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The Value of Safety as Revealed in the Swedish Car Market: An Application of the Hedonic Pricing Approach

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Abstract

In this article the hedonic regression technique is used to estimate the value of traffic safety, using information from the Swedish market for automobiles. The results from the study show that the market price of an automobile is negatively correlated with its inherent risk level, i.e. Swedish car consumers pay a safety premium for safer cars. In comparison to previous Swedish stated-preference studies, this study reveals a lower willingness to pay for additional car safety, which might be a result of the interaction between government interventions and individual self-insurance and self-protection.

Keywords: car safety, value of characteristics, revealed preferences, willingness to pay

JEL Classification: C51, D61, J28

Risk is an inherent part of everyday life, and many of the risks that individuals encounter are risks that cannot be eliminated, since they are tied to the consumption of goods and services or to activities that are necessities for them. One risk that can be reduced, but not eliminated, is the risk we are exposed to when travelling. By choosing the safest mode available, we will minimize our risk exposure, but we will not eliminate it.

Individuals can handle traffic-risk exposure in three different ways; (i) reduce the probability of a crash, (ii) try to minimize injuries and damage if a crash does occur, and (iii) seek compensation for injuries and damage (see, e.g., Royal Society, 1992). Drivers can influence the probability of a crash by, e.g., reducing the amount of driving, reducing the speed, choosing to travel when other traffic elements (e.g. road conditions, other road-users, and the time of day) favor a safer journey. Individuals can try to reduce any negative consequences of an accident either by behavior, e.g. using seat belts, or by choosing a vehicle with higher safety standards for driver and passengers, or by doing both. By taking out injury- and damage insurances, individuals can seek compensation when negative consequences do occur.

The probability and outcome of a crash, and the compensation are not only affected by the driver's decisions. Government authorities, e.g., affect the compensation levels through social security systems. Other road-users, government authorities, and weather conditions are examples of factors affecting the probability and outcome of the crash. Figure 1 shows

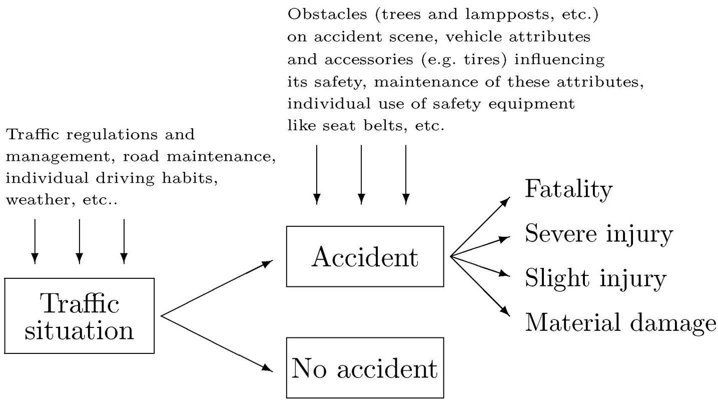

Figure 1. Accident event chain for road traffic.

a simplified event chain for a traffic accident, and shows that the probability of an accident depends on the "traffic situation", which in its turn, depends on the behavior and habits of road-users, traffic regulations, road maintenance, road construction, weather, visibility, etc. If a crash occurs, then the outcome depends on the decisions made by both drivers and passengers, on the vehicles involved, and on the traffic environment. It is not always possible to separate which factors cause the crash and which ones influence the severity of the outcome. High speed may, for example, be the cause of the accident, but may also increase the severity of the outcome. When an accident has occurred, the vehicle driven may influence the severity of the accident both for the passengers of the vehicle itself, and the passengers of the colliding vehicle. If, for example, a heavy vehicle collides with a lighter one, then the probability of a more severe outcome increases for the passengers of the lighter vehicle (other things being equal).

In this complex environment, where road users are not solely responsible for their own safety (i.e. the probability and severity of a crash), decisions on which mode or vehicle to choose to get to the desired destinations have to be made on a more or less daily basis. When making the decisions, the road users face several tradeoffs, and have to consider the opportunity costs a certain choice gives rise to. A mode that is both cheaper and safer than another mode might also require longer travel time and be more inconvenient. Depending on individual preferences, one traveller might prefer the first mode, whereas another traveller might prefer the latter. It might, for example, be rational (i.e. consistent with his preferences) for an individual to choose a mode with a higher risk (car) than one with a lower risk (train), since a higher safety level often implies opportunity costs in other respects. It may also be rational for an individual to drive faster and thereby reduce his travel time, even though he increases his risk exposure by driving faster.

This study will use the risk-money tradeoff from the Swedish automobile market to estimate the value of a reduced risk of dying in a car accident. This value is called the value of a statistical life (VSL), and is a benefit measure of how much people are willing to pay to reduce the risk so that there would be one less death in a population. Since empirical estimates of VSL often varies with context (e.g. country) or, e.g., with which evaluation method that was used (Viscusi and Aldy, 2003; de Blaeij et al., 2003), VSL needs to be estimated for different context, and also by different methods, to find an "appropriate estimate". Those Swedish VSL estimates for road safety that exists today are all from stated preference (SP) studies (Persson et al., 2001; Persson and Cedervall, 1991; Johannesson, Johansson, and O'Connor, 1996). It is, therefore, of interest to estimate a Swedish VSL for road safety using a revealed preference (RP) approach, where actual behavior is used instead of hypothetical as in the SP-studies, in order to study to what extent Swedish estimates of VSL for road safety using SP differ from estimates using RP.

The RP-method chosen to estimate VSL in this study was the hedonic regression technique, formalized by Rosen (1974). The hedonic regression technique can be used to derive monetary values for attributes of composite goods, e.g. a car. Atkinson and Halvorsen (1990) were the first to use the technique to estimate the value of car safety using data from the American market for automobiles. Dreyfus and Viscusi (1995) and Mount et al. (2001) also studied the value of car safety using American data, but in hedonic life-cycle models to account for the durable nature of automobiles. Dreyfus and Viscusi also studied time preferences and fuel efficiency and estimated an implicit discount rate for safety and fuel expenditure, whereas Mount et al. used data on household compositions of automobile owners in order to obtain different risk values for children and elderly people. In addition to estimate a Swedish value of VSL, another purpose of this study was to test for sensitivity of the estimated values by investigating how the estimates would be affected if either an atemporal or a life-cycle setting was used. Both an atemporal model and a life-cycle model were therefore estimated, where only the dependent variable differed between the settings.

In Section 1 the theory behind the hedonic regression technique is briefly presented, and how the technique can be used to estimate marginal WTP for a fatality risk reduction by employing it on the car market. The problem related to the fact that no "true" inherent risk measure for car-fatality risk exists and how observed accident statistics can be used as a proxy for the true inherent risk is also outlined in this section. In Section 2, the data set is described. Answers on automobile holdings from a Swedish SP-study (Persson et al., 2001) were used as a mean to collect a representative sample of the Swedish car fleet. Comparing the distribution of makes in the data sample with the market share of different makes at the time of the survey, shows that the data sample collected was representative of the Swedish car fleet at the time of the survey.

In addition to not having a true fatality-risk variable, another empirical issue which needed to be addressed concerning the risk variables was that the accident statistics originated from one year. In order to mitigate the problem of the accident counts from 1998 not reflecting the cars' safety level for a typical year Empirical Bayes was used. In Section 3, before describing the econometric models used for estimating VSL and the econometric considerations that were taken, the Empirical Bayes estimation of accident counts is presented. Preliminary test of the functional forms of the hedonic equations resulted in a semi-log linear form in the atemporal and life-cycle model, respectively.

The results, which are presented in Section 4, showed that; (i) when Empirical Bayes was used, that extreme values of accident counts were pushed towards the mean and that the variance was reduced, (ii) Swedish car consumers pay a safety premium on safer cars, and (iii) estimated VSL does depend on the setting, atemporal or life-cycle, and on the assumptions on discount rates. In Section 5 the results are compared to results from other studies on willingness to pay (WTP) for a reduction in car/road mortality risk. Estimated VSL is found to be considerably lower than both American hedonic car safety studies (Atkinson and Halvorsen, 1990; Dreyfus and Viscusi, 1995; Mount et al., 2001) and Swedish SP-studies (Persson and Cedervall, 1991; Johannesson, Johansson, and O'Connor, 1996; Persson et al., 2001). Suggested explanations for the differences between the results from this study and the results from the other studies are given in this section, e.g. that; (i) the American estimates are higher due to a wealth effect, (ii) the estimates from the Swedish SP-studies are higher due to hypothetical bias, but also that the estimates from this study are lower as a result of potential measurement errors in the fatality-risk variable. The final section, Section 6, then offers some concluding remarks.

