Universität Hohenheim

Institut für Financial Management

Lehrstuhl für Bankwirtschaft und Finanzdienstleistungen

Prof. Dr. Hans-Peter Burghof

An Empirical Analysis of Residual Value Risk in Automotive Lease Contracts

Dissertation

zur Erlangung des akademischen Grades

Doktor der Wirtschaftswissenschaften (Dr. oec.)

an der Fakultät für Wirtschafts- und Sozialwissenschaften

vorgelegt von:

Katharina Nau

Dekan:	Professor Dr. Dirk Hachmeister
Eingereicht am:	04.11.2011
1. Berichterstatter:	Professor Dr. Hans-Peter Burghof
2. Berichterstatter:	Professor Dr. Markus Voeth
Tag der mündlichen Prüfung:	14.05.2012
1. Prüfer:	Professor Dr. Hans-Peter Burghof
2. Prüfer:	Professor Dr. Gerhard Wagenhals
3. Prüfer:	Professor Dr. Jörg Schiller

Die vorliegende Arbeit wurde am 16.04.2012 von der Fakultät Wirtschafts- und Sozialwissenschaften der Universität Hohenheim als "Dissertation zur Erlangung des akademischen Grades Doktor der Wirtschaftswissenschaften" angenommen.

Contents

List of Tables

List of Figures

List of Variables

α	Regression coefficient denoting the intercept
AIC	Akaike information criterion
A_i	Market value of the leased asset at time i
$\bar{A}_i$	Boundary price of the leased asset at time i above which the lessee will choose to make the lease payment
$\ddot{A}_0$	Present value of $A_0/100$ compounded at maturity of the contract
β_i	Regression coefficient for the ith independent variable
B	Backwardshift operator
$chifo$	Rate of change in percentage of the ifo business climate index per month
$chur$	Change in percentage of the unemployment rate per month
$chzew$	Rate of change in percentage of the ZEW index per month
com	Absolute number of cars changing their ownership per month
$\mathrm{corr}(\cdot, \cdot)$	Correlation
$\mathrm{cov}(\cdot, \cdot)$	Covariance
$euribor3$	Rate of the EURIBOR three-month fund per month
d_i	Dummy variable for the ith successor of a car model since June 1992 indicating its model cycle

di	Disposable income per quarter
$dita$	Trend-adjusted disposable income per quarter
$d\,\cdot$	Denoting the first difference of the following variable
D_i	Aggregated demand function for a car of age i
ϵ_t	White noise error series at time t
$\mathbb{E}(\,\cdot\,)$	Expectation
$\mathbb{E}(\,\cdot\,\vert\,\cdot\,)$	Conditional expectation
$facelift$	Dummy variable indicating a rework of the car model
$frcm$	Absolute number of first registered cars per month
$f(u)$	Frequency function of consumer's tastes u
$F(W,w)$	Frequency function of consumer's income w which is uniquely determined by the national income W
gdp	Price-adjusted gross domestic product per quarter
$gdppq$	Quarterly rate of change of the gross domestic product related to the previous quarter
$gdppyq$	Quarterly rate of change of the gross domestic product related to the previous year quarter
$gdpta$	Trend-adjusted price-adjusted gross domestic product per quarter
$G_i(\cdot)$	Function determining the boundary for purchasing a car of age i
κ	Economic influence factor
$lnpp$	Logarithm of the petrol price for normal benzine per month
$lnppta$	Trend-adjusted logarithm of the petrol price for normal benzine per month

L	Equilibrium lease rate for an operating lease
L^{FL}	Equilibrium lease rate for a financial lease
$\bar{L}^{FL}$	Contractual fixed lease rate of a financial lease contract
mc	Dummy variable indicating a model change
md_i	Dummy variable for month i
$modern$	Modernity factor of a car model indicating the number of months the car is already available in the used car market for three-year old cars
$\tilde{n}$	Random variable for useful life
NAL	Net advantage to leasing
N_t	Residual of the structural equation of the ARMAX regression at time t
$N_i(\cdot)$	i-dimensional multivariate normal distribution function
$\mathbb{N}$	Set of natural numbers
ϕ_i	Coefficient of the ith autoregressive term
Φ_i	Coefficient of the ith seasonal autoregressive term
pcs	Price-adjusted private consumer spending per quarter
$pcsta$	Trend-adjusted price-adjusted private consumer spending per quarter
P_i	Actual price of a car at age i
$P(t, s)$	Price of a leased asset at time t and for age s
r_f	Risk-free interest rate
σ^2	Variance of the logarithm of the rate of change of the leased asset
σ_ϵ^2	Variance of the white noise error term
σ_{yl}	Covariance between $\ln(\tilde{A}_i/A_{i-1})$ ($\tilde{}$ denotes a random variable) and the market factor y

σ_i	Standard deviation of the independent variable i
$\hat{\sigma}$	Estimated standard deviation of the white noise error disturbance of the ARMAX regression
S	Residual value of a leased asset
S_0^n	Present value of the leased asset's residual value at maturity date of the contract
τ	Technological influence factor
θ_i	Coefficient of the ith moving average term
Θ_i	Coefficient of the ith seasonal moving average term
t	Time index indicating time in months
u	Consumer's tastes
w	Consumer's income
W	National income
V	Value of the leased asset in percentage to the basis of its new price
$value$	Monthly residual value of a car in percentage of its original manufacturer's suggested retail price when first registered
$\text{var}(\cdot)$	Variance
x^i	ith independent variable of the ARMAX regression
X	Price of the leased asset
z	Logarithm of the value of a three year old leased car divided by its original manufacturer's suggested retail price

Chapter 1

Introduction

Its increasing popularity has made leasing an important financial product that has even replaced the classical bank credit in some sectors. Over the last decades, a variety of assets could be leased resulting in a huge range of leasing products offered by various leasing providers such as the (classical) specialised lease institutions as well as an increasing number of banks. This development, however, calls for the necessity to establish a risk management for institutions offering leasing products. In Germany, the conferment of the trade tax privilege of banks (Bankenprivileg) to lease institutions further enforced this issue by having lease firms meet the regulatory requirements of Basel II albeit in a weaker form (e.g. they have to run stress tests) and having them monitored by the German institution for banking supervision BaFin (Bundesanstalt für Finanzdienstleistungsaufsicht).

The work at hand concentrates on the risk structure of lease contracts and therefore aims to give insights and support to the risk management of lease firms. The focus lies on a special and highly important type of risk in such contracts named RESIDUAL VALUE RISK. This risk is classified as market risk in terms of the definition of the Basel Committee on Banking Supervision and describes the risk arising from deviations of the actual residual value at maturity stage of the contract from the estimated one fixed in the contract at its completion. The residual value consequently denotes the market price of the leased asset at maturity of the contract and is of high importance in the valuation of lease contracts. Since the lessor is compensated for two terms including the lost interest payments and the depreciation of the asset, the main purpose of the residual value is to determine the depreciation. Thus, this value is of great relevance to various parties. On the one hand, from a funder's view such as banks or lease institutions it determines their financing costs. On the other hand, it determines marketing costs as an increasing number of manufacturers offer lease contracts in order to place their products in the market or to gain market share. While the scientific literature provides a fair analysis of the interest rate risk and exhibits good hedging opportunities, it deals only insufficiently with residual value risk. Hence, the development of proper instruments to identify, estimate and to manage this risk is essential.

My analysis is focused on automobile leases. In Germany, vehicles are the largest group of equipment leasing which compared to real estate leasing covers the major share of the leasing market. Hence, an analysis based on automotive leases examines the most important segment of the German leasing market.

The main objective of this work is the analysis of the following two research questions:

1. What determines residual values?
2. How can residual values be predicted?

To manage residual value risk a minimum level of predictability is necessary and a seemingly complete random pattern of residual values is not desirable. That is why the identification of determinants of residual values is extremely important. The possibility to link fluctuations in residual values to changes in explanatory variables allows one to trace the pattern of residual values based on the pattern of the identified risk factors. This is the idea behind the first research question which attempts to determine a relationship between particular explanatory variables and residual values of cars.

The little existing scientific literature on this topic mainly applies the *hedonic* approach to identify such determinants. Hereby the focus is on features of cars and their valuation over time. Consumers, however, rate features very inconsistently over time as many of them are subject to consumers' tastes and change over time (e.g. colour of a car). Hence, factors used in this analysis are hard to measure and observe. This consideration led me to divert from using variables linked to the equipment of a car to applying market factors which are observable, measurable, available and less influenced by consumers' preferences. The work at hand thus attempts to model the market environment of cars and to link fluctuations in residual values to changes in the underlying market situation.

I also refrain from the existing literature in the applied approach for identifying the determinants. Previous studies only examine a specific car during its ageing period meaning from its technical completion up to a certain age. Residual value risk, however, becomes apparent at maturity of the lease contract and leases have generally a fixed maturity. The examination of residual value risk requires therefore the analysis of the fluctuations of residual values over time. Lessors are interested in how their leasing portfolio evolves over time and in different economic situations, its development throughout the duration of the lease contract is of minor importance. Thus, I fix the age of the analysed car models but trace their development over time, which allows me to identify the persistence of the influence of the used factors during different time periods. In this way, the relationship between the car models and the market environment can be identified.

