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The European used-car market at a glance: Hedonic resale price valuation in automotive leasing industry

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The European used-car market at a glance: Hedonic resale price valuation in automotive leasing industry

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Abstract

In the leasing industry, the risk of loss on sales at the end of the contract term, as well as pricing are critically impacted by the forecasted resale price of the asset (residual value). We apply the Hedonic methodology to European auto lease portfolios, in order to estimate the resale price distribution. The Hedonic approach estimates the price of a good through the valuation of its attributes. Following a discussion on Hedonic prices, we propose an operational model for the automobile resale market. The model is applied to four European countries (France, Germany, Spain and Great Britain), and distributions are calculated on two vehicle versions (Audi A4 & Ford Focus) allowing a comparison of market depreciation patterns and residual value risks.

Keywords: Hedonic model, residual value, automotive market.

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1 Introduction

In the auto lease industry, a large part of the rent paid by the customer during a life contract is the difference between the list price and the residual value. The leasing company makes or losses money depending on whether it accurately predicts the value of the asset at the end of the contract (fair market value). If residual values are forecasted to be higher than what the asset is actually worth at lease-end, then there will be a loss. At the opposite, if residual values are forecasted to be lower, then there will be a gain on resale. The estimated resale price of the car at the end of the contract term appears as a key component for the pricing, the risk of losses and the reserve calculation[2].

Akerlof (1970) explained why used car valuation is so much lower than new car valuation. The automotive resale market is affected by something called the 'lemon effect'. A used car has the probability to be of a good quality or a bad one (i.e. lemon), and the uncertainty about quality implies a price adjustment[3]. The Akerlof theory helps to understand the large variance of prices between new and used markets, but it does not propose a methodology to calculate car depreciation.

Another way of looking at it is the Hedonic approach. The Hedonic theory provides solutions and estimates price-quality relation through a detailed calculation. A Hedonic model has been originally proposed by Waugh (1928) on vegetable products and by Court (1939) in the automobile industry. Hedonic models have been applied to a lot of commodities (mainly real estate and automobile but also fruits or vine[4]). The automobile market itself has had different applications (quality corrected price index[5], demand for fuel efficiency, valuation of environmental and safety demand[6], test of the Akerlof effect[7], behavior of the automobile market through price quality and competition[8]...). The main point underlying this paper is to

[2] This article is part of a general study on resale market hedging (Prado, 2008). We aim to estimate the distribution of the resale price in order to include the depreciation behavior in a derivative product.

[3] In the resale market, there is an asymetry of information; the car owner has a better knowlegde of the probability of bad lemons. If Second hand vehicles were valued like as new vehicles, then it would attract lemons (lemons' sellers would have the opportunity to sale their vehicles and buy a new one on the new vehicle market) and it would create an arbitraging opportunity. Akerlof used the automotive market as a best illustration and extended his idea to other markets (the cost of deshonesty...).

[4] Combris, Lecoq and Visser (1997).

[5] Cowling and Cubbin (1972) and Van Dalen and Bode (2004).

[6] Atkinson and Halvorsen (1990).

[7] Couton, Gardes, and Thepaut (1995).

[8] Cowling and Cubbin (1971) and Cubbin (1975).

apply the Hedonic methodology to estimate the resale price distribution of cars in a leasing perspective. This article is intended for people within the leasing industry interested by residual value risk, as well as academics concerned by a comparison of European markets.

We propose a methodology for operational applications to estimate the distribution of resale price. To this end, we apply a Hedonic model (a method of estimating value through constituent characteristics of the asset) on historical information from a major leasing company[9]. Further to this, we estimate a value according to vehicle characteristics and country singularities. Resale price distributions of two vehicles (Ford focus C-max, Audi A4) are calculated in various European markets (France, Germany, Spain and Great Britain). The paper is organized as follows. Section 2 discusses the Hedonic theory underlying our model. In section 3 some meaningful characteristics of the model are exposed. Section 4 presents our approach. Section 5 estimates the distributions and analyzes the results, finally. Section 6 concludes.

[9] In Europe, statistics on resale prices are not as abundant as in financial markets and leasing companies often have to use internal data to forecast the market value. External information is usually not available on line, costly and time consuming to collect. Morevover, there is a non homogeneous information and format by country. Therefore we use the internal resale information (GE resale data warehouse).

2 The Hedonic theory underlies our model

The section discusses the Hedonic model approach, identification issues and automotive assets specificities.

2.1 Goods attributes constitute the Hedonic theory.

To explain consumer behavior, Lancaster (1966) assumes that consumers get utility from goods attributes[10]. Assuming that a car is the only good involved in the activity consumption of driving, it produces a fixed vector of attributes and the level of activity is a scalar associated with the vector (the relationship could be linear). The driver chooses a combination to maximize his utility function according to the characteristics of the goods under a constraint budget.

Inspired by Lancaster (1966), Pickering et al(1973) added an empirical perspective to the approach by conducting a survey in the UK. Following their results, they defined five groups of commodities (utilities, luxuries, leisure goods, central heating and automotive) and identified eleven characteristics as significant discriminators between groups. The principal attributes desired by car buyers were comfort, durability, economical, manoeuvrability, performance safety and style. They acknowledged that products and attributes may change groups through time because of product life cycle, different tastes between consumers, the growth of the market penetration (i.e. luxuries becoming utilities), complementarity or substitutability of goods[11]. They also figured out that it could be relevant sometime to disaggregate a group (i.e. cars by makes).

The Hedonic model assumes that goods are valued for their utility-bearing attributes or characteristics. In 1974, Rosen[12] developed the framework of Hedonic models. The theory describes cars by n measurable characteristics (oil consumption, car size, power, technology...) and a vector $Z(= z_1, z_2, ..., z_n)$ with z_i measuring the amount of the i^{th} characteristics. The existence of product differentiation implies that a wide variety of alternative packages, completely described by numerical value of z, are available. Buyers and sellers

[10] Similar attributes or characteristics could be shared by different goods. Usually goods have several characteristics, and a combination of goods may have attributes different to goods used separately.

[11] We could also add the technology obsolescence to the list.

[12] See Appendix A1.

locate in a spatial equilibrium. On one side, the consumption decision is made by a maximization of utility. On the other side, the production decision is made by minimizing factor costs subject to a joint production function constraint relating to the number of units and factors of production. A price $p(z) = p(z_1, z_2, ..., z_n)$ is defined at each point on the plane. Both consumers and producers are guided by prices through packages of characteristics bought and sold. Observations of $p(z)$ represent a joint envelope of a family of value functions and another family of offer functions. At equilibrium, buyer and seller are perfectly matched when their demand and offer functions meet at eye level.

The approach consists in estimating the following model:

$Pi(z) = Fi(z_i, ..., z_n, y_1)$ (demand)

$Pi(z) = Gi(z_i, ..., z_n, y_2)$ (supply)

$Pi(z)$ is the implicit market price for attribute z_i, y_1 and y_2 are vector of exogenous demand shift variables and a vector of exogenous supply shift variables, respectively. At equilibrium, market quantity demanded for products with characteristics z, $(Q^d(z_i))$ is equal to market quantity supplied with those attributes $(Q^s(z_i))$. A $P(z)$ function has to be found to make this equality possible. Unfortunately, differential equations for setting $(Q^d(z_i)) = (Q^s(z_i))$ are not linear in most cases and closed solution are not always possible.

2.2 An identification problem appears in Hedonic models.

There are identification problems in the Rosen model : if $p(z)$ is non linear, it may not be possible to find closed solutions. A lot of conditions must be imposed and partial differential equations must be solved when there is more than one characteristic. Rosen believed that the form of the Hedonic function is an empirical matter and developed an empirical methodology to estimate demand and supply parameters (if no explicit solution for the Hedonic price function is available). Rosen solved the "garden variety identification problem" by simultaneous identification methods like 2SLS: $p(z)$ is estimated by regressing all observed differentiated product prices p on all their characteristics, z, using the best adaptable function. The estimated prices are then included in the complete formula as endogenous variables. Later, Brown and Rosen (1982) showed that this technique is not always possible (it still requires prior restriction on functional form)[13].

But Bartik (1987) argued that the econometric problem of estimating Hedonic demand parameters is not a standard identification problem caused by demand-supply interactions: because a consumer decision cannot affect an Hedonic function, it does not affect the supplier. He pointed out another identification problem: the Hedonic price function is not linear and the consumer can endogenously choose both quantities and marginal prices. Formulated through a characteristic bid equation[14] it highlights the impact of consumer traits. Let $\frac{\delta p}{\delta z_j}(Z_i)$ be the estimated Hedonic marginal price of characteristics $z_j = W_{ij}$, where Z_i denotes a vector of observed characteristics of the product and W_{ij} a consumer marginal bid for z_j.

$\frac{\delta p}{\delta z_j}(Z_i) = b_0 + b_1 Z_i + b_2 X_i + bD_{0i} + e_{ij}$.