1. Theoretical background

1.1. Characteristics theory of value

Automobiles are one example of goods known as composite, or differentiated, goods. Composite goods are goods that can be described by a vector of different characteristics, and an automobile embodies, for example, acceleration, comfort and safety. Becker (1965) and Lancaster (1966) suggested that utility is derived from the characteristics of the good and not the good in itself. In their studies they broke with traditional theory, i.e. that goods are the direct objects of utility, and instead assumed that goods and their characteristics do not raise the consumers' utility, but are instead used as input factors by the consumers in producing the ultimate characteristics.

Applying this theory to the consumption of automobiles means that the characteristics of a vehicle would be used as input factors in the household's production function of different desirable characteristics of a car ride. The compartment space of a car would, e.g., be used by the car consumer in producing "comfort". The reported risk level of a specific model (some "objective" measure of the probability of being involved in an accident with a negative outcome) would be used to produce safety. Since safety produced in the production process would be affected by the driver's age, sex, and, most importantly, driving pattern, it would probably differ between individuals owning vehicles with identical reported risk level.

Rosen (1974) used Becker's and Lancaster's theories on composite goods and their characteristics when developing his method on how to value these characteristics, called the hedonic pricing technique. In the hedonic technique, differentiated goods are also assumed to be valued by the consumers for their utility-bearing attributes. Therefore, the price for which a given unit can be sold in the market place is a function of the implicit prices of these attributes. Rosen's approach differs from the theory on households' self-production of ultimate characteristics. In Rosen's model, producers of composite goods tailor their products, so that they embody the final characteristics desired by the consumers. Since the final desired characteristics are assumed to be identical with the ones delivered, implicit values can be estimated by investigating how the price is affected by differences in bundle levels of characteristics within the same class of commodities (i.e. commodities with the same bundle of characteristics).

1.2. *The hedonic technique*

The hedonic price function is a result of consumers' and producers' maximizing behavior in a competitive market. In equilibrium, the price a utility maximizing consumer is willing to pay for a good and its characteristics is perfectly matched by a profit-maximizing producer's willingness to supply the good. Since the goods are valued for their utility-bearing attributes, the price in equilibrium also reflects the consumer's marginal bid (marginal WTP) for an extra unit of any of the attributes, which equals its implicit price, i.e. the producer's marginal cost for the attribute.

Following Rosen, let $\mathbf{A}$ denote a car and a_i its characteristics, $\mathbf{A} = (a_1, a_2, \ldots, a_n)$. It is assumed that these characteristics can be objectively measured, i.e. consumers' perception of the embodied amount are identical. The consumers' subjective valuation of the characteristic, or bundles of characteristics, may differ though. The hedonic price function is a function of the characteristics, and is defined as

$$P(\mathbf{A}) = P(a_1, a_2, \ldots, a_n), \tag{1}$$

which is the market price, or minimum price a consumer has to pay for the composite good.

The utility-maximizing consumer's utility function can be written as $U(x, \mathbf{A})$, where x represents all other goods consumed. The utility function is assumed to fulfill the usual properties of being strictly concave and increasing in its arguments.[1] If the price of x is normalized to unity (i.e. x = money) and y denotes income, then the consumer's budget constraint is given by, $x + P(\mathbf{A}) = y$. Maximizing utility subject to the budget constraint, the individual chooses an amount of each of the characteristics where marginal costs are proportional to the marginal rate of substitution between the characteristics and money, i.e. $P_{a_i} = U_{a_i}/U_x$.[2]

Rosen showed that the amount which the consumer is willing to pay equals the market price for the good. The consumer's bid function, $\theta(\mathbf{A}; y, u)$, is defined according to $U(y - \theta, \mathbf{A}) = u$. The properties of U imply that θ is increasing in a_i at a decreasing rate. Differentiating θ with respect to a_i gives the marginal rate of substitution between a_i and money ($\theta_{a_i} = U_{a_i}/U_x$). Since $\theta(\mathbf{A}; y, u)$ is the consumer's WTP, given utility index and income, and $P(\mathbf{A})$ is the minimum price the consumer has to pay in the market, utility is maximized when

$$\theta(\mathbf{A}^*; y, u^*) = P(\mathbf{A}^*), \tag{2}$$

and

$$\theta_{a_i}(\mathbf{A}^*; y, u^*) = P_{a_i}(\mathbf{A}^*), \tag{3}$$

i.e. optimum occurs where the two surfaces are tangent to each other. Figure 2 shows the market equilibria for two consumers in the θ-a_1 plane.

The firm's production decision is symmetric to the consumer's. The firm maximizes its profit given the market price. At optimum, the firm's marginal cost equals the marginal

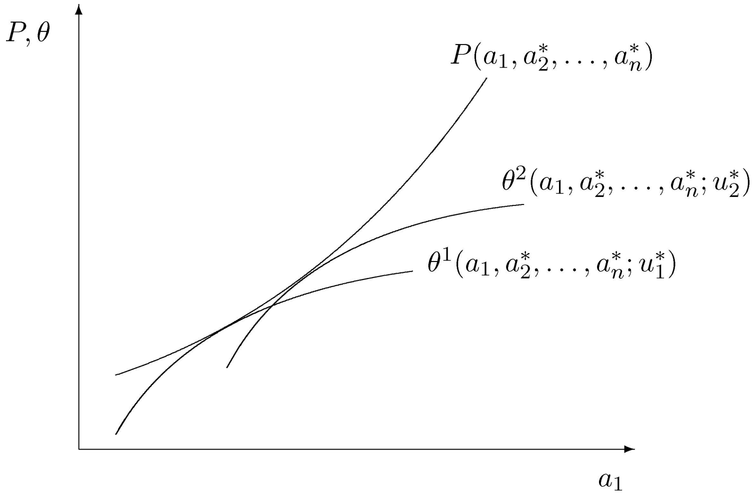

Figure 2. Consumer equilibrium (Source: Rosen, 1974).

revenue from additional attributes. Marginal revenue is dependent on the demand side, i.e. consumer's income and tastes for the attributes.[3]

1.3. Applying hedonic prices to car safety

Since the hedonic theory states that differentiated products are valued for their utility-bearing attributes, empirical application of the technique to cars and car safety requires that consumers (and producers) have information on all characteristics. For most of the characteristics this assumption is quite reasonable. For example, fuel efficiency, cargo capacity, and acceleration are easy to measure and are usually given in sales brochures and car magazines. It is, therefore, reasonable to assume that all car consumers have access to the same information and also make their decisions based on this information.

For the safety (risk) component, however, this assumption is more problematic. No measure of the "true" inherent risk of a fatal accident, R, associated with a specific make and model exists. If such a variable had existed, the hedonic price function would have been,

$$P_{\text{auto}} = f(R, \mathbf{A}), \tag{4}$$

where **A** from now on denotes the other car characteristics (other than "fatality risk"). But since no measure of the "true" inherent risk of a fatal accident exists, observed fatality rates, F, from traffic accidents for different car makes and models are instead used as a proxy for the "true" risk variable. The problem with accident data on the numbers of fatalities is that they do not give a true estimate of the risk of a specific model. Fatality rates also depend on how the car was driven at the time of the accident, and on the circumstances under which the accident occurred. The fatality rates, therefore, represent not only the true fatality risk of the car, R, but also driver characteristics and circumstances contributing to the outcome of the accident. The relationship can be written as

$$F = g(R, \mathbf{D}), \tag{5}$$

where $\mathbf{D} = (d_1, d_2, \ldots, d_m)$ denotes a vector of "accident characteristics". If F is monotonic in R, then we will have, $R = g^{-1}(F, \mathbf{D})$ (Atkinson and Halvorsen, 1990), and by substitution Eq. (4) can be written as

$$P_{\text{auto}} = h(F, \mathbf{D}, \mathbf{A}). \tag{6}$$

If "accident characteristics" were excluded, our estimated monetary risk value would have been biased, since we would have had omitted variables correlated with the risk variable. By including them this problem is reduced. The risk variable F can now be regarded as an acceptable proxy for R, and be used to estimate the value of a reduced risk of an accident with a fatal outcome. In equilibrium, the partial derivative of the hedonic price locus with respect to any attribute gives the implicit price of that attribute, and the risk value is therefore estimated as

$$P_F(\cdot) = -\frac{\partial P(\cdot)}{\partial F}, \tag{7}$$

and since F describes the attribute of the risk of a fatal accident, $P_F(\cdot)$ can be interpreted as VSL.