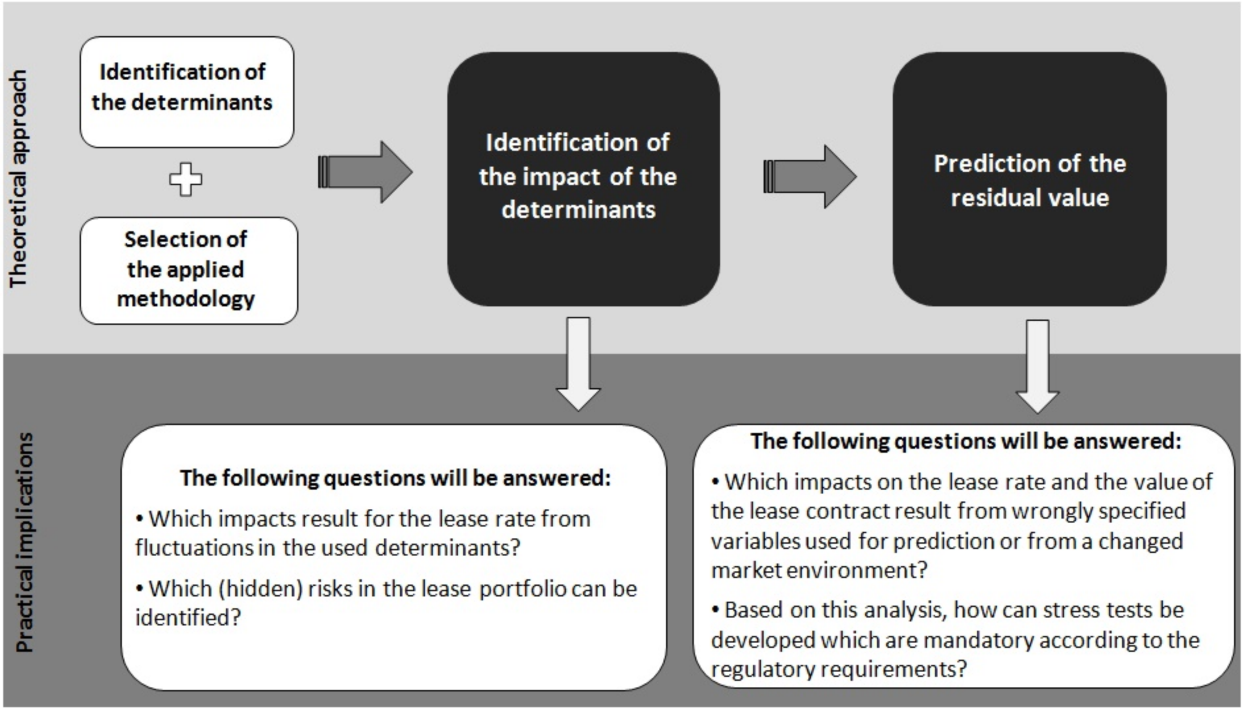
The second research question deals with the major challenge in the use of residual values. They are not known in advance but needed at the completion of the lease contract, which is why residual values have to be predicted. The literature provides only very few studies dealing with this issue. Moreover, the majority of them do not provide an empirical validation of their theoretical considerations. The work at hand extends the literature available by developing a theoretical model to forecast residual values and validating the model by using an actual dataset.

Besides the theoretical analysis of the two research questions, I also aim to draw conclusions for the risk management of leasing contracts. My work is therefore structured into two parts: the theoretical approach and the practical implications derived from these examinations. Roughly, I will proceed as follows in order to answer the research questions: First, I start by identifying the market factors providing a picture of the market environment of cars as accurate as possible and by selecting the appropriate methodology to approach the issues. I am then able to determine the impact of the chosen market factors on the residual values. With this analysis at hand, I am able to answer questions which may arise in managing residual value risk. Thus, I will then analyse how and to which extent fluctuations in the used market factors affect lease rates. Additionally, I discuss which risks – that may be hidden – can be identified in the lease portfolio of lessors.

Then, I turn to the analysis of the second research question, the prediction of residual values. By using the identified market factors, I develop a forecast model for residual values and test its performance for an actual dataset. The implications derived for risk management are also an important part in this examination. In order to predict residual values, figures are needed for the used market factors in the applied forecast model. These factors, however, are also not known in advance and bear the risk to be either misspecified or to be transformed into something different than expected due to unpredictable events or an unexpected future market environment. The main implication that arises for risk management is the impact of such a wrongly specified variable on the lease rate or the value of a lease contract. In addition to that, I will explain how stress tests may be created based on these forecast models keeping in mind the current regulatory situation of lease institutions. A schematic representation of the work's course of action can be found in figure 1.1.

My dissertation contributes to the existing literature in various ways. In the first instance, I apply a new approach, which in this way has not been used in the literature yet. As mentioned in the previous paragraphs, it neglects the effects of a car's ageing but analyses the development of the residual value over time. Hereby, market factors creating the market

Figure 1.1: Course of action



environment of cars represent the variables used to explain residual values. With this selection of variables the work at hand differs from the wide majority of former studies which essentially rely on variables describing the equipment of cars to explain price fluctuations.

The implementation of this approach uses a dataset of automobile prices which have been hand collected. The sample covers 17 automobiles and their monthly used car prices of three year old cars in Germany for the observation period from June 1992 to December 2008. The data has been provided by the DAT (Deutsche Automobil Treuhand GmbH), the oldest provider of automobile data in Germany. My dissertation uses a unique dataset with figures that had to be hand collected, as they have not existed in their present form. Besides its unique dataset, the length of the observation period and the analysis based on German data extend previous studies regarding the dataset of the empirical analysis. Since Germany is the largest leasing market in Europe, my dissertation examines the most important market in Europe and, therefore, also contributes to the existing literature regarding its validity.

The methodological approach is also new. I apply an ARMAX regression model for my analysis that previous studies did not consider. The application of this methodology is suitable since the error term of the usual time series regression inheres serial correlation. This, however, contradicts the necessary assumptions regarding a time series regression. To overcome this issue, the ARMAX regression approach allows to model the type of serial correlation directly via ARMA (**a**uto**r**egressive **m**oving **a**verage) models. Hereby, the dependencies between the errors of the regression model are identified and modelled as a linear function of lagged observations of the error term and of the lagged residuals. Thus, an ARMAX regression is basically a usual time series regression whereas the time series of the error term is modelled in terms of an ARMA model.

At last, the work at hand combines two areas of research. For the first time, the identification of influencing factors and the development of a forecast model are used to examine explicitly the impact of changing market conditions on the lease rate by using a theoretical valuation model. By doing this, it is possible to quantify the impact of altering market factors on the lease rate and the value of the lease contract by applying the results of the empirical analysis.

My work is structured into three main parts. I first start with an overview of the current literature in chapter 2. Hereby, I begin by discussing the term leasing and its various designs. This discussion is followed by looking at the incentives of leasing. The reasons why leasing exists at all are the idea of this brief literature summary which is followed by the various methodologies to rate a lease contract. Then, I turn to the analysis of the risk structure of leasing contracts. Hereby, I focus on residual value risk which is examined in detail whereas the determinants and risk factors of residual values are described. This examination finishes with an overview of existing prediction models and the attempts to forecast residual values. The summary of the literature shows that research on automobile leases is scarce. From this overview various issues especially in the context of residual value risk arise which have to be examined. This leads me to the two research questions above which are the focus of the following two chapters.

Chapter 3 deals with the first research question. For this purpose, I first identify variables which may drive the residual values of cars. Hereby, I use variables that can be classified into three main categories which are variables: specifying the overall economy, characterising the new and used car market and describing a specific car model. After determining the impact of the used factors and analysing the results, I turn to examining the effects of the empirical results on the risk management of lease contracts. For this purpose, I use the valuation model of McConnell and Schallheim (1983) to quantify the impact of fluctuations in the underlying factors on the lease rate.

The development of a prediction model is left to chapter 4. Based on the results of the previous chapter, I identify a forecast model for three cars of the sample. With the results at hand, I test the performance of the models for an out-of-sample period. The effects of a misspecification of a factor or a wrong expectation of the future market environment on the lease rate and the value of a lease contract are analysed thereafter. For this purpose, the impact of wrongly specified values on lease rates is also quantified by using the valuation model of McConnell and Schallheim (1983).

Chapter 5 finishes with an summary of the results of the work at hand.

Chapter 2

An Overview of the Current Literature

Abstract

Leasing of vehicles represents a major part of equipment leasing. A special importance is thus given in this type of leasing. This chapter is particularly concerned with automobile leasing and the existing literature available on this topic. The aim of this chapter is to find explanations on why people or institutions lease, how to value the great number of specific lease contracts and how to assess the specific risk structure of automobile lease contracts. To answer these questions, I review the existing literature and extract solutions from the scientific perspective. As a result, this chapter gives an overview of the current literature related to leasing.

2.1 Introduction

Leasing can be described as the relinquishment of a good's usage for an exchange of payments during a predetermined period. A general definition of the term "lease", however, does not exist in the literature. Instead, it is defined according to national legislation.

The origins of leasing can be traced back to 1877 when, instead of selling, the American Bell Telephone company first leased their telephones to their clients ((Feinen, 2002, p. 3), (Spittler, 2002, p. 17)). With the formation of the first institutional leasing provider in the USA in 1953 (the *United States Leasing Corporation*) the business model expanded to Germany, where the first providers *Deutsche Leasing AG* (formerly *Deutsche Leasing GmbH*), *Deutsche Anlagen-Leasing GmbH* and *Mietfinanz GmbH* were established in 1962 (Spittler, 2002, p. 17). Since then, leasing has become an important tool in the usage of goods over the last decades. The variety of leased assets ranges from classical ones like real-estate to modern technological assets like computational or medical equipment. At this point in time, Germany is the largest leasing market in Europe.[1] The German leasing investments rose since the German reunification from €26.7 billion in 1991 to €43.6 billion with a penetration rate[2] of 14.3% in 2010.[3] Thereby, equipment leasing covers the largest share with investments of €41.0 billion and a penetration rate of 20.7% in 2010 (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 14). Figure 2.1 illustrates the development of the penetration rates in Germany since 1991.

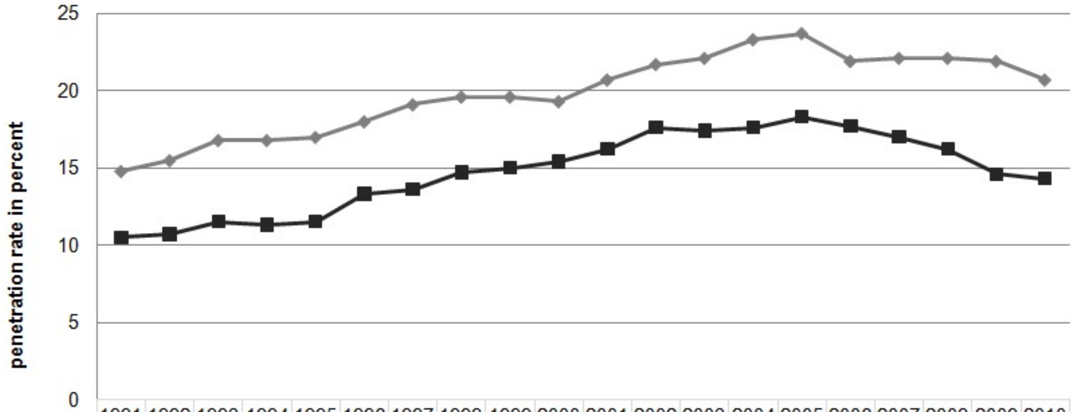
Whereas the proportion of overall investment in equipment due to leasing is more than 20%, leases account for approximately 50% of externally financed equipment (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 14). Thus, it has become a notable alternative to credit financing and has even replaced the classical credit in some sectors. Today, leasing

[1]The numbers of the market volume from Leaseurope (2011, p. 1) are used as a basis.

[2]The penetration rate is the share of leasing at the overall economic investments in percent.

[3]Compare Städtler (1997, p. 9) and Bundesverband Deutscher Leasing-Unternehmen (2011, p.12) for the figures on leasing investments and the penetration rate.