X_i is consumer expenditure on commodities others than Z. D_{0i} is a vector of observed demander traits affecting the marginal bid. e_{ij} is a disturbance term.

It becomes $\frac{\delta p}{\delta z_j}(Z_i) = b_0 + b_1 Z_i + b_2 X_i + bD_{0i} + D_{ui} + r_{ij}$.

D_{ui} is an unobserved taste component form. r_{ij} is a random component and $r_{ij} + D_{ui} = e_{ij}$. Therefore Z_i and X_i are correlated with unobserved tastes in the residual, leading to biased results (equivalent to different population of consumers).

In Bartik's article, the identification problem is caused by the endogeneity of both prices and quantities when households face a nonlinear budget constraint (the distribution of income follows no simple law through its range making it difficult to specify the problem entirely). An instrumental variable solution is suggested and applied (household example with addition of budget constraint). The implicit market price is estimated by regressing all observed differentiated product prices p on all their characteristics by group of modality of D_{ui} [15]. We follow on the Bartik critic in our analysis and propose a solution to manage the unobserved taste issue in Section 3.

[13] Ekeland, Heckman and Nesheim (2004) reconsidered the identification and estimation of the hedonic model. They show that most of empirical studies are based on arbitrary linearisation. Two new estimations procedures are proposed: a non parametric transformation method and instrumental variables in a general nonlinear setting.

[14] See Appendix A1.

[15] Bartick made an adjustment by group of cities.

2.3 Used cars are durable commodities.

Berndt (1983) provided general frameworks on Hedonic prices for durable goods. Assuming that the asset price of the n^{th} capital good of vintage ϕ at time t is equal to the present value of its future services, we have:

$$q_{n,t,\phi}=\sum_{s=0}^{s=T_n-\phi}\left(\frac{1}{1+r}\right)^s V_{n,t+s,\phi+s}$$

where T_n is the life time of the asset, r the interest rate, $V_{n,t,\phi}$ the value of the asset at time of the flow of services of the n^{th} capital good of vintage ϕ. Berndt demonstrated that the Hedonic price equation can be expressed in terms of service prices in a single equation[16].

This concept has been used originally in the second-hand automobile market analysis by Akerman (1973), who produced one of the first study on the rapid used car falling prices. The price of an automobile is evaluated as the discounted present value of its remaining services. The Akerman model included a Hedonic price, a repair cost, a service function and an expected gain on resale estimation. Akerman used a single equation and a regression to estimate the Hedonic price[17]. Hoffer and Pratt (1990), inspired by Akerman approach (the price of a resold vehicle as an implicit rental cost of holding a s year old automobile, including also automotive price less market price of interest) proposed a simpler model. A single equation, where depreciation declines with age at constant exponential rate, includes technological obsolescence, differential repair record and fuel efficiency as shift variables. The depreciated value $\phi(s,t)$ of an s-year old machine in year t is $ln(\phi(s,t)) = A - b_1 * s + b_2 * tech + b_3 * maint + b_4 * EPA$. $tech = 0$ if the vehicle is not discontinued. $maint = 1$ if the maintenance expenses are greater than average and EPA is a fuel efficiency indicator.

All along the referenced studies, methodology moved from a remaining service approach to a Hedonic model including essentially the vehicle characteristics (physical or not). We acknowledge the "remaining service approach", however we believe that vehicle characteristics contain most of the information. As a consequence, we adjust the resale price from inflation and we set a statistical model mainly through

[16] See Appendix A2.
[17] See Appendix A3.

variables related to the vehicle characteristics.

3 Some characteristics of the model are discussed.

The model construction brings comments and discussions: The used market is (i)demand oriented and (ii)correlated with fuel price; (iii)Multicollinearity is a critical issue in Hedonic calculation; (iv)We have to choose a functional form, and (v)Heteroscedasticity impacts the model specification.

3.1 Coefficients interpretation depends on used market substitution to new market.

Berndt (1983) pointed out an argument against the Rosen identification problem for the used market: under specific conditions, equation parameters can be directly interpreted as reflecting demand (rather than cost or supply) and there is no identification problem. If the supply curves of products are perfectly inelastic, then the market demand and supply curves would intersect at different levels of each combination of characteristics. The structure combination would be determined by the demand. The difference of price level among products could be interpreted unambiguously as providing implicit measures of consumers' evaluation of the characteristic combinations. So coefficients of the equation are well identified, as well as estimates of the demand function parameters. Because the total quantities are fixed (assuming that there is a non significant link with new market), the equation only reflects demand in the used car market.

Hartman (1987) results validate that an application to the resale market avoids the identification problem. If the supply of the attributes embodied into used cars is almost perfectly inelastic, he states that simultaneity should not pose a problem in recovering Hedonic demand and supply parameters in new product market. If the simultaneity is important, different assumptions about quantity of each make and model sold should generate different parameter estimates. Therefore the only question is : are the parameters statistically and economically significant ? In his analysis, the resale value calculation was very robust to alternative sales assumptions. Hartman applied a single equation model[18] to estimate the effect of product recalls on resale prices and firm valuation.

Two main conclusions can be stated: All referenced automotive studies use single equation techniques, and remarketing professionals usually believe in a substitution relation for young resale automotive market only which is a situation where demand and supply characteristics are quite similar. Therefore we apply a single equation and we exclude short term duration (less than 12 months age) vehicles.

3.2 Others products interact with price.

Defining a framework on the demand analysis, Berndt (1983) discussed the input price-dependent quality adjustment case: the quality of a good (i.e. fuel efficiency) is dependent on the quantity (or price) of another good (i.e fuel price). Berndt states that we could test the dependent[19] (or independent) price hypothesis using classical testing procedures (i.e. economical and statistical significance of fuel price on auto price). Fuel price has a significant part in the total cost of automobile usage, and then monthly fuel price constitutes our model.

3.3 Multicollinearity is a main issue in Hedonic models.

The econometrician walks between the two following risks while he selects the relevant variables for an Hedonic estimation: correlated explanatory variables and trickle down hypothesis.

In the automotive area, physical characteristics are often correlated (i.e. four wheels correlated to fuel capacities). According to the Gauss Markov theorem, OLS has the smallest variance. However, if explanatory variables are correlated, then small change in the data produces wrong sign, implausible magnitude and wide swings in parameter estimates [20]. As a consequence, parameter correlations present a major issue for forecast applications. The simplest solution is to exclude variables at risk (i.e all variables related to the engine power,

[18] See Appendix A4.
[19] See Appendix A5.
[20] But it also produces instability of coefficient and higher standard errors, R^2 quite high, coefficient with high standard error and low significance levels (even if significant). See Greene (2003) chapter 4 p57.

number of cylinders, kilowatt, fuel consumption, fuel capacity...) in the case of non economical significance[21].

Triplett (1969) highlights another problem. Because a small amount of variables is able to explain most of the variance (i.e. the weight of the vehicle correlated with engine power and price), there are some risk of biases in the Hedonic model and a substantial number of innovations are missed throughout this 'trickle down' hypothesis.

Therefore, the selected parameters of our model cover four axes of depreciation effects: the level of usage, the original equipment cost, the market interactions and the pure physical characteristics of the vehicle.

3.4 Which functional form ?

Rosen (1974) states that the functional form is an empirical matter. In the same logic, Grilitch and Otha (1976) choose a semilogarithmic form for their regression because 'it provided a good fit of the data'. Most of the literature suggests the log form, others studies apply the log-log form[22], and the Box Cox test[23] has also been used to compare several functional forms. The Hedonic functional form problem constitutes a great discussion but it is not the main purpose of the article.

We followed the Grilitch and Otha position (1976) ('a good fit of the data') and empirical results lead us to the linear form of Cowling and Cubbin (1972). Their linear model includes multiple physical variables like horse power and length and to allow approximation to a non linear form, square transformation, cubic transformation and log transformation were applied to exogenous variables. Interactions terms were also included.

[21] An advanced solution is the ridge regression estimator or principal component methodology. The problem is that we lost visibility on coefficients meaning.

[22] See Hogarty (1975).

[23] See Atkinson and Halvorsen (1990), Van Dalen and Bode (2004).

3.5 Unobserved tastes create heteroscedasticity.

As previously mentioned in Bartik's critics[24], because the choice for the studied commodities quality and other commodities is correlated with unobserved tastes in the residuals, then an heteroscedasticity issue appears. If residuals from the economic relation do not have constant variance, the model is not biased but the variance increases. Bartik states that any variable that exogenously shifts the budget constraint of the buyer will be an appropriate instrument: the budget constraint shift is correlated with the buyer choice of car attributes and the choice of other products yet uncorrelated with unobserved tastes.