2. Data

Data on automobile holdings originates from a SP-study conducted in Sweden in 1998 (Persson et al., 2001). The information on automobile holding in the SP-study was used in order to collect a representative sample for the Swedish car fleet. The SP-study was designed as a postal questionnaire and was sent to 5,650 randomly chosen Swedes between the age of 18 and 74. The response rate was 51%. Of the respondents who answered the survey, 83% (2,397 persons) stated that they owned an automobile. From that sample, 502 usable observations on different makes and models were available. The main reason for the loss of observations were that many households had the same make and model. Another problem was that some answers given on vehicle holdings were not usable for different reasons. Some answers were not precise enough to make it possible to establish what kind of model the respondent referred to, whereas some respondents gave answers from which it could not be established if the model existed at all. Data on prices for used cars existed only for 1987 to 1998, which also limited the sample size. There were also other problems with official data on accidents statistics and vehicles in use.[4] As shown in Table 1, the distribution of car makes and year model in the usable data set was well representative of the car fleet in Sweden in 1998.

The main source for vehicle attribute data was Autograph's "Bilfakta" (Autograph, 1987–1998), which is based on information from "The Swedish Motor Vehicle Inspection

Table 1. Manufactures' share in survey and actual market share.

Make	Survey Number	Survey Per cent	Market share[a]
BMW	11	2	2
VW	53	11	9
Audi	34	7	4
Citroen	12	2	1
Fiat	4	1	1
Ford	52	10	10
Honda	9	2	1
Mazda	23	5	4
Mitsubishi	13	3	2
Nissan	20	4	4
Opel	44	9	7
Peugeot	18	4	2
Renault	14	3	2
Saab	48	10	10
Toyota	40	8	5
Volvo	92	18	26
Other	15	3	20
Total	502	100	100

[a]SCB and SIKA (1999).

Company", a governmental authority, with complementary data from manufacturers and dealers. Accident statistics were collected from "Statistics Sweden". This data consists of number of accidents per make/model/year, and of accident characteristics of the reported accidents, all in the year 1998. Statistics Sweden also supplied the study with the number of cars in use and other official data. The following sections describe the variables used in the regressions.

2.1. Dependent and explanatory variables

Dependent and explanatory variables included in the empirical analysis are listed in Table 2, with a brief description, and anticipated signs of explanatory variables with respect to annual and annualized life-time costs of owning an automobile. The explanatory variables in this section were chosen on the basis of previous studies in this area and on characteristics presented in car magazines.[5] Car characteristics presented in car magazines can be regarded as good indicators of the characteristics of interest to potential buyers. Variables, where nothing else is stated, are from Autograph.

Table 2. Description of variables, and anticipated signs of variables with respect to the costs of owning and operating an automobile.

Variable name	Description	Mean (Std. dev.)	Anticipated sign[a]
Price	Price for each make/model/year in SEK 1998 price level.	84,235[b] (50,557)	N.A.
User costs	Annual costs of owning a vehicle. Defined as sum of owner- and operating costs.	47,756[b] (11,106)	N.A.
Operating costs	Annual fuel expenditures in SEK 1998 price level.	13,571[b] (1,987)	N.A.
Fatality	Number of registered fatalities for each make/model/year in 1998.	0.478 (1.106)	N.A.
Injury	Number of registered injures for each make/model/year in 1998.	24.759 (28.520)	N.A.
Acceleration	Inverse of acceleration time from 0 to 100 kilometers per hour.	0.091 (0.013)	+
Power	Horse-power to weight ratio.	0.089 (0.015)	+
Compartment	Size of compartment space.	0.636 (0.033)	+
Cargo	Vehicle cargo capacity.	0.369 (0.126)	+
Styling	Length plus width divided by height.	0.924 (0.053)	?
SizeX	Binary variable, coded as one for the size category, where Size4 is the largest.	-	+
Reliability	Binary variable, coded as one if technical reliability for model at least average.	0.797 (0.403)	+
Hatchback	Binary variable, coded as one for cars with hatchback and zero otherwise.	0.406 (0.492)	?
Station wagon	Binary variable, coded as one for station wagons and zero otherwise.	0.171 (0.377)	+
Diesel	Binary variable, coded as one for diesel models and zero otherwise.	0.018 (0.133)	+
Origin	Binary variable, coded as one for origin.	-	?
YearXX	Binary variable, coded as one for vehicle model year. Reference year 1987.	-	+
T	Expected remaining useful life of vehicle.	10.63[b] (3.62)	+
Exposure	For each make/model/year in 1998, number of cars registered in use, times the on-the-road factor	6,923 (8,891)	N.A.

[a]Anticipated signs based on Autodata (1998), and on the findings of Mount et al. (2001), Dreyfus and Viscusi (1995), and Atkinson and Halvorsen (1990).
[b]Weighted mean based on number of cars in use for each make/model/year.

The dependent variable in the atemporal model is the annual cost of owning and operating an automobile, denoted user costs, which is the sum of owner costs and operating costs. Owner costs include all costs an owner of a vehicle is faced with, except fuel expenditures. Examples of owner costs are depreciation, insurance, and repair costs and information on these costs was collected from Bilprovningen (2000). Annual fuel expenditures, denoted "operating costs", were calculated based on information on fuel price, annual kilometers driven, and fuel efficiency.[6]

The dependent variable in the life-cycle model was the annualized total costs of owning and operating a vehicle during its lifetime. Total costs are the sum of the price for each make/model/year in 1998 and operating costs for remaining useful life of the vehicle. Owner costs, as defined in the atemporal model, were assumed to be capitalized in the price of the vehicle. For model year 1998, the new vehicle price for a model of standard design was used (Autograph, 1998). For older cars, prices calculated on market transaction data for the period of March through May in 1998 were used (Autodata, 1998).

Two risk measures were included, fatality and injury rate. For non-fatal injuries, different degrees of severity were not considered. Accidents were just classified as resulting in fatalities or injuries. Both risk measures were calculated using actual accident statistics from 1998. However, since only approximately 500 deaths occurred in Sweden in 1998 (SCB and SIKA, 1999), using data from that year only resulted in a small data sample. It also meant that the reported numbers for some of the models could be suspected to be "extreme values" of annual accident numbers, both low (for example "zeros") and high values. Therefore, to increase the precision of the number of fatalities and injuries for each make and model the Empirical Bayes method was used. The method and the calculations are explained in Section 3.1. In short, the fatality and injury rates for each make/model/year were calculated using information on fatalities and injuries together with information on traffic exposure. *Exposure* is number of registered cars in use times an "on-the-road factor", where the latter takes into consideration the differing driving patterns for different vehicle models. Some models are driven more frequently and over larger distances than others, and therefore the fatality and injury rates should reflect this. The on-the-road factor was normalized so that the mean equaled unity, and it was calculated using information on kilometers driven annually per vehicle model from the The Swedish Motor Vehicle Inspection Company. The number of registered cars in use was collected from the Swedish National Road Administration, and mirrors almost precisely how many cars of each make and model were in actual use in Sweden in 1998.

Styling was used in previous hedonic car safety studies (Atkinson and Halvorsen, 1990; Dreyfus and Viscusi, 1995; Mount et al., 2001), and is a measure of the exterior styling. The variable was calculated as length plus width divided by height, and it was normalized so that unity equals vehicle with highest value.

Compartment, *Cargo*, and *SizeX* were included as different measures of size. The measure of the compartment space is an indexation of the size of the space according to the "Autograph-method", whereas cargo capacity is measured in liters (Autograph). *Compartment* and *Cargo* were both normalized so that the largest size equals unity. *SizeX* was based on styling and divided into four size categories, where *Size4* was the largest, and *Size1* the reference group.

Reliability is a binary variable coded as one, if the test record at The Swedish Motor Vehicle Inspection Company shows that the proportion of the model passing the test is at least average and zero otherwise (Bilprovningen, 2000). In Sweden automobiles older than three years have to undergo an annual test by The Swedish Motor Vehicle Inspection Company to ensure that they are roadworthy. *Reliability* was used as a proxy variable for maintenance costs of the automobile.

Origin is a binary variable coded as one for the nation of origin if pertinent, and zero otherwise. *Volvo* and *Saab*, which both were assumed to be regarded by the consumers as domestic manufacturers in this study, were included as two separate variables.[7] Foreign vehicles were divided into five groups; *Germany*, *Japan*, *France*, *US*, and *Others*. *Volvo* was used as the reference group.

To estimate expected remaining useful life of vehicles, T, no official data exists in Sweden. But according to the Swedish organization of manufacturers and importers (Bilsweden), the expected average remaining useful life of a vehicle is 17 years. This information was therefore used in this study.[8]

2.2. Accident characteristics

Accident characteristics were used as control variables for how the car was driven at the time of the accident and for the circumstances surrounding the accident. Accident characteristics reflect causes for and outcomes of the accidents that are not assumed to be dependent on the specific vehicle. For example, if a high number of the fatalities from accidents with a specific make and model are young males, then the accident statistics not only reflect the risk associated with the specific vehicle, but also the drivers of the vehicles at the time of the accidents. Therefore, the fatal risk measure would not be a good indicator of the risk associated with the car if no accident characteristics were included into the model as control variables.