Figure 2.1: Penetration rates since the German reunification



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Equipment Leasing	14,8	15,5	16,8	16,8	17	18	19,1	19,6	19,6	19,3	20,7	21,7	22,1	23,3	23,7	21,9	22,1	22,1	21,9	20,7
Leasing in total	10,5	10,7	11,5	11,3	11,5	13,3	13,6	14,7	15	15,4	16,2	17,6	17,4	17,6	18,3	17,7	17	16,2	14,6	14,3

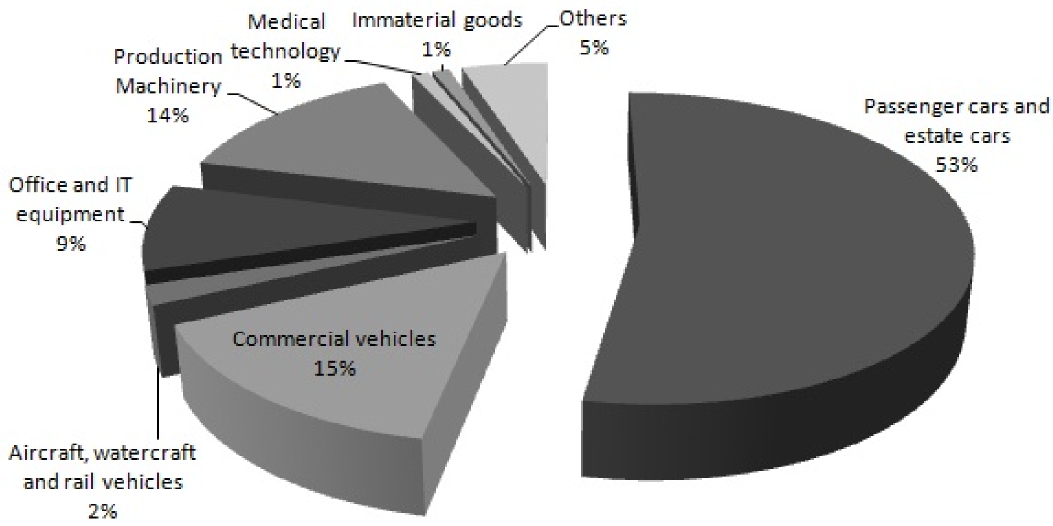
Source: Compiled according to data of Städtler (1997, p. 9), Städtler (2001, p. 44) and Bundesverband Deutscher Leasing-Unternehmen (2011, p. 13).

is not only provided by specialised lease institutions but also by a wide majority of banks. The latter ones account for this development in popularity of leasing by including lease options in their product portfolio. It is therefore not sufficient to focus on a specific group of institutions when dealing with leasing issues as the concept has spread across the whole financial sector.

With about 53% leased cars and estate vehicles in Germany in 2010 (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 15), leasing of vehicles represents the major share of equipment leasing (the various investment categories and their proportion of equipment leasing can be found in figure 2.2) which stands at the core of my analysis. On the following pages, the current literature as well as the results from my findings regarding this literature review will shed light on the following questions:

- What drives people and institutions to undertake leasing?
- Which options are available to value specific lease contracts?

Figure 2.2: Investment categories in equipment leasing in Germany in 2010



Source: Compiled according to data of Bundesverband Deutscher Leasing-Unternehmen (2011, p. 15).

- Which methods can be used to assess the special risk structure of automobile lease contracts?

In order to answer these questions, I shall begin with the examination of the basic principles of leasing which besides the automobile sector may also be applied to equipment lease contracts in general. However, where possible in my overview, I try to focus on their applications to automotive leases provided that such studies exist in the literature. I will first explain the term lease in section 2.2 before I will deal with the question why it is recommended to lease instead of financing or renting in 2.3. The fourth section focuses on certain valuation techniques to assess the value of lease contracts where I distinguish between methods using the present value analysis in 2.4.1 and methods stemming from the option pricing literature as shown in 2.4.2. The input for the present value methodologies largely derives from the literature on incentives to lease that can be found in more detail in section 2.3. While the present value analysis is mainly limited to the valuation of specific types of lease contracts, also known as financial leases, the option related valuation techniques are used for various specifications of lease contracts. After this rather general approach to leasing, the next section 2.5 solely examines the risk management of automotive lease firms. First, I assess the risk structure of these firms and then I take a closer look at a special and important risk inherent in lease contracts arising from residual values. Therefore, the determinants of residual values are analysed in 2.5.2.2 and the existing methods to forecast residual values are surveyed in section 2.5.2.3. The chapter at hand concludes with a summary and ideas for future research opportunities in section 2.6.

2.2 An Explanatory Note on Leasing

As already mentioned in the introduction, there is no universal definition of the term leasing. Its interpretation as well as its implementation is subject to national legislation. Whereas Germany is lacking a legal definition of the term leasing, the American (US GAAP) and International Accounting Standards (IFRS) provide such a definition. In the USA, according to FAS 13.1 "a lease is defined as an agreement conveying the right to use property, plant or equipment (land and/or depreciable assets) for a stated period of time". The International Accounting Standards are inspired by the American definition but describe the lessor-lessee relationship by defining according to IAS 17.4 a lease as "an agreement whereby the lessor conveys to the lessee in return for a payment or a series of payments the right to use an asset for an agreed period of time". In Germany, according to a decision of the Federal Court of Justice (Bundesgerichtshof) leasing is essentially classified corresponding to tenancy law under the German private law (Zivilrecht) in BGB §§535 et seq.[4] As a result, leasing is similar to renting and can thus be generally described as the right to use the leased asset in trade for payments.[5]

[4]Compare for this classification the decision of the Federal Court of Justice from 10/09/1985 – VIII ZR 217/84.

[5]For a more detailed distinction between leasing and renting as well as leasing and financing view for example Helwig (2008, pp. 8-12).

Equipment leases are the main focus of this study which can be classified by numerous ways such as the type of the leased asset (e.g. automotive leases), the volume of the value of the leased asset (small ticket and big ticket leasing), the type of lessor (e.g. leasing by manufacturers (direct) or dealers (indirect)), the type of lessee (private or institutional), the domicile of lessee and lessor (cross-border-leasing) and particular specifications of the leasing contract (e.g. leased asset with specific requirements of the lessee or sale-and-lease-back contracts) (Moldenhauer, 2006, pp. 10-23). The most commonly used classification in the literature is by type of contract and distinguishes between *financial lease* and *operate lease*. As one faces again the fact of non-standardized definitions of those two leases in different national legislations[6], the distinction provided in the literature mainly relies on the cancellation of those leases[7]. While a financial lease cannot be cancelled during its duration, the lessee has the right to terminate an operating lease during the contract period. Financial leases can further be classified in non-full payout (Teilamortisationsvertrag)and full payout leases (Vollamortisationsvertrag) with the latter one guaranteeing the complete return on the initial investment costs for the lessor by the lease payments of the lessee. In the case of non-full payout leases, this amount is covered by the additional guaranteed residual value.

There are additional possibilities for a more precise classification of the type of financial lease. This, however, is beyond the scope of this study and would require a deeper understanding of national legislation. The classifications above provide a good overview of the possible differentiations of lease contracts according to various characteristics and alter only slightly in the respective countries. For the work at hand, I will mainly base my arguments on the differentiation between financial and operating leases as found in the international scientific literature and as described above.

[6]For a definition of the term financial lease in Germany see the "Mobilien-Leasing-Erlass des Bundesminister der Finanzen" BMF IV B/2 – S 2170 – 31/71 from April 19th, 1971 regarding the decision of the Federal Fiscal Court (Bundesfinanzhof) BStBI. 1970 II p. 264 from January 26th, 1970.

[7]See for instance Copeland and Weston (1982) or McConnell and Schallheim (1983).

2.3 Incentives to Lease

The data provided in the introduction underlines the popularity of leasing. From this observation the question arises why leasing has become such a widely offered product and what motivates people rather to lease than to rent or finance. In the next few pages, I will examine the scientific literature for explanations concerning incentives to lease. I will hereby not distinguish between incentives to lease from the perspective of the lessor or the lessee since the advantages are reciprocal (otherwise there would not exist the opportunity to choose the product leasing besides renting and/or financing). I rather discuss those incentives regarding their thematic relation.

The first studies recorded use the present value approach to evaluate lease agreements in order to compare their profitability with the leasing alternatives. Starting from the valuation formulas constructed by this approach, the authors examine the elements of these very formulas and the selected definition for those elements to deduct possible leasing incentives. Early studies of this kind attribute the profitability of leasing to the applied discount rate in the present value analysis. Thus, the appropriate choice between leasing and its alternatives depends on the proper use of the discount rate in the valuation formula. Bower et al. (1966) for instance base their study on this issue. They classify the advantages of leasing according to three characteristics: *operating advantages* like tax advantages, *risk advantages* like transferring the residual value risk to the lessor or *financial advantages* like the treatment of leases different to debt (Bower et al., 1966, p. 258). These advantages (or disadvantages) have to be taken into consideration when applying the discount rates to the different cash flows of the present value evaluation of a lease in order to rate the lease's profitability. Depending on the value of those three leasing characteristics which are included in the used discount rates, the advantage (or disadvantage) of leasing can be determined. Another study by Johnson and Lewellen (1972) states that lease payments and their tax savings should be discounted at the same rate reflecting the predictive character of these terms. Bower (1973,

p. 29), however, argues that Johnson and Lewellen (1972) use a higher discount rate for the tax shelter given up in leasing than the tax shelter with leasing which results in a bias preferring leasing over financing. He corrects for this bias in his approach by using the same discount rates for the tax shelters. Then, the profitability of leasing just depends on the level of the used discount rate. Schall (1974) also criticises the choice of the discount rates used by Johnson and Lewellen (1972) since he argues that the use of the same rates to discount the lease and purchase streams leads to incorrect results due to the different distributional characteristics. Furthermore, he expands on their approach by including a term for the tax benefits in the calculations of the return of a purchase. As a result of this debate using the present value analysis, we can observe a shift in the focus of the lease incentives literature to a discussion using rather tax-related arguments.