We follow Bartik's approach including the index of industrial production[25] as a proxy of the economic situation of the buyer (we propose a *temporal* budget constraint shifter). Because most of buyers are professionals impacted by a market seasonality, we include a seasonality variable on a quarterly basis. Finally, in order to manage unobserved characteristics (i.e. brand name perception and reputation...), we also insert a manufacturer effect [26].

4 We use the Hedonic model to estimate the distribution of resale price.

We apply the straightforward regression approach of Otha and Grilitch (1976). Removing the impact of uncertain variables and using the classical OLS properties, resale price distributions are calculated.

[24] See Section 2.

[25] Excluding energy and construction.

[26] We do not work with a model car type level, because our goal is to apply a methodology flexible enough to include new cars and non exhaustive data. Moreover, our model does not include the life cycle of vehicles ('honey moon' effect for new models...) because of the difficulty to collect and to standardize the information. In the list of unobserved characteristics, there is also the remarketing performance. The value could be impacted by the remarketing team in charge of the resale process. Finally, we do not include macroeconomic impacts (which need a proper analysis). Therefore unobserved effects mentioned above constitute the random variable of the statistical model.

4.1 Ohta and Griliches have an empirical approach.

Regarding theoretical issues (including the one discussed in Sections 2 and 3), Ohta and Griliches state that Hedonic model usage 'has an air of "measurement without theory", but one should remember the limited aspirations of the Hedonic approach and not confuse it with attempts to provide a complete structural explanation of the events in a particular market'[27]. They exposed a strong empirical criterion for hypothesis testing[28]. They included a make effect as a proxy of unmeasured characteristics. A real effect linked to unmeasured physical characteristics and a putative one (linked to prestige, service availability...) constitute the make effect.

In their model, the price of model k of make i and age s at time t is $P_{kits} = fct(M_i, P_t, D_s, e^{\sum a_{ij} x_{kivj}})$ with M_i the effect of the i^{th} make, P_t the pure Hedonic price index at time t, D_s the effect of age s (depreciation). a_{ij} are parameters reflecting the imputed price of physical characteristic j at time t. x_{kivj} is the level of the physical characteristic j embodied in model k of make i and vintage v ($v = t - s$).

They applied their models on new and used cars and tested different hypotheses[29] (i.e geometric depreciation held separately from makers). Otha and Grilitch approach is now a standard. As a consequence, Yerger (1995) used this method to discuss an article written by Hoffer and Pratt (1990) which was inspired by Akerman approach[30].

Following these authors, our approach is mainly empirical. We select the model structure that best fits to reality and choose exogenous variables with a statistical and economic significance.

[27] Ohta and Griliches (1976) p326.

[28] "The rejection or acceptance of an hypothesis should depend on the researcher's interests and his loss function"(p 339). Grilitch and Otha put in perspective the statistical and economic significance. Instead of following a formal Fisher test, they use the difference in the standard errors of the unconstrained and constrained regressions as a relevant measure of the price-explanatory power of a particular model. They do not reject null hypothesis if differences between the standard errors of the unconstrained and constrained regressions are less than or equal to 0.01.

[29] Their results on the US market are worth to mention: no gains to move to performance variables (so we can only use the vehicle characteristics); geometric depreciation is an adequate approximation but it is not constant accross time and manufacturers; New and used car market can be analysed jointly. Unfortunately, because of the rise of fuel cost (1973) they aknowledged that their analysis was already obsolete.

[30] See Appendix A6.

4.2 Statistical models are slightly different by country.

Our analysis includes four countries (France, Germany, Spain, Great Britain) and we define a model for each of them[31]. The real resale price is explained by a first group of variables indicating the level of usage: age and mileage are in logarithm due to the well known non linearity property of car depreciation. An indicator of usage intensity, the mileage per month, is also included and significant. The second group of variables is related to the list price. A cubicle variable of list price is added (high initial price increase devaluation). The make effect is introduced through a dummy variable of manufacturer multiplied by the list price. Variables bringing market information contitute the third group: the diesel pump price, the industrial production index and the quarter sale date. The last group includes pure physical characteristics that are slightly different from a country to another (average fuel consumption, body type, number of seats, engine power, number of cylinders, automatic transmission, number of doors).

4.3 We estimate the distribution of resale price.

We wish to calculate the distribution of y_0 (the resale price) for a regressor vector x_0 (group of variables explaining the resale price). The usual regression formula is $y_0 = a_0 - b_0 x_0$. X and y_0 denote the full data matrices. b_0 is the coefficient vector. We assume[32] that y_0 follows a normal distribution[33] equal to $N(x_0^T b_0 + e, s^2[1 + x_0^T (X^T X)^{-1} x_0])$.

The confidence interval is calculated with

$$x_0^T b_0 \pm t_{/2(n-p-1)} \sqrt{MSE}[1 + x_0^T (X^T X)^{-1} x_0]^{1/2}.$$

[31] See models details in Appendix B.

[32] Data are composed of subgroups by models, age, mileage and physical vehicle characteristics. Normality hypothesis test are possible on subgroups with a significant amount of data. For models with same age and mileage, H0 is not rejected. The test of normality on the two analyzed vehicles (Ford focus and the Audi A4) is not rejected.

[33] See Appendix A7.

4.4 An adjustment removes uncertain variables effects.

All the exogenous variable values are known with certainty[34], except the fuel pump price and the production distribution index. We aim to remove the product interaction effect (Dp) and the temporal budget constraint (Ip) in order to focus on the vehicle valuation. Assuming that the diesel price and the production price follow a normal distribution, we calculate the mean and the variance from 2004 to 2008 and we estimate a risk neutral distribution of the resale price.

The unconditional resale price distribution of $x_0^T b_{e0}$ can be solved as

$$N\left(\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} m(x_0/Dp, Ip) * g(Dp) * j(Ip)\ dDp\ dIp,\ \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} n(x_0/Dp, Ip) * g(Dp) * j(Ip)\ dDp\ dIp\right)$$

Where $m() = x_0^T b_0 + e$ and $n() = s^2[1 + x_0^T (X^T X)^{-1} x_0]$. $g()$ and $j()$ are the probability density of the fuel pump price and the production distribution index. The integrals are calculated with numerical integration.

5 We apply the methodology to four European countries.

Models by country, regression results and graphical illustrations, through two vehicle versions, provide an insight of European markets.

5.1 Models are created according to the information usually available in the leasing industry.

In order to quantify the Hedonic price, we apply the model to four European markets (France, Germany, Spain, and Great Britain[35]) using internal sales data from January 1st 2004 to December 31st 2008 of a major leasing company. Statistics are based on random samples of cars sold in various channels (auction, dealers, private sellers, etc). Vehicle age samples range from 1 to 10 years, and have mileage ranging from

[34] We limit our analysis to fixed contract with no purchase option and no rewrite, therefore age, mileage and sale dates are known with certainty.

[35] Great Britain has a sterling pound currency and very limited cross bordering sales with others european countries because of the right hand side weel of the car. Therefore, GB statistics add an original perspective of european markets analysis.

1,000 to 400,000 km. As expected for leasing companies resale statistics, a concentration of vehicles with high mileage and short age spans (concentration on 24, 36 and 48 months of age with a mileage between 80000 km and 120000 km) constitutes a large part of our sample. All monetary values (sales prices, diesel prices) are adjusted according to the inflation. We aim to create a tool allowing a leasing company to catch all the available Hedonic information of the car activity from it's historical sales. According to the company position in markets, the amount of data is significantly different by country but sufficient for calculation (Fr: 112,875 units, Ger: 7,398 units, Sp: 14,674 units; Gb: 33,506 units). Contrary to some referenced studies applying the Hedonic model to the car market, we do not limit our analysis to a segment or version of cars. As a consequence, the explained variance (R^2) is slightly lower (and even more to applied studies on the much more stable new car market). To estimate the manufacturer effect, statistics include several manufacturer names (Fr: 9, Ger: 4, Sp: 6, Gb: 8) by country.

5.2 The regression provides a Hedonic price assessment of the European markets.

All variables have a significant economic value[36]. The explained variances of the OLS regressions are between 0.75 and 0.8. Characteristics adding quality to the car (engine power, number of seats, etc) as well as the industrial production index (as a proxy of budget variation) have a positive sign. According to the Hedonic theory, the price of fuel is an additional cost of the driving activity and has therefore a negative effect. The variables of age, mileage and usage intensity (mileage per month) reduce the resale price, there are parameters correlated to obsolescence and wear. A slight seasonal effect exists in all markets. The well known and better valuations of German manufactured cars (positive make effect) are verified in all countries.

[36] See models results in Appendix C. An indicator of automatic transmission was tested and statistically significant for France. Because the coefficient sign was negative, we removed it.

