller 1958).

The estimated coefficient associated with hours of use can be interpreted as an estimate of $(1 - \beta)/\beta$. Thus, an estimate of the probability of successful use, β, can be calculated from the estimated coefficients. In the context of the model this is a technical reliability, determined by the manufacturer. It can be viewed as the manufacturer's contribution to failures, while the number of hours of use can be viewed as the consumer's contribution to failures. When the estimation is done using the total sample, the estimated coefficient can be viewed as the weighted average $(1 - \beta)/\beta$ across all brands of television sets. When the estimation is done for each brand, the estimate is, of course, a brand-specific estimate.

The estimated coefficients for brands B and E, and for the sample whole, are significantly different from zero at the .05 level or better. The estimated coefficients for brands C and D are negative, suggesting the puzzling result that as use increases the number of failures decline. These coefficients, however, are not significantly different from zero. It may be that for brands C and D use is essentially unrelated to failure. A test for the brand-to-brand equality of the estimated regression coefficients allows rejection that brands do not vary in technical reliability.[7] R^2 in all of the estimated equations is quite low. Nevertheless, use of the television set does account for some variation in failures. Using this estimation technique, the constant term should be interpreted as the mean of the disturbance.

The use elasticity of the demand for repair for the sample as a whole is .99. The elasticity of demand for use with respect to the value of female's time is 5.66, a 1% increase in the value of the female's time will reduce the demand for repairs by almost 5.6%. The elasticity of the demand for use with respect to the value of the male's time is 5.3, implying that a 1% increase in the value of the male's time will result in almost 5.6% increase in the demand for repairs.

The probability of a successful use, β, shown in table 4, is very high, regardless of brand. To put this in perspective the probability of at least one failure over a year of usage is calculated in table 5. This calculation

7. F-statistics = 3.72; see Kmenta (1971).

TABLE 5 Probability of at Least One Failure in the First Year

Brand	N	Predicted Average Hours of Use per Year	Predicted Failures per Year Given Predicted Average Hours of Use	Predicted Failures per Year Given 2,250.53* Hours of Use per Year	Predicted Probability of at Least One Failure in the First Year Given Predicted Average Use	Predicted Probability of at Least One Failure in the First Year of Ownership Given 2,250.53* Hours of Use per Year
A	76	2,503.58	.47	.45	.20	.18
B	52	2,214.48	.42	.44	.70	.68
C	27	2,215.09	.33	.33	.27	.27
D	67	2,395.82	.70	.71	.15	.14
E	13	2,173.56	.76	.76	.20	.20
Total	245	2,363.03	.53	.51	.35	.33

*2,250.33 hours of use per year = actual mean hours of use per year.

is done recognizing that in large samples the number of breakdowns is distributed approximately normal with mean of $\alpha_0 + \alpha_1 N$ and standard error of $\hat{\sigma}$. Although no brand has a very high probability of failure $(1 - \beta)$ in any 1 hour, the probability of failure over a year is, of course, much higher and varies from brand to brand and with use. The overall probability of at least one failure is .34. Manufacturers typically compute failure rates as number of television sets with at least one failure ÷ number of television sets. Using this measure, the failure rate in this sample is .31. Taking average hours of use into account, then, slightly increases the failure rate. Of course, consumers who use the television set more than average can expect higher failure rates than consumers who use the television set less than average.

Implications and Conclusions

The estimation of this system, the demand for warranty comprehensiveness, the demand for use, and the demand for repair provide several insights into consumer behavior during the warranty period and the effect of consumer behavior on failure during this period. The demand for warranty comprehensiveness suggests that consumers respond to the economic variables, particularly the value of female's time, in their choice of warranty. In addition, the demand for television use appears to be quite responsive to components of the price of use, including the female's value of time and the comprehensiveness of the warranty. Consumers who are more likely to own comprehensive warranties are also more likely to use the television set more and more likely to experience repair.

The impact consumers have on the repairs, and thus on repair rates, through their use of appliances, has seldom been taken into account by either manufacturers or policymakers. It may have particular importance in any attempt to label appliances with their expected failure rates, since in part that failure rate will be the result of consumers themselves.

This work does not take into account the more usual kinds of moral hazard problems, that is, mistreatment and abuse which may occur because of warranty coverage of breakdowns. This might be expected to further increase the extent to which consumers control failure of their appliances.

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