The incentive to lease is narrowed down by Myers et al. (1976) to the different tax rates of lessors and lessees. Lessees with low marginal tax rates should lease from lessors facing high marginal tax rates in order to achieve a gain for both contracting parties. This effect is especially significant in the case of high interest rates and of a possible accelerated depreciation for tax purposes. For a fixed non-tax paying period, Franks and Hodges (1978) show that the benefits of leasing are still apparent in the context of the approach of Myers et al. (1976). In another study, Miller and Upton (1976) breaks with former concepts stating that the decision on whether to lease or using alternative finance options can be established a priori. They argue that in a competitive leasing market, both companies and individuals are indifferent towards financing or leasing. The benefit of one of the alternatives is only attributed to the existing legislation where tax subsidies cannot fully be utilised by companies. Empirical examinations of the tax impact on the leasing decision are also documented in the literature such as Sharpe and Nguyen (1995) who show that tax liabilities describe an incentive to lease. Using a regression analysis with two proxies for this influence – the first proxy is tax expense divided by pre-tax income and the second is tax-loss carry-forwards (Sharpe and Nguyen, 1995, p. 281) – they show for the USA that firms with lower tax liabilities tend to lease more. Another study performed by Shanker (1997) for a Canadian sample confirms their findings. She shows that firms having a higher marginal tax rate lease less which supports the theoretical considerations of Myers et al. (1976). Focusing on operating leases in the USA, Graham et al. (1998) find further evidence that firms with low tax rates lease more. These firms use leases to sell their tax shields to lessors with high tax rates since they value the tax benefits to a higher extent (Graham et al., 1998, p. 134).

Another field of the literature regarding leasing incentives examines on the one hand the relationship between debt and leasing and on the other hand the related costs. Ang and Peterson (1984) analyse the degree to which leases displace debt. Their empirical results contradict the predominant view prevalent at the publication time of their study. Prior to this, the scientific community has considered debt and leases as substitutes, whereas Ang and Peterson (1984) find evidence that those are complements. Their analysis shows that firms with a higher use of debt also have a greater use of leasing. This result is backed up by various explanations given by Ang and Peterson (1984), one of them being qualitative differences between the debt of leasing and of non-leasing firms (Ang and Peterson, 1984, p. 1064). Empirical support for this explanation is provided by Finucane (1988) who examines a positive significant relationship of bond-related variables (i.e. bond rating, presence of mortgage bonds and the number of bond issues outstanding) with the level of financial leases of corporations. An additional approach comes from Krishnan and Moyer (1994) that focuses on the costs related to leasing. They show empirically that the expected bankruptcy costs are lower with leasing for the lessor than with borrowing for the lender which decreases the financial costs to the lessee. The impact of financial contracting costs on the leasing decision is examined by Sharpe and Nguyen (1995). They provide empirical evidence that firms facing high costs of external funding can lower their average capital costs by leasing as it offers fixed capital costs. Eisfeldt and Rampini (2009) provides additional empirical support to Sharpe and Nguyen (1995) by identifying that financially constrained firms lease more. They argue, however, that this results from the comparison of the higher debt capacity and agency costs associated with leasing. The advantage of an additional debt capacity to financially constrained firms prevails which is why they tend to lease more.

In contrary to debt contracts or renting agreements, some lease contracts contain options like a call option to purchase the leased car at maturity stage. Not taking the value of these options into account for a leasing decision might lead to a bias against leasing. Miller (1995) analyses the value of purchase options in closed-end automotive leases with guaranteed buy-back provisions and finds empirical evidence that the call option is of considerable value. He argues, therefore, that the estimated capital costs regarding guaranteed buy-back lease contracts are too high which biases the lease versus buy decision against leasing. Giacotto et al. (2007) affirms the results as he provides an empirical analysis of the call option value inherent in automotive lease contracts. In line with Miller (1995), Giacotto et al. (2007) confirms that the embedded call option is of considerable value. Their results show that the stand-alone value of this option is on average 16% of the market value of the leased vehicle (Giacotto et al., 2007, p. 441).

Another explanatory approach for leasing arises from the well-known adverse-selection problem in the used car market which was demonstrated by Akerlof (1970). He argues that the used car market is inefficient due to the asymmetric information between buyers and sellers that leads to a decreasing number and quality of used cars traded at a low price level. The question of how leasing affects this adverse-selection problem is addressed in Hendel and Lizzeri (2002). They develop a theoretical model of the car market under adverse-selection where the consumers can either enter a lease contract with a purchase option or buy the car. The results show that leasing attracts consumers who demand higher quality and who respectively have a higher income. Thus, off-lease used cars have a higher average quality and consequently a higher turnover. These results of the theoretical model are consistent with observations in the car market. Depending on the value of the purchase option, manufacturers are able to segment the market. Consumers with a low demand for quality will rate the price of the call option higher, whereas consumers with a high demand for quality will likely not exercise this option and therefore not value it. Hence, consumers with a low quality demand will tend to buy while the others will be inclined to lease. This effect can be enhanced if the manufacturer sets the option price. Johnson and Waldman (2003) extend the study of Hendel and Lizzeri (2002) by various aspects including costs associated with restrictions in lease contracts – for instance kilometre restrictions – being the most important one. They show that when a new car is leased rather than bought, new car leasing reduces the adverse-selection in the used car market.

Besides the prevailing reasons in the literature mentioned and categorized above on why people feel inclined to lease, there are a variety of other reasons which address this issue from different angles. This section concludes with the following four studies that give a very brief excerpt of further reasons found in the literature on why to lease.

A very elaborate discussion can be found in Smith and Wakeman (1985). They list eight reasons that increase the probability that firms lease. They argue that leasing is more likely to be undertaken when the value of the asset is less sensitive to usage and maintenance decisions; the degree to which the asset is specified to the firm is high; the expected utilisation period of the leased asset is short compared to its expected useful life; there are corporate bond contracts with certain restrictive covenants; the management receives provisions based on the return on capital invested; the firm is closely held; the lessor has market power and when the lessor holds a comparative advantage in asset disposal (Smith and Wakeman, 1985, p. 907).

There are real-life examples where manufacturers solely use a lease-only policy. Waldman (1997) focuses on these examples in his study and derives another explanation for leasing. He argues that in monopolistic situations, leasing arises from the possibility to eliminate the second-hand market. This then allows manufacturers to charge higher prices for their new products.

Desai and Purohit (1999) examine the leasing policy in a competitive market environment theoretically and practically by using data from the automobile industry. They show that the degree of leasing decreases when competition increases. Furthermore, they find evidence that the degree of leasing is related to the rate of deterioration of the product. Firms with a high rate of deterioration are less competitive and, therefore, pursue a rather aggressive selling strategy and a low level of leasing.

Mannering et al. (2002) take a closer look at U.S. households and their decisions on either to buy or to lease a car. They provide evidence that the decision to lease is related to the desire of being able to afford a more expensive vehicle. This shows that the sharp increase in vehicles leased in the USA in the 1990s can be explained by higher incomes of households and their desire to upgrade their type of car.

2.4 Valuation of Leasing Contracts

2.4.1 Lease Valuation Using Dicounted Cashflows

Early valuation methods can be mainly found in the literature dealing with either the lease-or-buy or the lease-or-borrow decision. These papers use discounted cash flow techniques to assess the value of a lease contract and thus to compare its profitability. Generally, this valuation approach is applied to pure financial leases. More complicated leases like operating leases or leases with options cannot be valued by using this methodology. The focus of the present value approach mainly relies on the incorporation of taxes, capital costs and depreciation benefits. Hence, these studies have rather an accounting background and involve fiscal incentives in their examinations.

Johnson and Lewellen (1972, p. 820) for instance have evaluated a leasing contract as the net present value of the after-tax cash operating profits minus the after-tax net present value of lease payments using different discount factors for both terms. The first term is discounted at the after-tax rate of cost of capital of the lessee while the second term is discounted at the after-tax interest rate on the lessee's debt. Based on these considerations Gordon (1974) extends this model by substituting the discount rates of Johnson and Lewellen (1972) with the risk-neutral interest rate and a risk-adjusted interest rate for the cash flows before taxes and depreciation of the leased asset.

Schall (1974) incorporates the acquisition decision into his considerations. He accounts for the decision whether an asset shall be purchased or not. This type of decision strongly depends on the suggested financing method, which will either yield a gain or a loss to the lessee. Hence, a lease valuation should account for this fact. Including this decision leads to adjustments in the comprised cash flows and in the used discount rate for those cash flows. In another study conducted by Myers et al. (1976, pp. 800-807), they use the work by Schall (1974) as a basis to construct their model, however simplify its complexity by reducing the involved variables. This reduction of complexity is achieved by considering the lease-or-borrow decision. In this context, borrowing is not understood as an alternative to leasing. It is rather the case that a lessee reduces his or her ability to borrow through other channels. This leads to a dependency between lessee's debt and the value of the lease in a sense that the displaced debt is correlative to the value of the lease and vice versa. Consequently, a simultaneous solution between the value of displaced debt and the lease value is required. This will reduce the necessary variables in the valuation of the lease and diminish the set of used variables to the time schedule of lease payments, leased asset's depreciation tax schedule, the lessee's borrowing rate and its marginal tax rate. The same formula is derived by Franks and Hodges (1978) without having done a simultaneous solution. Instead, the authors base their solution on the analysis of displaced cash flows. Hereby, they compare the combined time profile of cash flows for the borrowing and purchasing decision of the leased asset with the time profile of cash flows for the lease payments. They argue that the two cash flows must be equal and derive the valuation formula of Myers et al. (1976) accordingly.

Miller and Upton (1976, pp. 767-774) deal with residual value uncertainty by valuing lease contracts. They consider contracts with short- and long-term lease payments. In a deterministic world a short-term lease rate respectively a single period lease rate compensates the lessors for the depreciation on their asset and the foregone interest on the capital invested in the asset. The long-term rate can be derived by extending the short-term rate to several periods. When accounting for residual value risk, they then go on and assume that the depreciation rate and the cost of the leased asset are uncertain. This is incorporated by using the capital asset pricing model to determine the expected rate of depreciation and the expected rate of return of the leased asset. Thus, the single period lease rate in an uncertain environment can be described as the foregone expected return rate on capital invested in the leased asset and the expected depreciated value of the asset.

The studies mentioned above all take tax-effects on lease values into account but neglect the factors that may influence taxes or tax shelters. For instance, Hochman and Rabinovitch (1984) argue that inflation affects the real value of tax liabilities and thus the value of leases. They therefore include the anticipated inflation rate into their lease valuation by adjusting the discount rate for the impact of inflation. Their model yields declining lease payments for leases stretching over more than one period since inflation decreases the real tax payments. These results vary if tax differentials in the American legislation are taken into account.

2.4.2 Lease Valuation Using the Option Pricing Theory

The seminal work of Black and Scholes (1973) provided a new basis for the evaluation of leasing contracts. Black and Scholes (1973) developed a theory to value financial options which made it possible to value financial contracts which can be described in any terms as a contract including an option to do something. Their concept added a new dimension to the leasing valuation literature and established a new approach for the evaluation of leases. Valuation was no longer restricted to mainly financial leases but could be extended to operating leases or leases including options.