5.3 The analysis on Ford focus and Audi A4 give additional informations.

France, Germany and Spain share the same currency (Euro) and results estimate the resale price distribution of a vehicle, according to the amount of information available from historical sales. The samples of the four countries have two manufacturers in common: Audi and Ford. We choose the characteristics of the Ford Focus (C-max 1800 TDCI 115 Ghia 5P) and Audi A4 (1.9 Tdi 130 Pack 4P) as a basis to compare the four markets. The information provided by the model could be summarized by two elements. On one hand, a higher valuation of car at the end of the contract reveals better opportunities for leasing business. On the other hand, a higher volatility implies uncertainty on the resale price, and therefore a higher risk of loss on sale.

Bucket results: A first analysis approach[37] on the bucket of a 36 month age group, and 90000 kilometers emphasizes three points. First, the Audi A4 has a better valuation than the Ford Focus in every country. As mentioned previously, German cars benefit from a *'positive make effect'*; they are objects of prestige and share a reputation of good quality cars. Secondly, the high level of standard deviation in all markets reveals a huge volatility. Acknowledging that the second hand market is not as liquid as a financial market, it illustrates that a car, as an asset in a balance sheet of a company, constitutes a significant risk. Thirdly, in Germany, cars get a better valuation. A high resale price constitutes a good element for a leasing business; however the German market also has a higher standard deviation, and therefore a higher risk of loss on sales.

Graphical results: The graphics of distribution through age and mileage give an additional perspective of the depreciation[38]. The variance is not economically different when we modify age and mileage parameters (whatever the currency, the age and the mileage, the standard deviation does not exceed two Euros). Age and Mileage do not increase the volatility. Regarding average depreciation, German vehicles are highly correlated

[37] See Appendix D.
[38] See Appendix E.

with mileage, but Spanish cars are not. Surprisingly, the graphical analysis of age impact on vehicles, reveals that British cars are heavily impacted by the level of usage (kilometer per month variable coefficient) and as a consequence, 12 month age vehicles have a resale price equivalent to 24 age month vehicles. The last two points indicate that Hedonic valuations are significantly different by country. European markets are not homogeneous, and residual value distributions are always singular. On a business perspective, leasing contracts would be impacted by country specificities.

6 Conclusion and extensions

The Hedonic theory has been widely used for the automotive market analysis. We discuss and propose an application to second-hand vehicles in the leasing industry, where the residual value is a critical parameter (residual value risk). The model is based on attributes in order to estimate the resale price distribution. A product interaction effect (fuel price), and a temporal budget shifter (industrial production index) are also included. The methodology applied to four European countries provides a perspective of the automotive resale markets. Focusing on the pattern of depreciation of two vehicles (Ford Focus and Audi A4), the approach illustrates the different levels of probability of losses according to the resale information available by a leasing company. The approach also allows the comparison of market opportunities, through pricing analysis and risk. Our study can be extended in several ways. The leasing industry includes all types of equipment and the application of the Hedonic valuation would be flexible enough to be extended to assets other than automotive. Moreover, our analysis could also be extended to contracts with a purchase option or a rewrite option on age and mileage (i.e. customers can choose to extend or interrupt their contract(s)). Two other elements in the area of residual value risk should be included to complete the analysis: the vehicle life cycle impact and the macroeconomic impact (the general market depreciation). The macroeconomic element would need a more thorough study.

APPENDIX

APPENDIX A: Methodological aspects.

A 1: In Rosen Hedonic framework, we can define the marginal price on a characteristic level. For any vector of observed characteristics Z (of the car), the Hedonic marginal price for a characteristic z (i.e. fuel consumption) is an estimate of both the marginal bid for z of the household purchasing Z and the marginal offer for z of the firm producing z. Linear version of these marginal bid and marginal offer function are defined through two equations: Estimated Hedonic marginal price of characteristics $\frac{\delta p}{\delta z_j}(Z_i) = W_{ij}$ consumer marginal bid for $z_j = B_0 + B_1 Z_i$(vector of observed characteristics of the product) $+B_2 Xt$ (consumer expenditure on commodities others than Z) $+B_2 D_{0i}$(vector of observed demander traits affecting the marginal bid) $+e_{ij}$. $\frac{\delta p}{\delta z_j}(Z_i) = G_{ij}$ firm marginal offer price for $z_j = Ao + A_1 Z_t + A_2 S_{0i}$(vector of observed supplier traits affecting the marginal offer) $+u_{ij}.u_{ij}$ and e_{ij} are disturbance terms.

A 2: Berndt defines general framework on durables commodities in term of service price. He demonstrates that in the case of the input price-dependant quality adjustment ("variable repackaging hypothesis") the Hedonic price equation can be expressed in term of service price as:

$\ln u_{n,t,\phi} = lnp^*_{n,t} + \ln h'_n(z_{n1}, z_{n2}, ..., Z_{nk}, p_{n-1}) + lnD_{n,\phi}$.

With $u_{n,t,\phi}$ the resulting asset price, $lnp^*_{n,t}$is the quality adjusted "base" price index of the n^{th} capital good at time t, $D_{n,\phi}$ is a depreciation index varying only with the age of the asset. h_n is the quality aggregation function that link the quality b_n to the physical characteristics z_n.

$b'_n = h_n\prime(z_{n1}, z_{n2}, ..., z_{nk}) \sum_{s=0}^{T_n} (\frac{1}{1+r})^s d_{n,s}$. $d_{n,s}$ is the deterioration of the service over time. The intercept is the quality adjusted service price.

A 3: Akerman model estimates used car value.The price of an Automobile of a given age, K, can be expressed as the discounted present value of its remaining services: $P(K) = \int_K^D S(X)e^{-r(X-K)}dX$ with K present age of car, D age of scrappage, X age, r discount rate(assumed constant), $S(X)$ value of services provided by a car of age X, $P(K)$ price of a car of age K.

An Hedonic price, repair cost, service function and expected gain on resale estimation are components of the model. Akerman use a single equation and a regression to estimate the Hedonic price:

$logA(v,m) = C + E(v,m) + C(v,M) + W(v,M) + L(v,M) + H(v,M)$. with $A(v,m)$=new car list price including federal tax and handling and transportation charges.

$E(v,m)$=1 if car has height cylinders. $C(v,M)$=1 if compact. $W(v,M)$, $L(v,M)$ and $H(v,M)$ are weight, length and horse power. v is model year and m is the model.

A 4: Hartman Equation inspired by Grilitch and Otha equation:

$LogPkit = Bo + B_1MK_i + B_2MD_k + \Sigma B_3AGE_s + \Sigma B_4jA_{kij} + \Sigma B_{5j}R_{jk}$

$Pkit$ is the resale price in period t for a car of make i and model k.

$M_{Ki}$and $MD_k$are dummy variables indication Make and model. Age is the age of the car in t. A_{kij} is the level of attribute j embodied in model k and make i. R_{jk} summarize the car recalls history indicating cumulative recalls of type j for model k.

A 5: Berndt defines a general framework on commodities.

$X(= x_1, x_2, ...x_n)$ a vector of commodity, $B(= b_1, b_2, ..., b_n)$a vector of qualities for each commodity, $Z(= z_1, z_2, ..., z_i, z_n)$ a vector of physical characteristics for each commodity and $P(= p_1, p_2, ..., p_n)$ a vector of price for each commodity. Moreover we have an utility function $u = F(x; b)$ and $B_n = H_n(Z)$.

$x_n = f(u, x_1, x_2, ..., x_{n-1}, b_n)$

For a new quality level from b_{n0} to b_{n1} under the assumption of a log-log form;

In the case called the "simple packaging hypothesis" (or input price-independant quality adjustment), b_n is only dependant of z_i, we have a quality function $b_i = h_i(z_i)$;

x_n must be equalized at the margin: $\frac{p_{n0}}{p_{n0}} = \frac{p_{n1}}{p_{n1}} = p_n^*$

where p_n^* is a base price constant reflecting the price of the standardized unit.

Through a log transformation of 1), then $lnp_{n1} = lnp_{n\prime} + lnh_{n1}(z_{n1})$ and an assumption of log-log form of the quality conversion function $lnh_{n1}(z_n) = \sum_{k=1}^{k} b_{nk} \ln z_{n1,k}$:

$lnp_{n1} = lnp_n^* + \sum_{k=1}^{k} b_{nk} \ln z_{n1,k}$ where b_{nk} are the coefficient on the k^{th} characteristics of the n^{th} commodity.

Using this framework we are now able to calculate a price according to the physical characteristics of a commodity.

In the case called the "variable packaging hypothesis" (or input price-dependant quality adjustment), for instance if b_n is dependant of x_{n-1}as well; $b_n = h_n(x_{n-1,} z_n)$:

$lnp_n(b_n) = lnp'_n + lnh_n(p_{n-1}, z_n)$

Using this formula, in an empirical analysis, we could test the simple versus the variable repackaging hypothesis using classical hypothesis testing procedures. (i.e. fuel price on auto price).

A 6: Yerger(1995) applied Grilitch and Otha method to discuss an article written by Hoffer and Pratt which was inspired by Akerman approach.