The variables listed in Table 3 are those used as control variables in this study. The data had to be ordered from "Statistics Sweden", since information on driver characteristics in fatal traffic accidents is protected by secrecy laws, and therefore, not accessible any other way. Several other non-obtainable and obtainable variables would have been desirable, e.g. seat-belt usage and information on the other vehicle(s) in accidents involving more than one vehicle. Information on seat-belt usage is not included in the police reports in Sweden, whereas information on other vehicles was neglected by the author when data was gathered.

3. Empirical models and methods

We start this section by describing how we dealt with the problem of a small sample on fatal and non-fatal accidents used to calculate the risk variables used in the regressions, and how the risk variables were calculated. We then describe some general econometric considerations, before presenting the two hedonic price equations estimated, one atemporal and one life-cycle model.

Table 3. Accident characteristics.

Variable name	Proportion of fatalities for make/model/year in which ...	Mean	(Std. dev.)
Alcohol	driver was under influence of alcohol	0.011	(0.081)
One-car	only one vehicle was involved.	0.084	(0.232)
Young	the driver was younger than 25.	0.046	(0.178)
Old	the driver was 45 or older.	0.205	(0.372)
Male	the driver was male.	0.339	(0.461)
Night	accident occurred in other than daylight.	0.161	(0.331)

$N = 502$.

3.1. Empirical Bayes and accident statistics

We follow Hauer (2001) in the Empirical Bayes estimation of accident counts. The accident counts on fatalities and injuries were assumed to have a negative binomial distribution, which is the standard assumption for accident counts. Using a negative binomial regression model, fatalities were regressed on *Exposure* and the control variables, and injuries on *Exposure*. The calculation procedure for the fatality-risk variable (*Fatal*) is presented in this section, and since the non-fatal risk variable (*Non-fatal*) was calculated in the same manner, the procedure for how to calculate *Non-fatal* was omitted.

Focusing on *Fatal*, and denoting number of registered fatalities for each make and model by z_i, the weights for the Empirical Bayes estimation were calculated as follows

$$W_i = \frac{1}{1 + \hat{z}_i/\varphi}, \tag{8}$$

where $\hat{z}_i$ is the predicted fatality numbers from the negative binomial regression, and where φ denotes the "overdispersion parameter", which also was obtained from the regression. The Empirical Bayes accident counts on fatalities, EB(fatality), were then calculated as

$$\text{EB(fatality)} = W_i \times \hat{z}_i + (1 - W_i) \times z_i. \tag{9}$$

The fatality rate for each make/model/year was then calculated by first calculating a mortality rate (M),

$$M = \frac{\text{EB(fatality)}}{\text{Exposure}}, \tag{10}$$

which then was anchored to the objective risk of a fatal traffic accident in Sweden in 1998 (SCB and SIKA, 1999). The motive for this was that we wanted the model with an estimated mean risk level to equal the mean objective risk estimated for Sweden. *Fatal* (F) was, therefore, calculated by dividing the mortality rate by its mean ($\bar{M}$) and multiplying the ratio with the calculated objective risk of a fatal traffic accident in Sweden in 1998,

$$F = \frac{M}{\bar{M}} \times \frac{6}{100,000}. \tag{11}$$

3.2. Econometric issues in hedonic equation

When deciding what car and accident characteristics to include in the hedonic equation, the researcher has the usual tradeoff to consider between omitted variable bias from excluding variables, and multicollinearity problems from including too many. The variables chosen as explanatory variables were chosen on economic grounds, i.e. variables assumed to be "utility-bearing attributes". Some of these variables were then dropped on the basis of significance tests or for causing collinearity problems. Some attributes were omitted since no measures of them were found.

Another issue to solve is the functional form of the econometric model. The functional form cannot be determined on theoretical grounds, but we know, however, that only when consumers can "re-package" characteristics of the differentiated good according to their tastes will the model be linear (Rosen, 1974). Since a car consumer cannot buy a specific characteristic of a given car and combine it with a different characteristic of another, the model is expected to be non-linear, but the exact form is not known. The functional form, therefore, has to be either predetermined or chosen from fitting the model to the data.

A common predetermined functional form for hedonic price studies is the log-linear form (e.g. McMillan, Bradford, and David, 1980; Mount et al., 2001). In this study, the functional form was not predetermined but instead determined by the data set. To allow for flexibility of, and to test for the functional form of the hedonic price equation within the model, variables were transformed according to the Box-Cox transformation.[9] The transformation was chosen on the basis of the results in Cropper, Deck, and McConnell (1988), and it was also used in Atkinson and Halvorsen (1990), and in Dreyfus and Viscusi (1995).[10] Variables were transformed in the following manner, one transformation coefficient for the dependent variable and another for all transformed explanatory variables (dummy variables not transformed).

3.2.1. Atemporal model. The atemporal model is straightforward, since the annual costs of owning a vehicle are regressed on the annual risks of involvement in fatal or non-fatal accidents. In the one-period setting, we do not have to consider issues like time preferences and expected life of the cars. The dependent variable in this setting, annual cost of possessing and operating a vehicle, was denoted "user costs" (C), and was defined as the sum of owner costs and operating costs (OC), i.e.

$$\begin{aligned} \text{Usercosts} &\equiv \text{Ownercosts} + \text{Operatingcosts} \\ &= \text{Carprice} \times \phi + OC, \end{aligned} \tag{12}$$

where ϕ denotes the estimated fraction for each make's owner costs of the car price. To calculate ϕ information from "tables" (Bilprovningen, 2000) on different owner costs were used. Owner costs in this study were depreciation, taxes, insurance, repair costs, maintenance costs, accessories (e.g. tires), and interest. This fraction differs within each make, for year, but not for model.[11] Preliminary tests of functional form, using the Box-Cox transformation, showed that a semi-log linear form was the most pertinent form for the one-period model, and therefore, the hedonic equation estimated was defined as

$$\ln(C_i) = \beta_0 + \beta_1 F + \sum_{k=2}^{22} \beta_k a_{ik} + \sum_{l=23}^{28} \beta_l d_{il} + \varepsilon_i, \tag{13}$$

where subscript i refers to make/model/year. We know from Eq. (7) that VSL is the partial derivative of the price locus with respect to the risk variable, and since the estimated equation was semi-log linear, VSL was calculated as follows,

$$\text{VSL} = -\frac{\partial C}{\partial F} = -\beta_1 C. \tag{14}$$

3.2.2. Life-cycle model. A life-cycle model is intuitively appealing, since the vehicle owner's "...principal concern is not simply the probability of a fatal accident, but the discounted duration of life and the associated lifetime utility at risk..." (Moore and Viscusi, 1988, p. 370). The duration of life of interest here is, however, not the expected lifetime of the owner but of the vehicle. The owner of the vehicle is only exposed to the fatality risk during the expected remaining useful life of the vehicle, T. The owner is also expected to be able to sell the vehicle at its present value. But, in spite of being intuitively appealing, a life-cycle model depends on both expected remaining useful life of the vehicle and on assumptions on time preferences, reflected by r. A very unsophisticated preliminary sensitivity test of the chosen level of the expected remaining useful life, performed simply by increasing the life expectancy, indicated that the estimates were insensitive to changes in this variable. However, as the results of this study showed, the final results were sensitive to the discount rate chosen.

The dependent variable in this model was the annualized total cost of owning and operating a vehicle during its expected lifetime (AC).[12] The different owner costs in the atemporal model were assumed to be capitalized in the car price, and operating costs were added up and discounted for the remaining useful life of the vehicle to get the total cost of a vehicle during its lifetime (TC).[13] The dependent variable was then calculated by annualizing TC, which resulted in

$$\text{AC} = P\left[\frac{1 - e^{-rT}}{r}\right]^{-1} + OC, \tag{15}$$

where r is the discount rate. Tests of the functional form, with an exogenous given discount rate using the Box-Cox transformation, then resulted in a semi-log linear model, and hence, the estimated hedonic price equation was given by

$$\ln(\text{AC}_i) = \beta_0 + \beta_1 F + \sum_{k=2}^{22} \beta_k a_{ik} + \sum_{l=23}^{28} \beta_l d_{il} + \varepsilon_i, \tag{16}$$

and since the life-cycle model also was semi-log linear, VSL was calculated as

$$\mathrm{VSL} = -\frac{\partial \mathrm{AC}}{\partial F} = -\beta_1 \left\{ P \left[\frac{1 - e^{-rT}}{r} \right]^{-1} + OC \right\}. \tag{17}$$

4. Results

This section follows the same order as Section 3, i.e. we start by presenting the results from our Empirical Bayes estimates and summary statistics for the risk variables, before presenting the results from the hedonic regressions.