An early application of option pricing theory to value leases was done by Smith (1979, pp. 105-106) valuing leases according to collateralised loans. This type of loan is equal to a sale of the collateral to the lender from the borrower by receiving the proceeds of the loan plus a lease which allows the lender to use the collateral over the time period of the loan plus a call option to purchase the collateral asset at a certain promised repayment (Smith, 1979, p. 104). Consequently, a lease can be valued as a collateralised loan where the leased asset functions as the collateral. Copeland and Weston (1982, pp. 61-65) value operating leases via American options. Operating leases allow a lessee to cancel the leasing contract during the leasing period which is an additional right that must be incorporated in the lease payments. The authors value this right by an American put option written by the lessor. This option is then priced via the binomial methodology of Cox et al. (1979).

A very extensive demonstration of valuation for various types of leasing contracts can be found in McConnell and Schallheim (1983, pp. 242-252). Based on the valuation of a rescindable operating lease, the authors derive valuation formulas for various leasing contracts including different types of options.[8] A valuation formula for financial leases is also given since a financial lease is an operating lease with a non-cancellation period equal to the maturity of the leasing contract. In general, McConnell and Schallheim (1983) describe operating leases as compound options which is an option having an option as underlying asset. The

[8]The leasing contracts in their study are: (a) leasing contracts with an option to the lessee to extend the life of the lease, (b) leasing contracts with a lessee's long position in an European call option on the leased asset, (c) leasing contracts with a call option to the lessee to purchase the leased asset at the market price of the asset at maturity, (d) leasing contracts with a lessee's long position in an American call option on the leased asset, (e) leasing contracts with a lessee's short position in a European put option on the leased asset and (f) leasing contracts with a non-cancellation period.

authors assume a discrete model where lease payments are made at the end of consecutive discrete time intervals. They examine the lessee's decision on either to lease or to cancel the lease at maturity of the lease backwards. A lessee will cancel the lease if he or she could rent the same object on the market for the time period to the next lease payment for less than the bargained leasing rate. Otherwise he or she will continue with the lease. Going backwards from maturity beginning with the point in time when the last leasing rate is due, the leasing rate is paid if the rental rate is higher. Considering the point in time when the second to last leasing rate is due then, the leasing rate contains the choice to use the asset for the next period and contains a long position in a call option for the lessee to use the leased asset for the last period. Applying this method to all further payment points in time yields a valuation structure that contains compound options. The lease contract can then be valued according to the model for compound options by Geske (1977). This methodology and the idea of McConnell and Schallheim (1983) of valuing operating leases enables then to rate various types of leasing contracts containing options.

A recent study by Giacotto et al. (2007) tests empirically parts of the valuation technique of McConnell and Schallheim (1983). The valuation method implies that the value of the option to cancel the leasing contract and the value of the call option to purchase the asset at maturity of the contract by the lessee has a significant value and thus increases the leasing rate. This model implication is tested in an empirical analysis for the American automobile market in the years from 1990 to 2000. Their results show that the value of cancellation options is little due to penalties that arise from early cancellations in real world applications of leasing contracts. On the contrary, the call option is quite remarkable as its stand-alone value is on average 16.4% of the market value of the leased asset.

Grenadier (1995) values different types of leases based on a real-options approach. The structure of his model follows the term structure of interest rate models. The real-options approach is used to model the underlying asset value. As option pricing according to the arbitrage argument is not applicable (assumptions of missing transaction costs or short sales cannot be maintained for leased assets in most cases), he uses an equilibrium model – to be more precise the capital asset pricing model of Merton (1973) – to derive the value of the leased asset. Then, a financial lease can be described as a portfolio where the lessee has a long position in one unit of the leased asset and a short position in a call on the leased asset with a strike price of zero.[9] The payable amount from the lessee to the lessor during the duration of the contract is then equivalent to the value of the constructed asset. It must be noted that this construction values the asset without regards to the ownership of the leased asset. Moreover, the leased asset's price is exogenous in the model of McConnell and Schallheim (1983) whereas this price here is derived endogenously. In general, this model can be used to rate a variety of lease contracts. In his study, it is used to value forward leases, lease contracts which contain the option to renew or to cancel the lease, lease contracts with variable lease rates, lease contracts which condition lease rates on the level of usage of the leased asset as well as to derive insurance premiums.

A modification of the model of Grenadier (1995) is the study by Bellalah (2002). Both his approach and structure are analogous to Grenadier (1995) but he adds incomplete information in his examinations. More precisely, Bellalah (2002) incorporates information costs in the valuation of leases by substituting the application of the capital asset pricing model with the concept of Merton (1987) including incomplete information.

Grenadier himself extended his model of 1995 with a revised paper of Grenadier (1996) accounting for credit and residual value risk. He applies the model to a variety of real-world lease contracts which are used to protect the lessor against losses due to default of the lessee. The examined applications are: (a) lease contracts with a security deposit requirement, (b) lease contracts with prepaid lease payments, (c) lease contracts with credit insurance, (d) lease contracts with a lessee's long position in a call option to purchase the leased asset under consideration of default risk and (e) percentage-lease contracts which have the lessor take a share in the gain of the usage of the leased asset.

[9] This assumption follows the approach of Miller and Upton (1976).

Realdon (2006) adjust the model of Grenadier (1996) to value financial leases with credit risk. Instead of using the time until a default barrier of the lessee is reached, Realdon (2006) takes a default intensity to determine the probability of default. Moreover, he compares the impact of credit risk on financial leases and secured loans. His model provides different effects on those two types of financial contracts.

A separate valuation of options inherent in lease contracts may lead to mispricing as some options devalue other options during duration. For example, an option to cancel the lease contract may disable an option to purchase the leased asset at the end of the lease contract when exercised during duration. This fact is not taken into account by any of the above-mentioned valuation models. Trigeorgis (1996) is the first to construct a valuation technique which includes a combination of the contingent claims analysis and the backward valuation via a binomial tree. By considering the value of different inherent options and the value of the leased asset on single time points in the binomial tree, it is possible to evaluate the options in the contract by discounting backwards with the risk-neutral interest rate on each time point in the tree. This makes it possible to account for the interaction of different options and to value numerically such lease contracts.

Finally, I would like to mention some empirical studies of the American automobile market which estimate values of European call options embedded in several automobile leasing contracts. In addition to the already introduced study by Giacotto et al. (2007), these papers deal with the valuation of options inherent in automotive lease contracts, however, the scientific literature lacks an extensive empirical testing of option valuation models in the context of the automobile market. The study of Miller (1995) for instance, analyses 36-month leases on a Honda model of the year 1994 received by a Honda dealer. White (1996) uses a sample of 1995 model cars with lease terms ranging from 12 to 48 month. The results of both papers are in agreement with the findings of Giacotto et al. (2007) as they find evidence for valuable call options in automobile lease contracts. This has significant implications. While Miller (1995) argues that this affects the purchase versus lease decision, White (1996) deduces guidelines for lessees and lessors to benefit from this fact. Thus, an accurate valuation of leasing contracts containing options is necessary.

2.5 Challenges in the Risk Management of Lease Firms

2.5.1 Risk Structure

The analysis of the risk faced by a leasing provider requires at first a risk classification in order to identify the sources of risk, which is necessary for its management. There are a variety of different risk systematisations in place for the application to leases. The categorisation of lease contracts as a financial product implies to use the risk classification of financial institutions or banks. Thus, like other authors[10], I choose to classify risk according to the four categories *market risk*, *credit risk*, *operational risk* and *liquidity risk* which are defined by the Basel Committee on Banking Supervision. The following paragraphs apply those definitions to the specialised business segment of the lease industry and illustrate their meaning in this context. In order to assure a common understanding of the terms, *risk* is defined as "the deviation of a value from a predefined reference value" (Perridon et al., 2009, p. 103).

LIQUIDITY RISK is the risk, that a leasing institution might not "meet [their] obligations as they come due, without incurring unacceptable losses" (Basel Committee on Banking Supervision, 2008, p. 1). Lease institutions usually buy the leased asset before they receive the lease payments. Moreover in most cases, the lease payments are paid periodically and are a recurring fee. On the contrary, the leased asset must be paid at once. This converse payment structure might cause financial difficulties for lease firms and makes them prone to liquidity risk.

[10] See for instance Diekmann (2007) or Helwig (2008).

The definition of OPERATIONAL RISK is “the risk of a loss resulting from inadequate or failed internal processes, people and systems or from external events” (Basel Committee on Banking Supervision, 2004, p. 137). An important type of operational risk is legal risk, which means risk arising from changes on a legal basis. A recent example for legal risk regarding the German lease industry is the ruling of the business tax reform (Unternehmenssteuerreform) of 2008 by the German government which was supposed to balance the trade tax (Gewerbesteuer) advantages of leasing compared to financing. This reform, however, implied a double taxation on leasing rates by the trade tax leading to a disadvantage compared to classical credit financing. In order to overcome this discrimination, the legislator conferred the trade tax privilege of banks (Bankenprivileg) upon leasing firms by the annual tax law (Jahressteuergesetz) of 2009. This, however, means that leasing firms have to meet the regulatory requirements of banks albeit in a weaker form. As a result, this leads to considerable consequences especially in the risk management of lease firms which have now to accomplish the regulatory requirements of the MaRisk[11]. Thus, leasing institutions require additional ressources in order to meet the legal regulatory framework.

CREDIT RISK defined as the risk of a counterparty failure (Basel Committee on Banking Supervision, 1988, pp. 8-9), addresses the loss which occurs if a lessee might not be able or willing to pay his or her lease rates. A decline in reliability is also part of credit risk, which may lead to a diminution in value of the lease contract.

A considerable type of risk is MARKET RISK which is the “risk of losses in on and off-balancesheet positions arising from movements in market prices” (Basel Committee on Banking Supervision, 1996, p. 1). In this context, it must be referred to risk bearing from changes in interest rates or exchange rates besides the risk arising from alterations in the market price of the leased asset. As already seen from the remarks of section 2.4, the interest rate plays a crucial role in the valuation of leasing contracts. A change in interest rates may cause a loss due to an alteration in the value of the lease payments. Whereas risk arising from changes

[11] MaRisk is the abbreviation of “Mindestanforderungen an das Risikomanagement”.

in the exchange rate is less reported on within the lease industry of national markets, it is vital for cross-border leases where the lessee and lessor are based in different countries.