For a model i and at trend variable, time t (($t = 1, ..., 12$), the price Pit is $LogPit = \beta_0 + \beta_1 * t + \Sigma j\beta_2 jCATj + \Sigma k\beta_3 kAik + \beta_4 TECH + \beta_5 RECOM + \beta_6 AVOID$ with $CATj$ as a variable of the category of vehicle (subcompact, midsize....) and Aik as a vector summarizing the level of attribute k in model i. If the vehicle is not discontinued then $tech = 0$. If the vehicle have been recommended to buy then $RECOM = 1$. If recommend to avoid to buy by 'consumer reports' magazine evaluation then $AVOID = 1$. By his model, Yerger tested and approved the market efficiency in Automotive market.

A 7: Ordinary Least Square allows prediction interval calculation[39].

The Ordinary Least Square Method estimate a and b by minimizing the sum of squared error $SSE = \sum_{i=1}^{n} (y_i - y_{ei})^2 = \sum_{i=1}^{n} (y_i - a - bx_i)^2 = e^2$

An unbiased estimate s^2 of e^2 is given by mean squared error:

$s^2 = \frac{SSE}{n-p} = \frac{1}{n-p} \sum_{i=1}^{n} (y_i - a_e - b_e X_i)^2 = MSE$. a_e and b_e denote the linear least squares estimators for a and b. n is the size of the sample and p the number of parameters.

Distribution and interval calculation:

[39] Green (1992) Econometric analysis. 5 th edition. p 111.

Let $x_0 = (1, x_1, x_2, x_3, ..., x_p)$; $b_0 = (a, b_1, b_2, b_3, ..., b_p)$ and $b_{e0} = (a_e, b_{e1}, b_{e2}, ..., b_{ep})$

$Y \mid (X = x0) = x_0^T b_0 + e_0.e_0$ is the random error corresponding to the new estimation Y and $e_0\tilde{}N(0, \sigma^2)$.

We use $x_0^T b_{e0}$ to estimate $x_0^T b_0 + e_0$.The distribution of $x_0^T b_{e0}$ is $N(x_0^T b_0 + e, s^2[1 + x_0^T (X^T X)^{-1} x_0])$ and the interval is $x_0^T b_{e0} \pm t_{/2(n-p-1)} \sqrt{MSE}[1 + x_0^T (X^T X)^{-1} x_0]^{1/2}$

APPENDIX B: Regression equations and notations

$Resaleprice = fct_1(age, mileage, mileagepermonth) + fct_2(make*listprice, listprice) + fct_3(pump\_price, industrial\_pro$ $fct_4(car\_physical\_attributes)$.

France:

$P = \beta_0 + \beta_1 * logAge + \beta_2 * logDis + \beta_3 * Kpm + \beta_{4j} * MK_j * Lp + \beta_5 * Lp^2 + \beta_6 * Indx\_pdrt + \beta_7 * QTR_l + \beta_8 * Diesl\_p + \beta_9 * AvgFuel1 + \beta_{10} * Seat + \beta_{11k} * Body_k + \beta_{12} * Kwt + \beta_{13} * EngnCap$

Germany:

$P = \beta_0 + \beta_1 * logAge + \beta_2 * logDis + \beta_3 * Kpm + \beta_{4j} * MK_j * Lp + \beta_5 * Lp^2 + \beta_6 * Indx\_pdrt + \beta_7 * QTR_l + \beta_8 * Diesl\_p + \beta_9 * AvgFuel1 + \beta_{10} * Seat + \beta_{11k} * Body_k + \beta_{12} * Kwt + \beta_{14} * FuelCap$

Spain:

$P = \beta_0 + \beta_1 * logAge + \beta_2 * logDis + \beta_3 * Kpm + \beta_{4j} * MK_j * Lp + \beta_5 * Lp^2 + \beta_6 * Indx\_pdrt + \beta_7 * QTR_l + \beta_8 * Diesl\_p + \beta_9 * AvgFuel1 + \beta_{11k} * Body_k + \beta_{12} * Kwt + \beta_{13} * EngnCap + \beta_{15} * Door\_5$

Great Britain:

$P = \beta_0 + \beta_1 * logAge + \beta_2 * logDis + \beta_3 * Kpm + \beta_{4j} * MK_j * Lp + \beta_5 * Lp^2 + \beta 6 * Indx\_pdrt + \beta 7 * QTR_l + \beta_8 * Diesl\_p + \beta_9 * AvgFuel1 + \beta_{11k} * Body_k + \beta_{13} * EngnCap + \beta_{16} * AutoT$

P is the real resale price.

Age is number of month between the registration and the sale date.

Dis is the distance travelled, including any distance done on an odometer that has been changed.

Kpm is the distance travelled per month.

Lp^2 is the cubic of the real least price (including option price).

MK_j are dummy variables indicating make multiplied by Lp. (France: Audi,Bmw, Citroen, Ford, Mercedes, Opel, Peugeot, Renault, Volkswagen. Germany: Audi,Bmw, Ford, Volkswagen.Spain: Audi, Ford, Opel,

Peugeot, Renault.Seat. UK: Audi, Bmw, Ford, Toyota,Vauxhall, Volkswagen.)

$AvgFuel1$ contains average fuel consumption figures as given by the manufacturer (urban and road). It is a company decision as to which statistical figure goes into this attribute.

$Seat$ is the number of seat.

$Body_k$ are dummy variable indicating the body type (France:berline, monospace. Germany: Kompact, Spain:estate, berline UK: estate car, or saloon (sedan))

Kwt is the power of the engine expressed in kilowatt given by the manufacturer.

$Indx\_pdrt$ is the Industrial production by monthly index (adjusted by working days).

QTR_l are dummy variables indicating the quarter.

$Diesl\_p$ is the diesel pump price, euro per liter all taxes included.

$EngnCap$ is the actual number of ccs the engine has.

$AutoT$ is equal to 1 if the vehicle has a form of automatic transmission fitted as standard or not.

$Door\_5$ is equal to 1 if the vehicle has 5 doors.

APPENDIX C: Regression results:

Rsq	0.80

PARMS	Coefficient	T value	P value
Intercept	30,210.805	140.4	0.00
ln_age	-3,827.575	-116.1	0.00
ln_Trmn_Dis_Real	-1,167.041	-42.4	0.00
km_per_mth	-0.372	-40.3	0.00
BMW_LP	0.060	42.3	0.00
AUDI_LP	0.081	71.3	0.00
FORD_LP	-0.087	-62.3	0.00
OPEL_LP	-0.070	-48.6	0.00
VOLKSWAGEN_LP	0.029	22.7	0.00
CITROEN_LP	-0.061	-47.3	0.00
PEUGEOT_LP	-0.029	-25.2	0.00
RENAULT_LP	-0.086	-74.4	0.00
real_LP2	0.000	87.6	0.00
r_Opt_P	-0.087	-50.9	0.00
r_Mth_Diesl_p	-2,040.973	-54.9	0.00
r_INDX_PDRT	709.354	17.2	0.00
QTR2	237.893	22.7	0.00
QTR3	257.117	23.6	0.00
QTR4	-103.308	-10.1	0.00
Avg_Fuel_Cnsm_1_Qty_Nbr	583.584	71.2	0.00
Seat_Cnt_Nbr	136.613	16.9	0.00
Body_type_berline	-1,430.070	-29.0	0.00
Body_type_monospace	-848.441	-17.4	0.00
Engn_Capc_Nbr	18.170	7.3	0.00
Kwat_Engn_Powr	56.589	130.9	0.00

France Results

Rsq	0.75

PARMS	Coefficient	T value	P value
Intercept	45,651.749	44.2	0.00
ln_Trmn_Dis_Real	-3,499.790	-45.1	0.00
ln_age	-2,577.455	-26.5	0.00
km_per_mth	0.269	29.4	0.00
BMW_LP	0.253	24.5	0.00
AUDI_LP	0.247	23.8	0.00
FORD_LP	0.190	17.5	0.00
VOLKSWAGE_LP	0.229	21.4	0.00
real_LP2	0.000	-8.3	0.00
r_Opt_P	-0.192	-17.8	0.00
r_INDX_PDRT	2,470.162	8.2	0.00
r_Mth_Diesl_p	-2,416.270	-11.0	0.00
QTR2	204.372	3.5	0.00
QTR3	143.076	2.6	0.01
QTR4	102.426	1.8	0.07
Avg_Fuel_Cnsm_1_Qty_Nbr	141.901	3.2	0.00
Seat_Cnt_Nbr	420.358	3.9	0.00
Body_Styl_Shrt_Nam_KOM	-891.736	-17.5	0.00
Kwat_Engn_Powr	29.747	14.1	0.00
Fuel_Capc_Nbr	45.108	16.0	0.00