4.1. Empirical Bayes and risk variables

The results from the negative binomial regression model are presented in Table 4. *Exposure* had a positive and statistically significant effect in the regressions on fatalities and injuries, respectively. Accident characteristics were omitted when regressing number of injuries on *Exposure*, since accident characteristics were related to fatalities and not injuries. All accident characteristics had a positive effect on fatalities and only *Night* was statistically

Table 4. Negative binomial regression: Dependent variables number of fatalities and injuries per make/model/year.

	Fatality		Injury	
Variable	Coeff.	(Std. err.)	Coeff.	(Std. err.)
ln(Exposure)	$0.506^{\ddagger}$	(0.081)	$0.773^{\ddagger}$	(0.027)
Alcohol	$2.534^{\ddagger}$	(0.656)	–	–
One-car	$0.627^{\dagger}$	(0.279)	–	–
Young	$1.046^{\ddagger}$	(0.364)	–	–
Old	$0.518^{\dagger}$	(0.261)	–	–
Male	$2.151^{\ddagger}$	(0.311)	–	–
Night	0.340	(0.237)	–	–
Intercept	$-7.194^{\ddagger}$	(0.750)	$-3.522^{\ddagger}$	(0.233)
α	0.384	(0.116)	0.342	0.027
$\bar{\chi}^2_{(01)}$	22.34		2,456.57	
N	502		502	
$\tilde{R}^2$	0.32		0.12	

Two-tailed test: ‡significant at .01 level, †at .05 level.
$\bar{\chi}^2_{(01)}$ denotes a 50:50 mixture of a chi-square with no degrees of freedom and a chi-square with 1 degree of freedom (StataCorp, 2001).
$\tilde{R}^2$ denotes the "pseudo R^2" (Wooldridge, 2002, p. 465).

Table 5. Description of risk variables, summary statistics for each make make/model/year in 1998, and anticipated signs of variables with respect to the costs of owning and operating an automobile.

Variable	Description	Mean (std. dev.)	Anticipated sign
EB(fatality)	Estimated number of fatalities after using Empirical Bayes weights.	0.478[a] (0.806)	N.A.
EB(injury)	Estimated number of injures after using Empirical Bayes weights.	24.759[a] (27.917)	N.A.
Fatal	Risk of fatality from car crash in Sweden.	0.00006[b] (0.0001)	–
Non-fatal	Risk of morbidity from car crash in Sweden.	0.00241[b] (0.00143)	–

[a] $N = 502$.
[b] $N = 500$.

insignificant in the fatality regression. The estimated α is the inverse of the overdispersion parameter, i.e. $\varphi = \alpha^{-1}$, and α was statistically significant in both regressions.

To calculate the weights in Eq. (8) the fitted values from the regressions were used together with the inverse of the estimated α. Using Eq. (9) resulted in "zeros" getting a positive value and high fatality and injury counts being smaller. Thus, extreme values were pushed towards the mean. Comparing the accident counts on fatalities and injuries in Table 2 with the estimated ones in Table 5 we can see that the variance is reduced for both variables. After calculating M in Eq. (10) two observations were dropped since they were regarded as outliers, $M > 1/1000$. The last two variables then show the risk variables used when estimating the hedonic equations. Both are assumed to have a negative impact on the amount car consumers are willing to spend on their vehicle.

4.2. *Atemporal model*

Three different equations were estimated. The first Eq. (A1) in Table 6 includes both risk variables, *Fatal* and *Non-fatal*, and accident characteristics. In the second Eq. (A2) *Non-fatal* was omitted in order to test if the non-fatal risk variable influences the estimate of the fatality variable. In the last Eq. (A3) accidents characteristics were omitted to test for their influence on the coefficient estimate for *Fatal*.

Some variables were excluded during the estimation process. *Hatchback*, *Diesel*, and some of the "origin variables" (*Saab*, *Japan*, and *Others*) were excluded since they were insignificant. After using the variance inflation factor to test for multicollinearity (Kennedy, 1998, p. 190), the binary variables for the four different size categories, *SizeX*, were excluded. Instead of using *Acceleration*, Dreyfus and Viscusi used the power-to-weight ratio since it was uncorrelated with the other explanatory variables (Dreyfus and Viscusi, 1995, p. 38). Power-to-weight was also tested as an alternative to *Acceleration*, but using power

Table 6. Atemporal model: Dependent variable, natural logarithm of user costs.

	Equation A1		Equation A2		Equation A3	
Variable	Coeff.	(Std. err.)	Coeff.	(Std. err.)	Coeff.	(Std. err.)
Fatal	−252.150**	(96.433)	−255.768**	(95.388)	−13.868	(51.215)
Non-fatal	−1.410	(4.412)	–	–	−2.457	(4.238)
Acceleration	4.039**	(0.337)	4.045**	(0.335)	4.092**	(0.340)
Compartment	1.506**	(0.210)	1.505**	(0.210)	1.500**	(0.210)
Cargo	0.045	(0.051)	0.047	(0.050)	0.038	(0.052)
Styling	1.791‡	(0.124)	1.797‡	(0.122)	1.810‡	(0.125)
Reliability	0.034**	(0.012)	0.034**	(0.012)	0.032**	(0.012)
Station wagon	0.069**	(0.015)	0.069**	(0.015)	0.074**	(0.015)
Germany	0.043‡	(0.012)	0.043‡	(0.012)	0.042‡	(0.012)
France	0.197‡	(0.020)	0.197‡	(0.020)	0.185‡	(0.019)
US	0.092‡	(0.012)	0.091‡	(0.012)	0.086‡	(0.012)
Year88	0.103**	(0.023)	0.103**	(0.023)	0.112**	(0.024)
Year89	0.185**	(0.025)	0.186**	(0.024)	0.179**	(0.024)
Year90	0.193**	(0.022)	0.194**	(0.022)	0.192**	(0.023)
Year91	0.243**	(0.023)	0.243**	(0.023)	0.240**	(0.022)
Year92	0.298**	(0.023)	0.299**	(0.022)	0.292**	(0.023)
Year93	0.346**	(0.023)	0.347**	(0.023)	0.340**	(0.023)
Year94	0.389**	(0.022)	0.391**	(0.021)	0.386**	(0.021)
Year95	0.405**	(0.024)	0.407**	(0.023)	0.397**	(0.023)
Year96	0.432**	(0.024)	0.434**	(0.023)	0.426**	(0.023)
Year97	0.421**	(0.027)	0.423**	(0.026)	0.419**	(0.026)
Year98	0.529**	(0.026)	0.532**	(0.023)	0.533**	(0.026)
Alcohol	0.161	(0.084)	0.162	(0.084)	–	–
One-car	0.004	(0.021)	0.004	(0.021)	–	–
Young	0.126**	(0.026)	0.127‡	(0.026)	–	–
Old	0.034**	(0.014)	0.035†	(0.014)	–	–
Male	0.009	(0.014)	0.010	(0.014)	–	–
Night	−0.005	(0.015)	−0.005	(0.015)	–	–
Intercept	7.377‡	(0.191)	7.367‡	(0.186)	7.372‡	(0.190)
N	500		500		500	
R^2	0.86		0.86		0.85	

One-tailed test: ** significant at .01 level, * at .05 level.
Two-tailed test: ‡significant at .01 level, † at .05 level.
Robust standard errors in brackets.
A2: Non-fatal risk variable omitted.
A3: Accident characteristics omitted.

instead of measured acceleration in this study did not change any results. *Acceleration* was therefore used, since it is more readily interpreted by car consumers. Based on examination of standard errors for estimated coefficients, and on multicollinearity tests, the conclusion was drawn that multicollinearity was not a problem.

The first column of Table 6 reports on results when both risk variables and accident characteristics were included. All explanatory variables (of those with an anticipated sign) had the expected signs. The coefficients for the *YearXX* were also logical, i.e. compared with reference year 1987, they were all positive and, with one exception (*Year97*), increasing in model year. The accident characteristics were only included as control variables for the fatality variables, and not as explanatory variables for the dependent variables in the regressions, and therefore, their signs and significance levels were not of interest here.

The results from the atemporal model also showed that, removing *Non-fatal* had almost no effect on the estimated coefficient for *Fatal*. This result was surprising. It was expected that the two variables would be correlated, and the removal of one of them would influence the estimate of the other variable. A car that is safer in terms of fatality risk would also be expected to be safer in terms of injury risk. But a correlation test between the two variables only showed a correlation of 0.18.[14] The two risk variables were designed using data on fatal and non-fatal accidents separately, but the result was still surprising.