Probably one of the most important risks in the lease industry is the risk arising from changes in the market price of the leased asset. On the one hand, it is strongly related to credit risk as the leased asset is the main collateral to secure the lease payments. In case the lessee fails to pay, the lease firm makes use of the collateral and gains the market price of the leased asset. If this price has declined during the lease contract, a lessor might generate a loss. Nonetheless on the other hand, the market risk of the leased asset is much more important in the valuation of the lease contract. Any calculation of lease rates requires the residual value of the leased asset. This value however, is nothing more than the market price of the leased asset at maturity. Consequently, a wrongly calculated residual value yields an incorrect lease contract's value, which may cause losses on lessor's side. This type of risk is called *residual value risk* and differs from the risk as a collateral just by the time of its occurrence. While the risk as a collateral may only occur during the duration of a contract, the residual value risk becomes apparent at maturity.

A survey of 56 managers of automotive lease institutions in the German market conducted by Dudenhöffer and Neuberger (2007) further confirms the relevance of residual value risk. They point out that calculated residual values are on average eight to ten percent less than the market price at maturity. Moreover, the study ascertains that 90% of automobile dealers who also function as lessors expect a risk for their lease firm from incorrect residual value figures (Dudenhöffer and Neuberger, 2007, p. 6). This appraisement is verified by a dealer of BMW (Bayerische Motoren Werke) who had to declare bankruptcy because of misspecified residual values amongst other reasons according to an article published in Der Spiegel (2009).

The significant importance of residual value risk will be the main focus of the following sections. I will discuss the relevance of residual values in more detail and, furthermore, examine the analysis of determinants of residual values and the possibility of predicting them.

2.5.2 Residual Value Risk: A Closer Look

2.5.2.1 Relevance of Residual Values in Leases

The impact of RESIDUAL VALUES on the value of a lease contract is remarkable as it is a crucial component in the valuation methods illustrated in section 2.4. Just to recap, the lessor is in general compensated for two terms: The first term is the foregone profit on interest rates, the second one is the depreciation and decline due to the use of the leased asset during the duration of the contract. Depreciation is calculated as the difference between the new car price respectively the used car price at completion of the contract for second-hand car leases and the future value of the car at maturity of the contract, i.e. the residual value of the leased car. Hence, residual values have a direct influence on lease rates. If the residual value is too high, the lessee will pay a low leasing rate which will be reflected in a lower depreciation compared to the actual decline in the car's value. Consequently, the lessor will not be compensated for the complete depreciation of the leased asset resulting in a loss on his or her side. On the contrary, if the residual value is too low, the lessee's lease rate will be charged too high. This indicates a higher depreciation compared to the actual decline of the car's value. Ostensibly, this solely yields a loss on lessee's side but it may also generate losses to the lessors. The results are also based on the fact that the lease market is a highly competitive market with about 2,221 lease institutions in Germany alone in 2009.[12] Lease firms that offer higher lease rates than their competitors run the risk to loose market share. Thus, high lease rates may also result in losses on the lessor's side.

[12] Compare Wassermann (2009, p. 262) for the number of lease institutions in Germany.

Besides the function mentioned above, residual values are of further interest. Another aspect of their relevance arises from the manifold specification of lease contracts. A considerable amount of these contracts include options either to the lessee or the lessor. For instance, the call option for the lessee to purchase the car for a specific price at maturity is a commonly used option in lease contracts. Residual values function hereby very often as strike prices. This means that lessees have the right to buy the leased car at the predefined residual value at maturity of the contract. The value of those options, therefore, is influenced by the determination of the residual value at completion of the contract. As derived from the discussion in section 2.3 and 2.4.2, empirical studies find a significant value of the options offered in lease contracts which may be the decisive factor in the leasing decision and affect the value of the contract. Thus, the additional option value which should be incorporated in the lease rates impacts the lease payment for the lessee. Residual values therefore need to be calculated carefully as a false value might affect the lease payments in two ways: the calculation of lease rates and the calculation of the option value. Moreover, the function of residual values as strike prices in options also has an effect on turn-in rates. For example, if the residual value is set too high, the call option price will be low which increases the probability that the car will be turned-in at maturity of the contract. On the contrary, if the residual value estimate is too low, the call option price will be high and the probability decreases that the vehicle will be turned in at maturity of the contract. These interconnections show the strong impact of residual values on the second-hand car market.

To conclude, residual values used as strike prices in options may result in changes in lease rates and turn-in rates. As the discussion above shows, lease rates may cause losses on lessee's and lessor's sides as well. The effect on the turn-in rate, however, mainly affects lessors. They are forced to exploit the leased car in order to gain a profit. Hence, they are interested in a speedy usage of the car that can either mean the completion of a new lease contract or a sale in the second-hand car market. The latter one however usually results in a loss; otherwise the lessee would have exercised his or her option. Furthermore, a new lease contract only compensates the lessor for the future and not the foregone depreciation, which also results in a loss to the lessor.

Finally, I would like to mention another function of residual values that is strongly linked to the particular specification of lease contracts and neither includes any options nor additional rights to the lessee or the lessor. Additionally, leased cars of those contracts are not of any use to second-hand car leasing because they have already completed a considerable proportion of their useful life. Hence, at maturity of the lease contract the automobile is turned in and it is the lessor's task to exploit the car. In these cases, the residual value is mainly used as the car's future price the lessor assumes to receive in the second-hand car market. As discussed above, this might have a considerable effect on lessor's profit and may lead to write-offs on the balance sheet. This was the case in Germany in 2008 when, as a consequence of the crisis and the public subsidies for scrapping an old car and buying a new one (the so called *Abwrackprämie*), prices in the second-hand car market fell. Many lease providers incurred losses as leased cars could not be sold at the lessors' estimated prices at completion of the lease contract (Deutsche Bundesbank, 2011, p. 39).

The considerations above have pointed out how residual values may affect profit and loss for both lessor and lessee as well as which implications they might have on the risk structure. Hence, both parties are highly interested in receiving a precise examination of residual values. The following two sections deal with the analysis of residual values of cars in order to assess residual value risk.

The first paragraph determines what drives residual values, respectively used car prices. From this discussion it becomes apparent what factors influence residual values and which ones may result in changes in this value. Thus, changes in residual values can then be linked to changes in certain influences and become partly predictable. In this context, it is of interest to know how a car depreciates and what factors are on the one hand responsible for the depreciation of cars and on the other hand influence the depreciation of cars.

The second paragraph focuses on techniques to predict residual values. As they are needed at the completion of the contract, those values must be forecasted. The forecast methods applied and their performance is the main focus of this paragraph. The different approaches and results in these sections stem from the literature researched on these topics.

2.5.2.2 Characteristics and Determinants of Residual Values

Cars are durable goods with utilisation periods that can possibly last for years. In Germany in 2006 for instance, the average age of cars at scrappage was twelve years (Kraftfahrt-Bundesamt, 2009, p. 5).[13] From their production until their scrappage, cars loose in value. The depreciation of a car defines its residual value which is of special interest in the automotive leasing industry as discussed in section 2.5.2.1. However, as the market for automobiles is determined by the mechanisms of demand and supply, depreciation is influenced by various factors. In order to provide solutions to manage residual value risk, it is necessary to determine and to understand the relation between residual values of cars and different factors. For this purpose, it is crucial to gather information about the depreciation pattern of a car, i.e. how a car depreciates. With this material, it is possible to identify how factors form the depreciation pattern, how they may alter it, how this information may be included to manage residual value risk and how this evidence can be used for the prediction of automobiles' residual values.

The focus of a study by Wykoff (1970) deals with the nature of the depreciation of cars and belongs to one of the few studies covering this topic. In an analysis of ten models from 1950 to 1969, he centres his research on three aspects of depreciation rates of cars. He begins by testing the hypothesis that cars depreciate independently of time (Wykoff, 1970, pp. 170-171). This means that depreciation patterns do not alter during different time periods but remain fixed over time independent of changes in technology or any other exogenous factors.

[13]Due to a change in data collection in 2007, there are no records available of the average age of cars at scrappage after 2006 (Kraftfahrt-Bundesamt, 2009, p. 5).

This first hypothesis is not rejected on the basis of his dataset (albeit the evidence is weak), which gives no evidence that there is a changing depreciation pattern over time. Further, he analyses whether cars of different makes and models depreciate identically (Wykoff, 1970, p. 172). His results show that this thesis does not hold. Depreciation rates vary between different cars and need not to be constant for homogenous goods like automobiles. Finally, he detects that in general cars do not decline with age at an exponential rate (Wykoff, 1970, pp. 171-172). Especially for new cars, this specific depreciation pattern cannot be confirmed as they depreciate much faster in the first year than the exponential depreciation pattern would suggest. Instead, examinations of cars aged one year show that their prices decline exponentially. Consequently, an exponential depreciation rate is applicable to values of used cars. This result is also confirmed by Ackerman (1973, pp. 463-466) who illustrates that used car prices decline with age at a constant exponential depreciation rate as given by her data on six makes from 1954 to 1963.

The study of Ohta and Griliches (1976) contributes to the results of Wykoff (1970) as they analyse new and used car prices of thirteen makes from the model years starting in 1955 to 1971. Their analysis of used car prices shows that depreciation patterns are not stable neither across time nor across different makes (Ohta and Griliches, 1976, pp. 353-360). These results refer to the first and second hypothesis of Wykoff (1970). The findings differ for the first one yielding a rejection of the assumption of independent depreciation patterns over time whereas the results of Wykoff (1970) regarding the second hypothesis can be confirmed. Furthermore, Ohta and Griliches (1976) conclude that an exponential depreciation pattern is a suitable assumption for used car prices and can be used for their approximation (Ohta and Griliches, 1976, pp. 360-362) which is in line with Wykoff (1970) and Ackerman (1973). However, the empirical results must be handled with caution. They argue that "on the average" this assumption may not be too bad though the hypothesis might be rejected for large samples (Ohta and Griliches, 1976, p. 362). Additionally, their analysis illustrates systematic deviations from exponential depreciation. Thus, they conclude that cars decline faster at age (Ohta and Griliches, 1976, p. 363).

Like Wykoff (1970), Peles (1988) focuses his research solely on the characteristics of a car's depreciation. He analyses which type of depreciation pattern has the best fit for 34 car models in the years from 1975 to 1985. For this purpose, he distinguishes between three approaches with the first one stemming from the economics literature and the others being derived from the accounting literature. The first one examines the so called *one hoss-shay* type which assumes a constant stream of benefits in every period. This leads to an increasing depreciation stream which is rejected according to the sample. Instead of that, the *straight line* and the *accelerated* depreciation achieve good results. A linear and an exponential function for the value of the car are used to represent these two depreciation types. Both show a good fit and can be used to approximate the depreciation pattern although the actual one lies between these two types.

A more recent study of Storchmann (2004, pp. 382-399) tests a dataset of used car prices for depreciation patterns of used vehicles in 30 different countries for a four month period from January to April 2001. According to Peles (1988), he finds evidence that either a convex or a straight-line depreciation pattern is applicable to the sample. Except for four out of 54 models, the goodness of fit prefers an exponential depreciation rate for used car prices. Moreover, a comparison between developing (non-OECD countries) and developed countries (OECD countries) shows that the vehicles in developed nations depreciate on a faster rate than cars in developing countries. This might be explained by faster substitution cycles from old to new cars due to product improvements in developed countries.