Germany Results

Rsq	0.78

PARMS	Coefficient	T value	P value
Intercept	27,361.764	78.6	0.00
ln_Trmn_Dis_Real	-984.326	-35.9	0.00
ln_age	-3,547.212	-68.7	0.00
AUDI_LP	0.141	53.8	0.00
FORD_LP	-0.019	-8.4	0.00
PEUGEOT_LP	0.026	13.1	0.00
RENAULT_LP	-0.015	-7.0	0.00
real_LP2	0.000	6.8	0.00
r_Opt_P	-0.007	-5.2	0.00
r_INDX_PDRT	1,200.019	10.1	0.00
r_Mth_Diesl_p	-4,515.196	-31.6	0.00
QTR2	278.026	9.4	0.00
QTR3	351.842	11.5	0.00
Avg_Fuel_Cnsm_1_Qty_Nbr	-68.670	-18.5	0.00
Body_Styl_Shrt_Nam_EST	-2,021.356	-24.2	0.00
Body_Styl_Shrt_Nam_BER	-1,768.817	-22.0	0.00
Kwat_Engn_Powr	47.427	50.3	0.00
Engn_Capc_Nbr	146.417	17.3	0.00

Spain Results

Rsq	0.79

PARMS	Coefficient	T value	P value
Intercept	21,428.345	50.3	0.00
ln_Trmn_Dis_Real	-467.923	-8.9	0.00
ln_age	-4,053.082	-68.5	0.00
km_per_mth	-0.711	-21.1	0.00
MERCEDES_LP	0.311	87.3	0.00
PEUGEOT_LP	0.229	50.5	0.00
TOYOTA_LP	0.234	55.7	0.00
BMW_LP	0.311	88.5	0.00
AUDI_LP	0.316	88.7	0.00
FORD_LP	0.191	49.5	0.00
VAUXHALL_LP	0.215	51.1	0.00
VOLKSWAGE_LP	0.298	76.2	0.00
real_LP2	0.000	-21.6	0.00
r_Opt_P	-0.259	-64.6	0.00
r_INDX_PDRT	3,322.905	18.9	0.00
r_Mth_Diesl_p	-4,497.430	-48.9	0.00
QTR2	141.925	5.6	0.00
QTR3	-121.267	-5.0	0.00
QTR4	-676.227	-28.5	0.00
Avg_Fuel_Cnsm_1_Qty_Nbr	-5.188	-4.2	0.00
Body_Styl_Shrt_Nam_EST	-134.428	-6.7	0.00
Body_Styl_Shrt_Nam_SAL	-355.102	-15.4	0.00
Engn_Capc_Nbr	150.819	27.6	0.00
Auto_Trnss_Ind	346.587	10.6	0.00

Great Britain Results

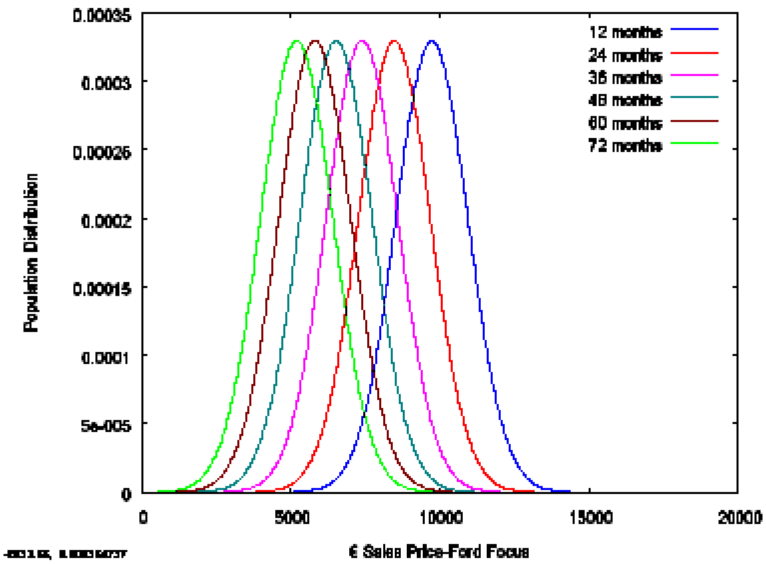
APPENDIX D: Pivot Point results:

	Ford Focus		Audi A4	
	Average Local Currency	Standard Deviation	Average Local Currency	Standard Deviation
France	7390	1210	11084	1210
UK	4793	1420	10310	1420
Germany	8369	1672	12924	1675
Spain	7282	1315	7751	1316

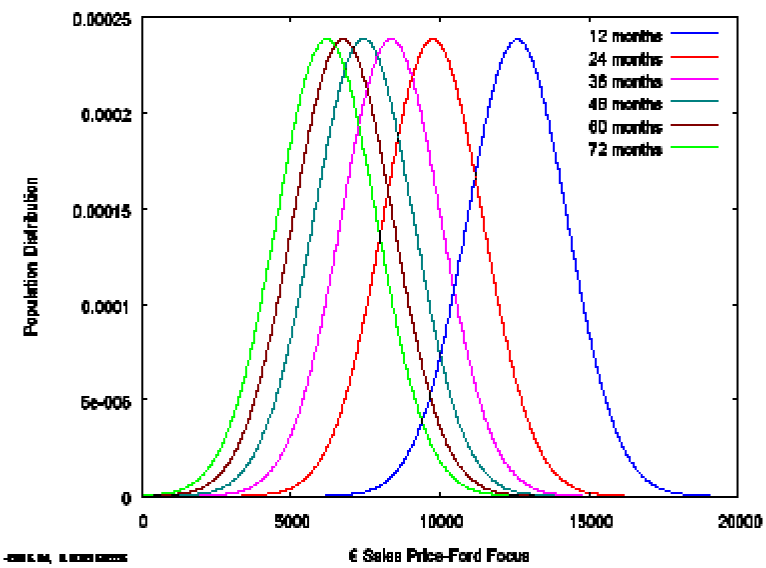
Bucket 30 months and 90,000 kilometers

APPENDIX E: Graphical Analysis:

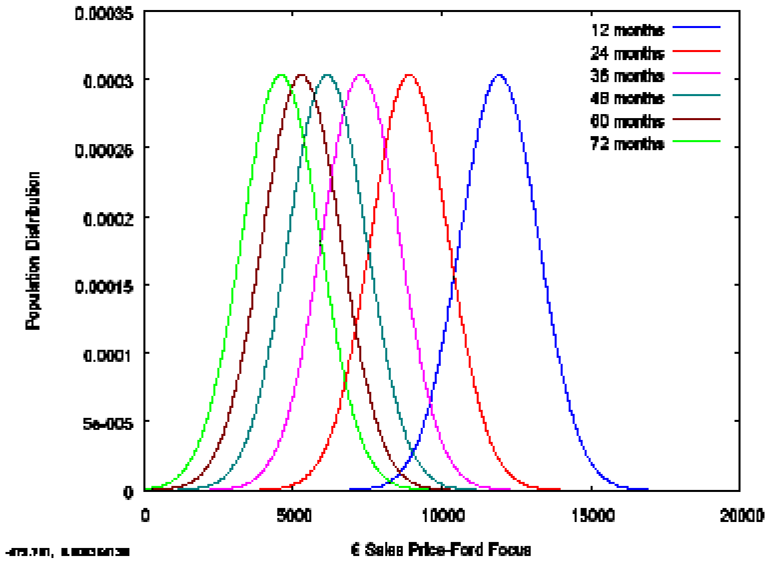
Ford Focus age impact:



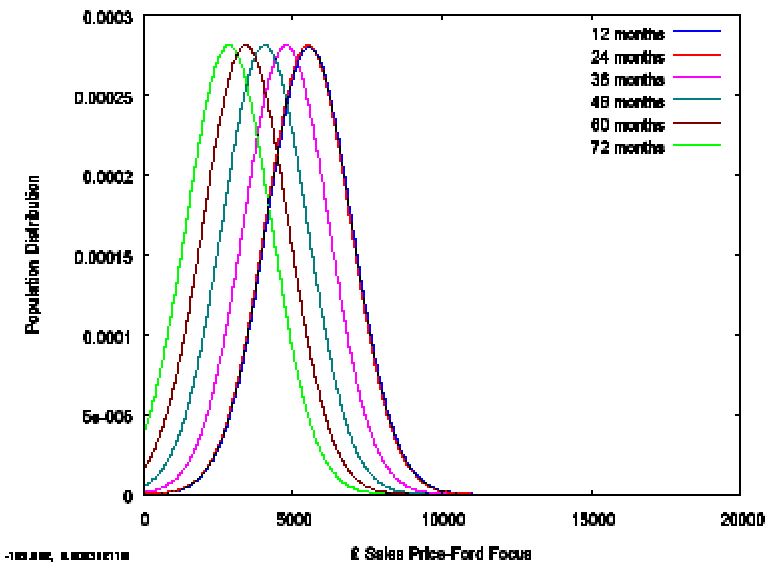
France



Germany

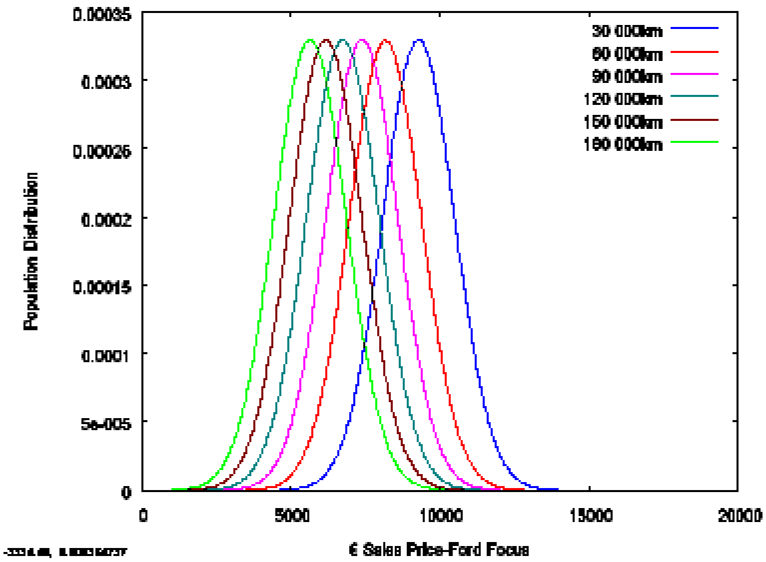


Spain

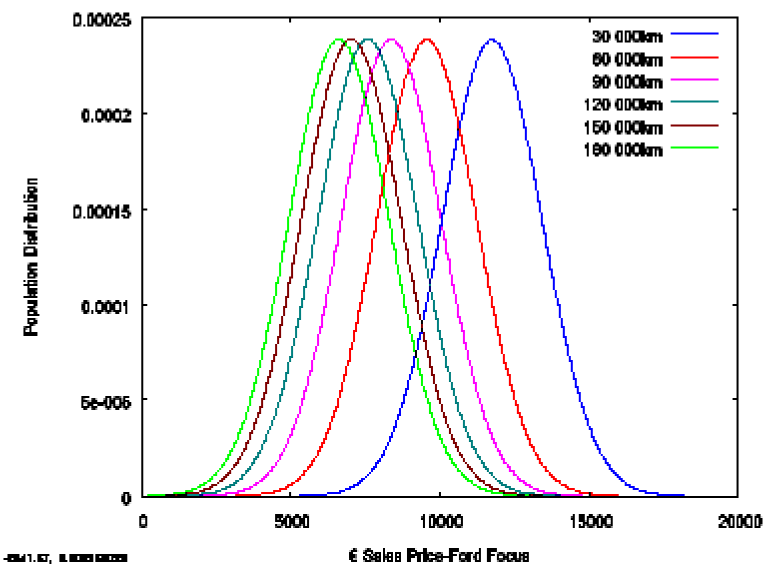


Great Britain

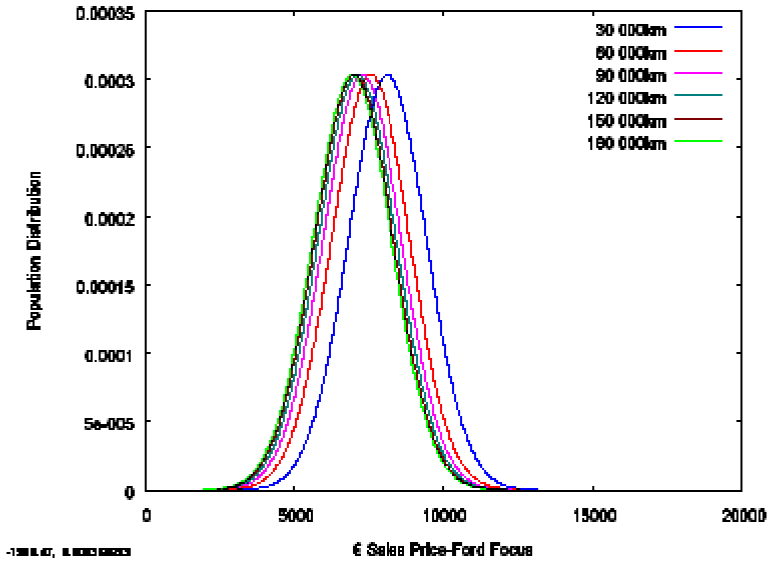
Ford Focus mileage impact:



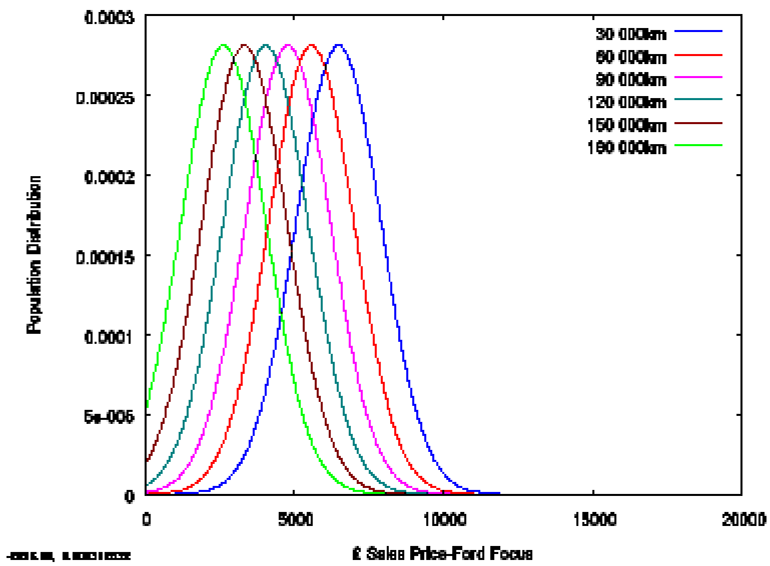
France



Germany

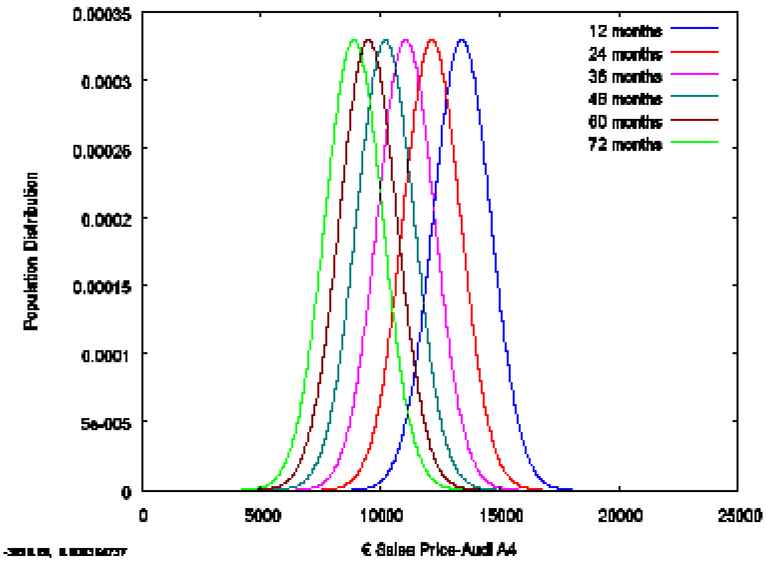


Spain

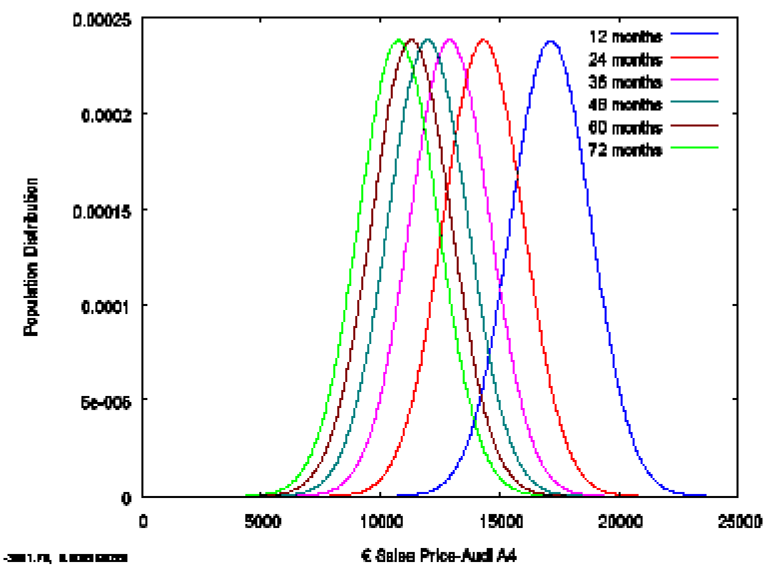


Great Britain

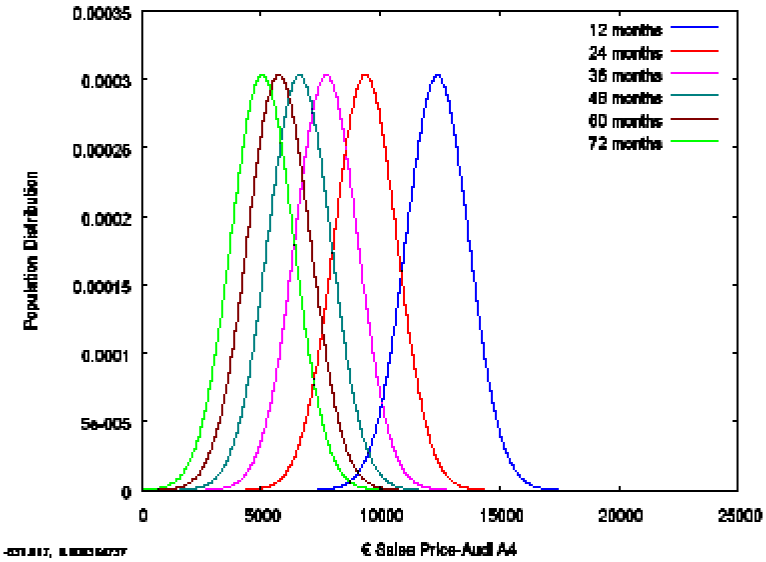
Audi A4 age impact:



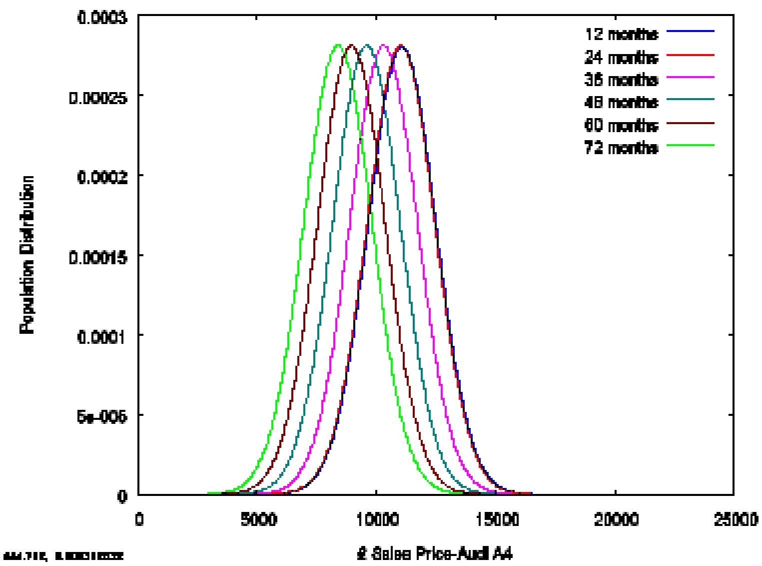
France



Germany

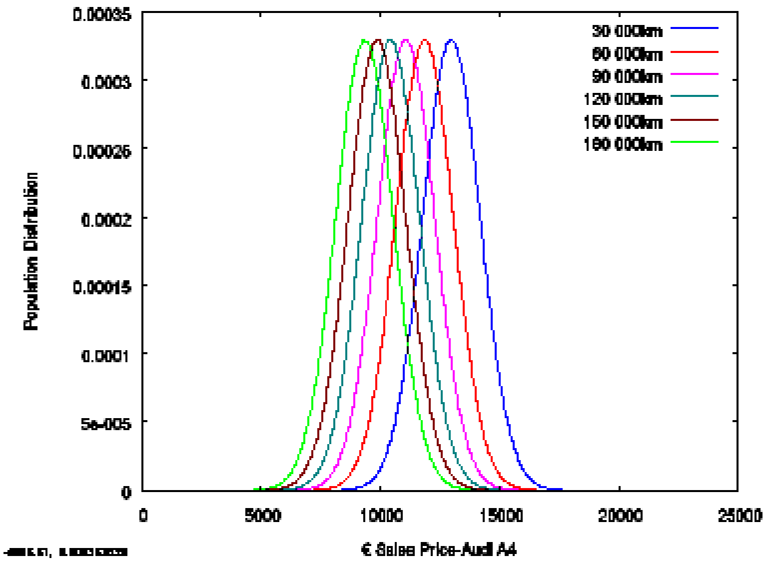


Spain

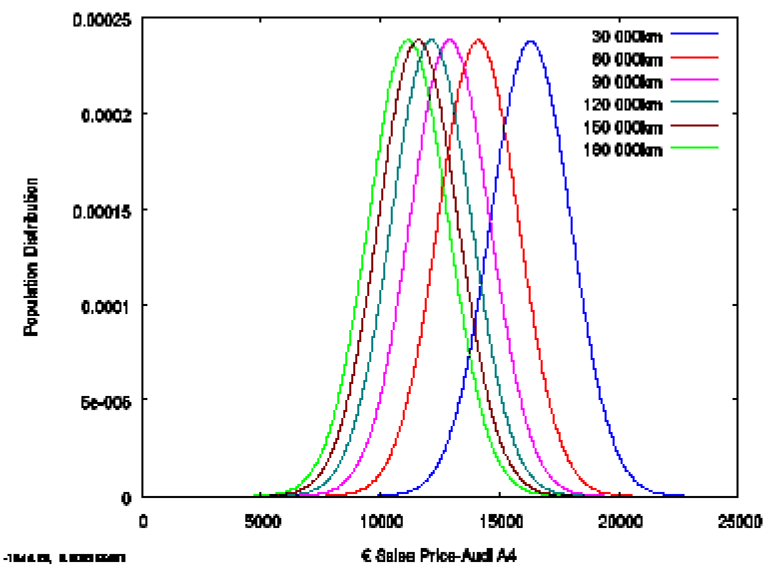


Great Britain

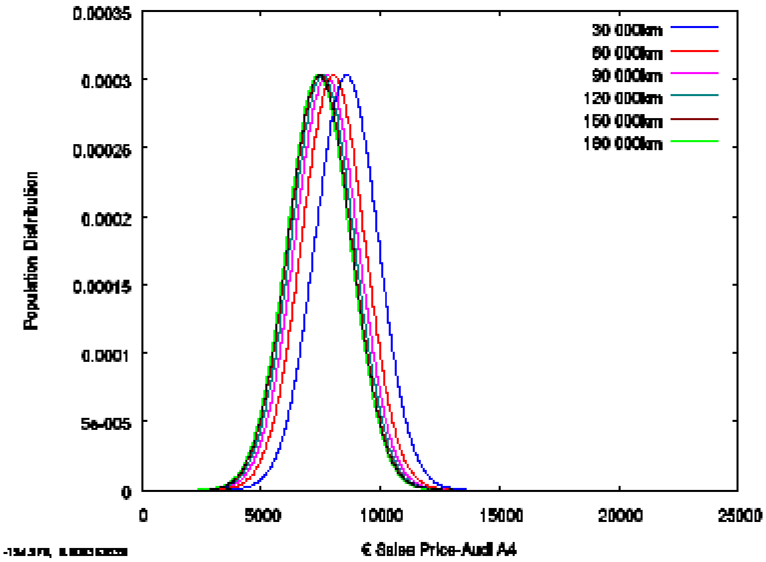
Audi A4 mileage impact:



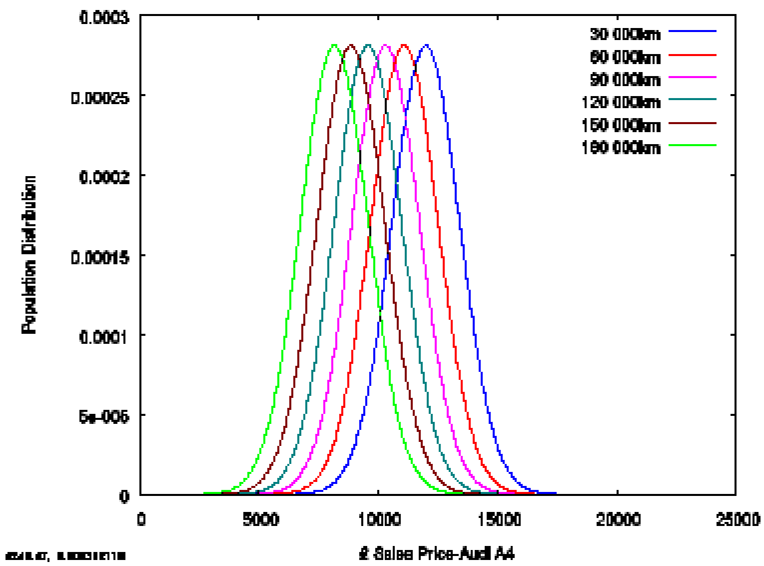
France



Germany



Spain



Great Britain

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