Omitting accident characteristics from the hedonic model had a large impact on the coefficient estimate for *Fatal*. The coefficient in A3 was reduced to about 5% of the estimate in A1, and also became statistically insignificant. The coefficient estimate for *Non-fatal* was also affected by omitting accident characteristics. It now got a higher negative value, but it was still statistically insignificant. The other variables in the regression were not affected, though. The results in Table 6 strengthen the theoretical assumptions that the accident characteristics were correlated with the risk variables but not with the other explanatory variables.

Using the one-period model to estimate VSL based on the results from Table 6, equations A1 and A2 can be used. Equation A1 is the preferred model and the estimated VSL from equation A1 was SEK 12.04 million in 1998 price level. Since omitting the non-fatal risk variable from equation A2 had almost no effect on the estimates, the estimated VSL from equation A2 was close to the VSL from A1, SEK 12.21 million.

4.3. Life-cycle model

For the life-cycle model also, three equations were estimated, which are presented in Table 7. The equations were identical except for different discount rates. The same explanatory variables were used as in the atemporal setting. The reason for this was to make a direct comparison possible between the two settings. In the first equation (L1), the discount rate was set to 4%, which is the discount rate used in Sweden for cost-benefit studies within the "transport sector" (SIKA, 2002, p. 43). In the second equation (L2) a discount rate of 8% was used, reflecting a level of market interest rate in Sweden in 1998.[15] The last equation used a discount rate of 18.7%, which was the discount rate needed to get the same VSL estimate as in equation A1 in the atemporal model.

Table 7. Life-cycle model: Dependent variable, natural logarithm of annualized total costs.

	Eq. L1: $r = 4\%$		Eq. L2: $r = 8\%$		Eq. L3: $r = 18.7\%$	
Variable	Coeff.	(Std. err.)	Coeff.	(Std. err.)	Coeff.	(Std. err.)
Fatal	−321.881**	(98.352)	−338.544**	(98.878)	−378.713**	(101.668)
Non-fatal	−5.249	(5.556)	−5.724	(5.553)	−6.647	(5.512)
Acceleration	3.390**	(0.351)	3.521**	(0.350)	3.806**	(0.358)
Compartment	1.433**	(0.172)	1.465**	(0.178)	1.538**	(0.191)
Cargo	0.122**	(0.041)	0.121**	(0.041)	0.121**	(0.043)
Styling	1.811‡	(0.115)	1.876‡	(0.115)	2.021‡	(0.119)
Reliability	0.002	(0.011)	0.003	(0.011)	0.004	(0.011)
Station wagon	0.060**	(0.016)	0.066**	(0.016)	0.079**	(0.016)
Germany	0.060‡	(0.012)	0.068‡	(0.012)	0.086‡	(0.012)
France	0.021	(0.018)	0.018	(0.018)	0.010	(0.018)
US	−0.013	(0.011)	−0.018	(0.011)	−0.027†	(0.011)
Year88	−0.015	(0.023)	−0.006	(0.023)	0.017	(0.023)
Year89	0.033	(0.022)	0.049*	(0.022)	0.091**	(0.023)
Year90	0.020	(0.019)	0.044*	(0.019)	0.110**	(0.020)
Year91	0.040*	(0.020)	0.072**	(0.020)	0.161**	(0.021)
Year92	0.068**	(0.019)	0.112**	(0.019)	0.232**	(0.019)
Year93	0.115**	(0.021)	0.169**	(0.021)	0.312**	(0.022)
Year94	0.147**	(0.020)	0.213**	(0.020)	0.385**	(0.021)
Year95	0.164**	(0.021)	0.242**	(0.022)	0.440**	(0.023)
Year96	0.201**	(0.022)	0.288**	(0.022)	0.510**	(0.022)
Year97	0.220**	(0.023)	0.313**	(0.023)	0.548**	(0.024)
Year98	0.293**	(0.025)	0.409**	(0.025)	0.689**	(0.025)
Alcohol	0.183†	(0.085)	0.192 †	(0.086)	0.209 †	(0.089)
One-car	0.011	(0.020)	0.013	(0.020)	0.016	(0.019)
Young	0.078‡	(0.029)	0.086 ‡	(0.028)	0.105‡	(0.027)
Old	0.032†	(0.013)	0.035‡	(0.013)	0.043‡	(0.014)
Male	0.048‡	(0.014)	0.048‡	(0.014)	0.049‡	(0.014)
Night	−0.022	(0.014)	−0.021	(0.014)	−0.019	(0.014)
Intercept	6.903‡	(0.161)	6.846‡	(0.165)	6.737‡	(0.173)
N	500		500		500	
R^2	0.83		0.87		0.92	

One-tailed test: ** significant at .01 level, * at .05 level.
Two-tailed test: ‡significant at .01 level, †at .05 level.
Robust standard errors in brackets.

Year88 now got an unexpected coefficient sign. *Year88* had a negative coefficient sign in the models where the discount rates were 4 and 8%. The coefficient for the *Year88* was, however, statistically insignificant in all models. Three other differences with the results in the one-period models were that *Cargo* became significant, *Reliability* insignificant, and that the variables for French and US makes also became insignificant. In addition, the coefficient estimates for *Year89* and *Year90* were statistically insignificant when the discount rate was set at 4%.

The results in Table 7 show that the coefficient for *Fatal* is increasing in the discount rate, and therefore sensitive to the assumptions on time preferences. A high discount rate reflects time preferences for a risk-averse individual in the classical sense, i.e. an individual averse to "gambling". An individual with an high discount rate puts more weight on his present utility than on his future, and is not as prepared as an individual with a low discount rate to postpone his consumption. The impact of the different discount rates on the estimated coefficients results in the following estimates for VSL; (i) equation L1, SEK 7.50 million, (ii) L2, SEK 8.58 million, and (iii) L3, SEK 12.04 million.

5. Discussion

This study estimated VSL for car safety in both an atemporal and a life-cycle setting. Prior studies within the area only used one approach each, and it is therefore difficult to compare and interpret the results from these studies. Since, in this study, the same explanatory variables were used as regressors for the cost of owning and operating an automobile in both settings, it enables us to make a direct comparison of the estimates from the two approaches.[16]

The results were sensitive to which approach, one-period or life-cycle model, was taken and to the assumptions on time preferences within the life-cycle model. The estimated VSL from the atemporal model were $1.50 million and $1.52 million 1998 dollars, whereas the estimates from the life-cycle model were in the range $0.93–1.50 million.[17] The results indicated that car consumers discount the value of future health, measured as the value of future consumption, higher than the market discount rate. A discount rate of 18.7% was needed to get estimates in the life-cycle model to be equal to the estimate from the atemporal model, in which both risk variables were included. Several studies have also shown that a discount rate higher than the market rate of interest is appropriate for individual discounting in welfare analysis (Cropper, Aydede, and Portney, 1992; Dreyfus and Viscusi, 1995; Harrison, Lau, and Melonie, 2002).

All estimates were considerably smaller than the estimates from the American hedonic car-safety studies. Atkinson and Halvorsen (1990) reported an estimate of $5.00 million using an atemporal model. Dreyfus and Viscusi (1995) estimated three different life-cycle models, omitting the non-fatal risk variable from one model, and in one model both the non-fatal variable and accident characteristics. The three different models resulted in estimates in the range $3.59-5.10 million, where $3.59 million was the estimate when all variables were included.[18] Mount et al. (2001) got an even higher estimate after adjusting for income elasticity and bias in drivers' risk perceptions, $5.84 million (unadjusted, $3.20 million).

The estimates were not only smaller than the American estimates, but also smaller than VSL estimates for road safety from Swedish SP-studies. The study from which the data on automobile holdings was collected, Persson et al. (2001), reported an estimate of \$2.77 million. Another Swedish study reported estimates in the range \$3.72–7.32 million (Johannesson, Johansson, and O'Connor, 1996), and finally Persson and Cedervall (1991) recommended that an estimate of \$1.99 million should be used for VSL in Sweden (Trawén, Maraste, and Persson, 2002). These Swedish studies show that there is a wide range for the estimates. Still, the estimates from this study are below all these.

The preferences revealed in this study are those from Swedish car consumers, not American ones, and the usefulness of a direct comparison of estimated risk values from different countries and different points of time is questionable, since (i) preferences may differ between samples, and (ii) contexts may differ substantially and the tradeoffs individuals have to consider may therefore not be directly comparable. The comparison of the Swedish estimates is also problematic, since there is both the problem of different samples, and most importantly, the different scenarios, actual WTP vs. hypothetical WTP. Nonetheless, a discussion on potential explanations for the reported differences is meaningful, since it can explain some of the diversity between the studies, but also since it highlights some problems with the different estimation techniques.