While the previous mentioned papers examine the "technical" characteristics of depreciation of cars, the next studies deal with the factors that finally determine depreciation. By having some information on the functional form of the depreciation rate by the authors above, the focus of this branch of research lies on the factors that influence at which rate the car prices decline. The majority of those papers use the so called *hedonic approach* to assess this topic. According to Ohta and Griliches (1976, p. 1), this approach means that cars can be interpreted as bundles of different characteristics. Each car is defined as a special composition of those characteristics with each one having its own implicit market price which can be derived from different combinations of cars with different levels of those specific characteristics. The method used to determine the relevant characteristics and thus the car prices is a linear regression method with the price of the car functioning as the dependent variable and the single characteristics as the independent variables.

One of the early applications of this technique is the construction of car price indexes which dates back to 1939 as Court (1939) first used the hedonic approach for the automobile market. The invention of these car price indexes pursued the goal to illustrate price changes of cars. Such a change in price can arise from technical or rather quality improvements. The hedonic approach enables to distinguish between pure price changes and changes due to quality improvements, so that price variations can be quality-adjusted. The first papers using this hedonic method primarily identify quality-related characteristics (which describe car prices) in order to construct quality-adjusted price indexes. Most of these papers use new car prices for their analysis.[14] Having the aim of this section in mind to examine determinants of residual values, I am highly interested in an application of the hedonic method to samples of used car prices. Hence, the following survey will solely focus on studies dealing with used car prices and neglect studies for the new car market.

The paper of Ohta and Griliches (1976, pp. 351-367) uses such a sample for their analysis. They select several factors to examine how they influence used car prices. For this purpose, they classify their variables in *physical* (for example horsepower, weight, length) and *performance* variables (for example acceleration, handling or fuel economy). This is done in order to differentiate between those (physical) characteristics which influence the cost function of

[14] See for instance Cowling and Cubbin (1972), Ohta and Griliches (1976), Gordon (1990), Murray and Sarantis (1999), van Dalen and Bode (2004), Reis and Santos Silva (2006) or Matas and Raymond (2009).

producing cars and those (performance) characteristics which influence the utility function of consumers (Ohta and Griliches, 1976, pp. 327-328). They evaluate a semilogarithmic regression equation to test the influence of those characteristics on the car prices. In a first analysis they focus on physical characteristics and use two approaches to identify their effect on car prices.

For the first approach Ohta and Griliches (1976) choose a total of 32 independent variables. The huge number of variables arises from the fact that the authors constrain all coefficients except for time dummies to be constant during their observation period for the years from 1961 to 1971. They apply dummy variables for each year from 1961 to 1971, for each age of car ranging from a two year to a six year old car and for each make of car with an overall of twelve makes in the sample. Besides these dummies Ohta and Griliches (1976) use five physical variables which are maximum brake horsepower, shipping weight measured in pound, overall length measured in inch, a dummy variable which has the value of one if the car has a V-8 engine and zero if the car has a 6-cylinder engine as well as a dummy which is one if the car is a hardtop and zero if not. The results show a positive and significant influence of the variables weight, horsepower and the dummies for hardtop and V-8 engine on the car prices, the estimation yields no influence of the factor length on these prices.

The second approach of Ohta and Griliches (1976) estimates regression equations for overlapping three- and two-year intervals in the observation period. This technique allows the coefficients to vary over time. For this approach all independent variables remain the same except for the dummies of the years 1961 to 1971, those are skipped in the regression. The results show positive significant effects for the variables horsepower, V-8 engine and hardtop and significant negative effects for all dummies determining the age of the car. The other variables have mixed outcomes. The coefficients for weight and length show positive as well as negative results on different significant levels across the years. The effects of the car's make vary across different brands with makes having very high significant estimations and some without significant estimations at all. In a more detailed analysis of make effects, Ohta and Griliches (1976, p. 358) find large positive cost effects for high-priced makes and negative cost effects for low-priced makes.

In order to test how used car prices are described by performance variables, the authors use once more the dummy variables for the age of a car, the make of a car and dummies for the years from the observation period. Instead of using physical variables they include nine performance variables in order to test their effect on car prices. Those are variables which have numbers on a predefined scale measuring handling, steering, engine, engine power, automatic transmission, ride, accommodation, probable trade-in-value and probable dollar depreciation from the consumer's point of view. Most variables do not have statistically significant results on commonly used significance levels. Those variables with a correct sign and significant results could be separated in factors which are interconnected with either the physical characteristics or the depreciation rate; for those variables without statistically significant results there does not exist a high correlation to physical characteristics (Ohta and Griliches, 1976, p. 371).

To conclude, Ohta and Griliches (1976) shows that using performance characteristics above physical ones does not yield any noteworthy advantage when explaining car prices. Additionally, the physical characteristics applied describe used car prices quite well as can be seen by a high fit of the semilogarithmic regression equations measured by a R^2 of at least 0.92.

The work of Gordon (1990, pp. 335-350) extends the former study as he analyses a longer time period ranging from 1947 to 1983. His sample consists of used car prices for one and two year old automobiles for the American second-hand car market. Gordon (1990) estimates a semilogarithmic regression equation with the same independent variables as Ohta and Griliches (1976). The variable for the engine type is broken down into four dummy variables, each covering one of the engine types in his sample: a 4 cylinder, a 6 cylinder, a straight 8 or a V-8. Additionally, a dummy variable for the level of trim is introduced scaled from one to four with one being the most expensive and four being the cheapest trim. In accordance to the study of Ohta and Griliches (1976), he regresses at overlapping two-year intervals from the observation period and estimates a total of 36 regression equations. The variable for the age of a car is highly significant and shows negative effects for all 36 time intervals. Weight and brake horsepower mostly have positive coefficients though on different significance levels. The newly added variable for trim levels always has a negative sign except for the two years 1955 and 1956, however again on different significance levels. There is no clear trend visible from all other variables. The fit of the regression ranges from a R^2 of 0.377 for the years 1978 and 1979 to one of 0,971 for the years 1953 and 1954.

Moreover, Gordon (1990) estimates pooled regressions for a seven year period with adjacent intervals which yields five pooled regressions. Those estimations show quite similar results to the previous equations with weight of a car having a positive and age of a car resulting in a negative highly significant effect. The level of trim always lowers the used car price but on different significance levels. The fit of the pooled regressions are between a R^2 of 0,787 for the period 1976-1983 and 0.904 for the years 1947-1955.

Thus, Gordon (1990) confirms the result of the study of Ohta and Griliches (1976) and extends it by adding another variable for the level of trim which shows a negative effect. Moreover, Gordon contributes to the work of both authors due to his extended observation period that allows him to analyse the impacts of these different factors over a longer period of time.

German used car prices are analysed according to this hedonic methodology by Dexheimer (2003, pp. 5-8). She uses data of a total of 20 000-25 000 monthly used car prices from the years 2000-2003 and estimates a logarithmic regression equation for overlapping intervals of two months during the observation period. Compared to the previous mentioned studies, she chooses fewer variables with the independent ones being: age of car measured in months, relative mileage (i.e. kilometres travelled per month of age), logarithmic deflated original price of the new car and dummy variables for 15 different makes and dummies for the months of observation. Results are shown for the two-month interval for August and September 2003. They show negative significant effects for the coefficients of *age* and *relative mileage* and positive significant results for the *logarithmic deflated original price of the new car*. The brand dummies have mixed effects on used car prices but all of them are statistically significant. These results confirm the findings of former studies showing that used car prices significantly depend on the age of a car and its brand and make them transferable to the German second-hand car market. Moreover, the level of usage measured as relative mileage strongly influences used car prices. The fit of the regression equation is confirmed by a R^2 of 0.96.

Taking market factors into account, Storchmann (2004, pp. 399-402) analyses how per-capita private consumption, the list price of a new car, a dummy variable which is one if the vehicle is a truck or zero if the vehicle is a car and the gasoline price influence a car's depreciation rate. The results show that income is positive significant, new car price negative significant and the dummy negative significant on the 1% level for the whole sample of international used car prices from 30 countries and 54 models of spring 2001. A distinction between OECD and non-OECD countries as developed and emerging markets yields that income is highly positive significant for both samples. Gasoline price, however, is only positive significant in OECD countries and the dummy is highly negative significant for non-OECD countries. The adjusted R^2 is between 0.652 for the OECD sample and 0.772 for the whole sample indicating a good fit of the regression model. Hence, income increases depreciation rates, which also accelerates depreciation of cars in both developing and developed countries. Moreover, an increase in gasoline prices only affects depreciation rates in developed countries indicating an earlier substitution of older and presumably less fuel-efficient cars by newer ones, which also leads to an accelerated depreciation.

An examination of various influencing factors of used automobile prices specifically for the European market is provided by Prado (2009, p. 3-6). He analyses used car prices from

France, Germany, Spain and Great Britain. For every country he evaluates a different regression equation according to the hedonic method and groups all the characteristics into four groups. The first group includes factors describing the wear of the car which are the logarithm of its age, the logarithm of travelled distance in total and the monthly travelled distance. The second group describes the origin of depreciation and consequently contains factors like the list price in cubicle form, the real option price and a variable measuring the joined effect of the make and list price taking the value of the list price if the car is of a certain make and zero if otherwise. The next set of characteristics describes the market information for those four European economies. For this purpose, he uses the industrial production index, the diesel pump price and a seasonal dummy variable for the quarter of each year. The last set of variables includes the physical characteristics that describe a car. While the variables for the first three groups are used in every regression equation for each country, the factors of the last group differ between markets. A variable measuring the average fuel consumption and a dummy variable indicating the body type is used for all regression equations. The number of seats are only included for the French and German market. The power of engine is included in all markets except for the one of Great Britain. A variable for number of cylinders is only considered for France and Spain. A variable for the capacity of fuel tank measured in litres is solely applied to the German market, a dummy variable for a car with five doors solely for the Spanish market and a dummy variable indicating whether automatic transmission is standard or not is only used for the British market.

Almost all coefficients have highly significant results on the 1% significance level except the dummy variable for the fourth quarter of a year in the German market. This variable is significant as well but on a 10% significance level. The regression equations have a good fit with a value for the R^2 ranging from 0.75 for the German market to 0.81 for the French market. Two of the variables for wear of the car which are logarithm of age and logarithm of distance have negative signs in all markets. As a result, the age and the intensity of usage of the car lower its residual value. The price of diesel also has a negative effect on used car prices whereas the industrial production index adds with a positive sign to the used car price. Except for the variable indicating fuel consumption, all other physical characteristics have the same effect in the four markets. While the dummy for body type has negative signs, the remaining physical characteristics have a positive effect on residual values. This shows that the characteristics that improve the quality of the car also raise its used car price. Regarding the remaining variables, they indicate mixed results and show no consistent effects throughout the different markets.