First, VSL is increasing in wealth (Jones-Lee, 1989), which might be one explanation for higher American estimates, since wealth measured as GDP per capita is higher in the US than in Sweden.[19] Estimated VSL from Swedish studies are reportedly lower than from American studies. For example, Miller (2000) compared VSL estimates between countries and found a higher mean value for American than for Swedish estimates. To compare Swedish estimates with American ones, it is therefore common to adjust the values using estimated income elasticities. According to the findings of Miller (2000) American estimates were 12% higher than the Swedish estimates for VSL, and adjusting the estimates using income elasticities might then explain the difference. The difference in estimates from this study and the American ones, is however that large, that adjusting the values would not explain why they differ to the extent they do, and the estimates were, therefore, left unadjusted.[20]

Second, the low estimates from actual choices by Swedish car consumers in comparison to Swedish estimates based on hypothetical WTP, may be a result of the different scenarios. Both the hedonic technique and the SP-studies estimated VSL. But, since the hedonic technique estimates WTP based on actual choices and the WTP from the SP-studies is based on hypothetical choices, we are comparing two different WTP.[21] The respondents in the SP-studies might have stated a higher amount than they actually were willing to pay, since they knew that they were not obliged to actually pay the amount they stated. There might, therefore, be a positive hypothetical bias in the SP-studies. It is also plausible that the respondents in the SP-studies not only stated their WTP for a reduced risk of the outcome of an accident, but also for the risk that an accident may occur, i.e. they stated how much they were willing to pay to avoid the whole "accident event chain" (see Figure 1). Therefore, the answers from the SP-studies may also reflect the individuals' aversion to accidents per se.[22]

Third, since no true risk measure for cars is available, we had to use a proxy variable for fatality risk. If car consumers' subjective risk perceptions closely reflect objective measures of fatality risk, accident data can be used as a proxy. There is evidence that individuals respond in expected ways to risk, i.e. they respond in the expected direction and the greater the risk the more they respond (Blomquist, 2004). However, "their ability to perceive risk in a cardinally correct way is questioned" (Blomquist, 2004, p. 99). Whereas Persson et al. (2001) found that motorists underestimate risks in traffic, Hammerton, Jones-Lee, and Abbott (1982) found evidence that ". . . on average subjective assessments are of a broadly similar order of magnitude to the objective ratio" (p. 192) for a familiar risk activity like transport. In Persson and Cedervall (1991), the respondents overestimated the risk of death for an average car driver. When asked about the risk of death for themselves, however, the median of the respondents' estimates was equal to the calculated objective risk. However, even if the objective risk variable mirrors the subjective risk perception, "measurement errors" in the fatal-risk variable might have caused the coefficients of the fatality variable to be biased toward zero (Greene, 2000).[23] This could be one possible econometric explanation for the low estimates in comparison to both the American and Swedish estimates.[24]

Since the fatality-risk variable was based on reported fatal accidents from one year, with approximately 500 road fatalities (SCB and SIKA, 1999), the number of fatalities per make and model is expected to suffer from "randomness", which is a common problem with accident statistics based on short-time intervals or from specific locations (Hauer, 1997). To mitigate this problem the "Empirical Bayes" method was used. If we had had access to data on the model level for several years we would have been able to draw some conclusions on the magnitude of our measurement-error problem. Measurement error is less likely the more stable the rates, but since we did not have access to data on accident statistics on the model level for several years, we do not know how big the problem was and to what extent our method to mitigate the problem was successful.[25]

A second source of measurement errors is that individuals do differ. Car drivers not only form their risk perceptions on information they receive on accident statistics, but socioeconomic factors such as, e.g., age, gender, and driving patterns, will also be reflected in their subjective risk perceptions. Another reason why we might expect automobile safety consumption to be individual can be explained by the theory behind the household production function (e.g. Becker, 1965; Lancaster, 1966). One underlying assumption, when using the hedonic technique, is that the "objectively" measured characteristics are the ultimate characteristics for the consumer. We might suspect, however, that drivers' preferences for traffic safety may differ and that consumers of the same car do not necessarily consume the same level of safety when using the vehicle.

The difference in estimates may also be a result of the Swedish social welfare state, and a high traffic-safety ambition among governmental authorities in Sweden.[26] Swedes are, through the Swedish social welfare state, protected against many of the negative effects of traffic accidents, and it might also be that Swedish road users feel quite safe on the road because of the high governmental ambition level, and therefore, when it comes down to it, they are not prepared to invest more resources in their own safety. Thus, their marginal WTP for an additional risk reduction is small. Another effect of the Swedish social welfare state could be that Swedish car consumers do not regard car safety as a strictly private good, but a quasi-public good. Road safety is a mixture of governmental traffic safety programs, e.g. road investments where consumption of one driver of a reduced risk level on a specific road does not prevent another driver from enjoying the same consumption, and private safety investments in, e.g., car safety. If car safety is not regarded as a private good, which it is, since occupants of one vehicle cannot utilize safety standards of another vehicle, car consumers will mistakenly believe that there is the possibility of free-riding in consuming the desired car-safety level. Car consumers will then "reveal" a WTP that is lower than their true WTP when buying cars, and using a RP-method, like the hedonic regression technique, will only capture a fraction of the consumers' total WTP for safety.[27]

If Swedish car consumers respond to governmental interventions, it would mean that they use the car market to attain their optimal risk exposure by balancing marginal benefits from injury avoidance against the marginal costs of purchasing and utilizing safety equipment. Ehrlich and Becker (1972), in their theoretical paper, discussed the interaction of different "market activities" like market insurance, "self-insurance" (e.g. seat belt use), and "self-protection" (reduction by the driver of the probability of an accident). They showed that market insurance and self-insurance were substitutes and that self-insurance was likely to discourage self-protection. Policies aiming to increase the overall traffic safety level in the form of self-insurance may thus be offset by a reduction in the individual's self-protection. Market insurance, however, could both encourage and discourage self-protection, depending on the construction of the insurance contract. A negatively related price of the market insurance to the expenditures on self-protection would encourage self-protection, whereas an insurance price independent of expenditures on self-protection would create disincentives to invest in self-protection (moral hazard).

Peltzman (1975) studied American drivers' response to regulations on automobile safety standards (inflicted self-insurance). His hypothesis was that, if a higher safety level than that perceived optimal by the drivers was forced upon them by government interventions, they might respond by lowering their own self-protection. For example, they might respond by driving faster or more recklessly and not only not reduce their own risk exposure but also increase the risk for other road users. Peltzman found that the interventions he studied saved auto occupants' lives but increased pedestrian deaths and non-fatal accidents due to offsetting behavior by the drivers.[28]

6. Conclusions

The purpose of monetizing the value of car safety is to be able to evaluate traffic safety programs' welfare effects on society. With fully effective market forces, there would be no need for government interventions, but due to externalities and other sources of market failure, governments may increase overall welfare by increasing the level of safety through traffic regulations. The optimal safety level to strive for is, however, problematic. A high level of ambition in road traffic, e.g. minimizing mortality and injury rates, may be so costly that it would increase overall deaths and injuries (Elvik, 1999; Gerdtham and Johannesson, 2002; Hjalte et al., 2003).[29] In addition, governmental policy may not reflect society's preferences for safety, and it is therefore important to elicit individuals' preferences for safety and monetarize them.

There are several problems when using the hedonic regression technique in order to estimate the value of improved traffic safety. This does not mean that the technique is not appropriate. All non-market valuation techniques have shortcomings, and the problems with the hedonic technique are no greater than with the other techniques. The individual's risk perception is, e.g., not only problematic when estimating risk values for traffic safety in RP-studies, but also when using a SP-approach. Even if, e.g., the objective risk is presented to the respondents in a SP-study, it is not sure they truly understand it.

Three strengths of the approach are: (i) that it is based on actual behavior of individuals, (ii) that the potential problem of self-selection bias in some RP-studies is reduced, and (iii) individuals' total WTP for safety is revealed. The problem of using consumption data on safety equipment, e.g. airbags, is that on one hand it provides a lower bound of consumers' WTP for safety, since the consumers are faced with a discrete decision, and by buying the safety product they reveal that the benefit from the product will be at least as large as the cost of the product (Viscusi, 1993). On the other hand, people who value safety more highly are more willing to consume and pay for safety products than the average member of society. Using estimated WTP from such studies may, therefore, not be appropriate for evaluation purposes of safety programs. Using the hedonic technique on a representative sample of the car fleet, self-selection biased is reduced. But car driving is risky, and therefore car consumers can be expected to value safety less than others, which means that self-selection bias is only reduced not eliminated. Therefore, the utilization of the estimated WTP from this study for cost-benefit analysis within other areas than road safety, has to be done with caution.

Appendix

Road safety activities in Sweden

1975	Mandatory seat-belt-use by front seat occupants in passenger cars Mandatory to use motor cycle helmet
1977	Daytime running lights Random breath tests allowed
1982	All slow moving vehicles should have a warning sign Campaign "Soft Children. Hard Cars"
1986	Mandatory use of seat belt by adults in back seat
1987	Campaign "Slow down". Speed fines increased
1988	Mandatory use of restraint system for children Prohibition on producing, having, giving or using radar indicators
1990	New driving license. New theory test has to be passed before driving test. New license is provisional for the first two years.
1994	New law regarding drunken driving. Limit for seriously intoxicated drivers 0.10 percent Number of random breath tests doubled
1997	The "Vision Zero" is accepted by the Parliament. A vision of zero people killed or seriously injured as a result of a traffic accident.
1999	Winter tyres mandatory with winter road conditions, December to March
2000	Priority for pedestrians at pedestrian (zebra) crossings. Decreased number of pedestrian crossings.

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Notes

1. For simplicity, in this section all "bads", such as risk, are redefined as "goods". For example, risk can be redefined as safety.
2. Functions with subscripts are differentiated with respect to the subscript.
3. For a more detailed description of consumption and production decisions, see Rosen (1974).
4. For example, all Mercedes-Benz models had to be excluded since the official data on accidents statistics and vehicles in use could not be linked with models in the data set.
5. Some variables, "luxury-sport", ride quality, maintenance record, assumed to be of relevance for car consumers could not be included. The reason was that no variables, which were comparable for the whole sample (1987–1998), were found.
6. Gasoline and diesel prices are in Swedish kronor (SEK) per liter, annual kilometers (km) is the average for the Swedish car fleet, and fuel efficiency is the weighted average of urban and non-urban driving in liter per kilometer. Operating costs (OC) were then calculated as,

$$OC = \frac{\text{SEK}}{\text{liter}} \times \frac{\text{km}}{\text{year}} \times \frac{\text{liter}}{\text{km}}.$$

7. Saab belongs today to General Motors. In 1998, Saab was jointly owned by Swedish *Investor* and *General Motors*. Volvo was bought by Ford in 1999.
8. The variable used in this study for expected remaining useful life of a vehicle, T, does not take into consideration that different makes are expected to have different length of life. To capture this difference both Dreyfus and Viscusi (1995) and Mount et al. (2001) used sales value retained as a proxy variable for difference in durability of different vehicles, since vehicles with higher retained resale value were assumed to have longer expected remaining life. Also in this study, the percentage of the original sale value retained (as of mid-of-year 1998) was included, both as a stand alone variable and in a "adjusted T-variable". Both variables created multicollinearity problems and were therefore dropped from the regressions.
9. If the Box-Cox transformation coefficient is defined by λ, then the transformed variable is defined as follows,

$$A_k^{(\lambda)} = \frac{A_k^{\lambda} - 1}{\lambda} \quad , \lambda \neq 0,$$

where the model is linear if λ equals one. The model takes the logarithmic form when λ approaches zero,

$$\lim_{\lambda \to 0} A_k^{(\lambda)} = \ln A_k,$$

since by L'Hôspital's rule,

$$\lim_{\lambda \to 0} \frac{A^{\lambda} - 1}{\lambda} = \lim_{\lambda \to 0} \frac{d(A^{\lambda} - 1)/d\lambda}{1} = \lim_{\lambda \to 0} A^{\lambda} \times \ln A = \ln A.$$

10. Cropper, Deck and McConnell (1988) showed, when comparing different functional forms, that a linear Box-Cox function performs best for hedonic price functions.
11. Information on estimation procedure and fractions, available on request from the author.
12. This approach makes the comparison between the atemporal model and the life-cycle model more transparent than the alternative, i.e. regressing the total cost of the vehicle on discounted annual fatality risk. The discounted annual fatality risk (DF) during the life of the vehicle would then have been defined as,

$$\mathrm{DF} = \int_{t=0}^{T} e^{-rt} dt \times F = \frac{1 - e^{-rT}}{r} \times F.$$

The non-fatal risk variable, discounted injury risk, would have been defined analogously.
13.

$$\mathrm{TC} = P + \frac{1 - e^{-rT}}{r} \times OC$$

14. Significant at the 1% level.
15. The bank average lending rate in Sweden in June 1998 was 6.6 per cent (Swedish Central Bank, 1998, p. 75). The annual change in CPI for 1998 was -0.14 per cent (International Monetary Fund, 2002), resulting in a real interest rate of 6.74 per cent. The average lending rate includes rates on business- and real estate loans. Therefore, the lending rate was adjusted to 8 per cent to better reflect consumers' access to capital markets.
16. The underlying data set for automobile holdings in this study also consisted of information on the characteristics of the holders, e.g. risk perception and expected remaining life of the car owner. However, since individual transaction prices were not available, that information could not be used.
17. The estimates presented in this section were all converted into 1998 US dollars using exchange rates and CPI indexes for Sweden and US (International Monetary Fund, 2002). The average exchange rate in 1998 was $1 = SEK8.05.
18. Dreyfus and Viscusi (1995) used their hedonic equation to estimate an implicit discount rate. Their estimates were therefore based on implicit discount rates that differ between the different equations.
19. GDP per capita at purchasing power parity 1998 (US$); US, 29,340, and Sweden, 19,480 (Global Geografi, 2003).
20. Based on the GDP figures in endnote 5 and an estimated income elasticity of 0.24 from Persson et al. (2001), the Swedish VSL estimates should be adjusted by approximately 11%.
21. The respondents in the SP-studies were asked how much they were willing to pay for a "road safety device" that would reduce the risk of a fatal accident.
22. Meta analyses have shown that SP-studies generally produce higher estimates than RP-studies (de Blaeij et al., 2003).
23. We also suspect that we have measurement errors in the dependent variable. Automobile holdings originate from a SP-study, and respondents might have remembered incorrectly which model they possessed. We also chose to use only standard models and "average market prices" for the cars in the study which are two other sources for measurement errors. Using average prices will probably be a smaller problem in a Swedish study compared to an American study, since Swedish cars are tested annually by The Swedish Motor Vehicle Inspection Company, and the variation in quality, and hence in prices, can be assumed to be smaller. Under usual assumptions with measurement errors in the dependent variable, the OLS model will still have good properties, but larger variance of the OLS estimators (Wooldridge, 2002). The measurement errors in the dependent variable will not, therefore, lead to any bias in our VSL estimates.
24. One econometric problem not solved in this study was "omitted variables". Theoretically the hedonic technique overcomes the problem of omitted variables. But, as suspected, since some variables that were assumed to be of relevance for car consumers could not be included, the hypothesis of no omitted variables was rejected, when using a misspecification test for omitted variables (Ramsey reset test). However, the effect on the estimates from including all variables of relevance is not possible to predict here.
25. Levitt and Porter (2001) studied another problem using data on fatal car crashes, possible sample selection. Whereas this study related fatalities to the exposure of the vehicles and controlled for different circumstances surrounding the crashes, they instead used the number of fatalities to study the effectiveness of airbags and seat belts. Since the use of safety devices might affect the outcome, using data on fatalities from crashes will

result in sample selection bias. Their solution to this problem was not to relate safety devise usage in relation to miles driven or any other measure of "exposure". They instead limited their data sample to crashes where someone dies in another vehicle in a crash. By doing so, they addressed the correlation between usage of the safety device and the outcome of the accident, since usage in one car and the outcome in another can be assumed to be uncorrelated.

26. A survey of Swedish traffic safety activities for the last three decades can be found in Koornstra et al. (2002). Some examples of these activities are listed in the appendix.
27. In contrast to car safety, workplace safety can be regarded as a quasi-public good, since workers can enjoy the same safety level as their colleagues independent of their preferences for safety. There is, therefore, a possibility of free-riding in the work place, and there might be incentives for workers not to "...truthfully reveal his of her preference for safety" (Viscusi and Aldy, 2003, p. 43), since that could lead to a decline in his or her wage.
28. Lindgren and Stuart (1980) replicated Peltzman's study when they tested for "increased driving intensity" by Swedish drivers as a response to mandated improvement in physical vehicle safety. They did not in their study find any such offsetting behavior in Sweden.
29. It is also sometimes argued that the only ethically justifiable principle for safety policies is to do the utmost to prevent death or injury from traffic accidents. Apart from the problem of perhaps increasing overall death and injuries, Harris (1975) presented another problem with an ethical principle stating that society ought to minimize mortality. A minimizing-mortality principle would justify the killing of people as long as the number saved was larger than the number killed. Harris found that people would reject the idea of a survival lottery, where some individuals would have to sacrifice their lives for the benefits of others, on the basis that it is morally wrong to kill. An ethical principle stating that society ought to minimize mortality is therefore inconsistent with the principle that it is always wrong to kill.

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