Ackerman (1973, pp. 467-473) tries to explain changes of used car prices by including the service flow of a car. For this approach, she uses an indirect application of the hedonic methodology. She hereby does not identify directly influencing variables for used car prices. Instead, she constructs a model where a hedonic price index for new car prices is used to explain determinants of used car prices. Formally, the model describes price changes between cars of age $K+1$ and age K. Assuming that the price of every car of age K can be expressed as the discounted present value of its lasting services, price changes can therefore be modelled by accounting for the value of service. Hence, the price change between cars of age $K+1$ and age K is equal to the price of a car of age $K+1$ minus its discounted value for one period less the value of services of a K year old car and less the capital gains or losses over one period. The estimation of the value of services requires a regression equation which consists of the following independent variables: a trend for the calendar date, a hedonic price index for new cars multiplied with a factor for the constant exponential depreciation of the new cars and a term measuring the average repair costs. The model is estimated for the American market in the observation period from 1954 to 1963 achieving a R^2 of 0.62.

The main focus of the previous studies is the identification of specific characteristics determining used car prices and further residual values. Besides this application, the hedonic regression technique is also used to identify if a specific factor linked to one of the characteristics influences used car prices. In order to find out, the hedonic regression equation is extended to detect a certain influence of this kind. At the heart of this analysis are not the results of the physical or performance variables with their plausible and significant regression outcomes but the impact of the added variable of interest.

One of these extended versions of the hedonic regression methodology is used to test for the influence of gasoline charges on used car prices. In a study of Ohta and Griliches (1986) they analyse the impact of gasoline costs during the oil crises in 1973 and 1979 for the American car market. For this purpose, they construct a model including changes in gasoline prices based on the hedonic methodology (Ohta and Griliches, 1986, pp. 188-192). They find evidence that changes in the valuation of consumers' physical car characteristics derive from changes in gasoline prices (Ohta and Griliches, 1986, p. 195).

Ohta (1987) even extends these findings by constructing hedonic used car price indexes which account for consumers expectations of future gasoline prices. For this purpose, he builds three price indexes where one assumes constant gasoline prices at the present level over time, the second one assumes that consumers expect constant gasoline prices at the present level over the remaining life of the car (which means over a specific time period) and the third index assumes that consumers expect an increase of gasoline prices in the future (Ohta, 1987, pp. 521-523). Those indexes are estimated before, during and after the two oil crises of 1973 and 1979 for the American used car market. Due to the construction of these indexes, various consumer expectations are reflected due to different proportional rates of changes in those indexes. The results show that consumers' expectations about gasoline prices have a significant effect on used car price indexes. During both oil shocks the proportional rate of change of the second and third index are significantly larger than of the first. This indicates that consumers expected gasoline prices to stay at the temporary high level or even to rise in the future, which yields large variations in used car price indexes.

Another study which also focuses on effects of consumers' gasoline expectations on used car values is the paper by Kahn (1986). In this study, he models the expectations of gasoline prices of consumers in two ways. The first implicates that the best expectation of future gasoline prices is the temporary gasoline price. The other approach models those prices as an ARIMA[15] process whereas the best prediction of the price for more than one period ahead is the mean of the sample period (Kahn, 1986, p. 330). The empirical findings for the sample covering the period of both oil shocks of 1973 and 1979 for the U.S. second-hand car market indicate that the values of cars with different fuel-efficiency adjust for changes in gasoline prices. This means that relative price changes from a less to a more fuel-efficient car are significant when gasoline prices vary.

Without using the hedonic methodology, the effect of changes in gasoline prices on used car prices is analysed by Busse et al. (2009, pp. 25-27). They estimate how changes in gasoline prices influence the prices of more fuel-efficient or less fuel-efficient used cars via a regression analysis. According to the miles per gallon designation, they divide the sample of American used car prices into four groups from less to high fuel-efficient. This is also done for all the various car segments. They find strong evidence that an increase in gasoline prices leads to a decrease in used car prices for cars with a small miles per gallon designation (i.e. little fuel-efficient cars) and to an increase in used car prices for cars with a high miles per gallon designation (i.e. high fuel-efficient cars). Both results affect the used car prices in total as well as the used car prices classified in segments.

Indirectly dealing with the influence of gasoline costs on used car prices is the study by Goodmann (1983). He focuses on the question how much money consumers are willing to pay for a two year old higher fuel-efficient car. Given both oil shocks during the 1970s, he constructs a hedonic price for those used cars in 1975 and 1979 using the miles per gallon designation as a proxy for fuel-efficiency (Goodmann, 1983, pp. 249-250). By using a logarithmic regression equation, he first confirms the relationship between used car prices and the miles per gallon indicator. The results for 1975 do not query a relation and the 1979 analysis lacks completely an interrelation which cannot be explained plausibly. Using the

[15]ARIMA is the abbreviation for **a**uto**r**egressive **i**ntegrated **m**oving **a**verage and compared to ARMA models, it models the differences of the time series with an ARMA model.

results of 1975, the consumer's willingness to pay for a more fuel-efficient car is approximated by the partial derivative of the hedonic price regression equation to the miles per gallon indicator. A two-fold analysis for the whole sample based on some households shows that a 1% increase in miles per gallon yields an almost 2% decrease in consumer's willingness to pay for this improvement.

Another aspect of car depreciation deals with the link between the new and second-hand car market. Car models change over the years which poses the question of how used car prices of the same make or model are affected by the introduction of new car models. This issue is examined by Purohit (1992) for American used car prices from 1975 to 1985. He makes a general distinction between styling and quantitative changes. Moreover, he finds out that used car prices are influenced by introductions of new models, though the effect varies between segments according to the statistical significance and sign levels. Furthermore, the influence on used car prices strongly depends on the type of change featured in the new model. Purohit (1992) measures styling changes according to their degree of change. For example, a car with a tail-lamp change is classified as *no change* and a car with a platform change is classified as *major change* and so forth. A quantitative change in engine improvements is measured as the change of horsepower of the car. The empirical results imply that styling changes affect used car prices due to the attitude of the consumers toward this styling variation. A negatively viewed variation leads to an increase of prices for the older automobile. This is also the case when product lines of certain models are discontinued (Purohit, 1992, p. 165). Additionally, *major changes* do have effects on prices of related but different car models of the same manufacturer. Quantitative changes, however, show negative and significant effects only for two of the six segments including one segment with a relatively small impact. Thus, consumers react less to quantitative changes than to changes in styling.

As already seen by Ohta and Griliches (1976), the price of a car or its depreciation is related to its brand. This is the topic of a paper by Betts and Taran (2004) who analyse whether consumers evaluate American used cars on the basis of the reputation of their brand or rather on a specific attribute of it. For this purpose, it is argued that consumers mainly evaluate a car on its reliability. Hence, the brand effect is examined on the basis of reliability which is associated with a brand. The regression analysis yields a significant positive effect for the average reliability of all cars of one of the 17 brands in the sample covering the period 1993-1999. Hereby, reliability is measured on a scale of 14 ratings, each rating gathered from facts provided by consumer reports surveying data and by consumer s' evaluations of reliability. This shows that a positive brand reputation may enhance used car prices whereas a negative one may lower it.

The quality of a car is an important variable by estimating its price. The level of quality can be valued by a consumer via its brand for instance as assumed by Betts and Taran (2004). Another indicator for quality respectively bad quality is safety product recalls. How to account for this new information and how to measure consumers' reactions is the main focus of the study done by Hartmann (1987). He analyses American used car prices for all domestic and imported models of 1980 sold during the years 1981 and 1985. He provides evidence that used car prices decline when a manufacturer recalls the automobile because of defective safety equipment. Furthermore, he finds out that the second-hand car market reacts with different intensity to an automobile's recall in respect to an automobile's segment, to the type of defect or to the severity of recall. Just some of the other models of the manufacturer are not affected by product recalls at all.

Under the assumption that annual driven miles function as an approximation for the net benefit of owning an automobile, Engers et al. (2009) examine how annual miles affect the decline in used car prices during the car's lifecycle. Annual mileage is not a fixed variable but it is dependent on several factors determining its designated use. Hence, certain determinants of households are considered to model a household's decision on how much to drive a car per year, i.e. what net benefit is assigned to the car. Those factors included are family income, number of drivers in a household classified according to age, gender and work status as well as whether the household is located in an urban area or not. Two models for several brands are constructed to describe the interrelation between annual miles and those factors. The first one uses a linear relationship to describe the logarithm of annual mileage whereas the second one models this relationship non-linearly. Besides that, the second model includes the portfolio of cars owned by a household in order to incorporate the choices made on which car to use for a certain trip. The non-linear relationship provides a better explanation for annual mileage as the results show for the U.S. market of the year 1995. Furthermore, the effect on the decline of used car prices by the age of the car can be described best with this model by dissembling it in its components (being the pure aging effect, the effect derived from a household's portfolio of cars and the effect stemming from the household characteristics). Consequently, the study proves that car depreciation is not just dependent on the age of a car but also on the alterations in usage during the car's aging. This change in designated use of a car can be explained by the household's car portfolio and its characteristics.

The last part of this section deals with effects of regulatory sanctions on used car prices. Environmental and safety considerations have generated changes in emission and safety regulations. The question arises whether consumers value these changes and if so, how they value those changes. By analysing the period from 1972 to 1991 for the American second-hand car market, Dunham (1997) provides evidence that consumers evaluate differently both types of regulations. While changes in safety regulations decrease the value of used vehicles, a change in emission regulations increases it. The first effect is explained as consumers perceive contemporary safety standards as insufficient. This may have various reasons but it finally leads to a substitution of older cars for newer ones with higher safety standards. The effect of changes in emission regulations motivates consumers to buy less expensive and older cars instead of more expensive and newer cars. As a result, consumers are willing to pay the costs for higher safety standards whereas emission regulations are rather perceived as a fee.

2.5.2.3 Forecast Models for Residual Values

The probably most crucial task in valuing leasing contracts and assessing their risk structure is the estimation of the residual value of the leased automobiles. As the discussion of section 2.5.2.2 shows, there are several factors that influence used car prices and thus residual values. Concerning the considerations discussed in section 2.5.2.1, there is an obvious need to find a model which predicts residual values precisely and incorporates all influencing variables. It goes without saying however that it is impossible to construct such a model which forecasts exact residual values as the price of a car is a value shaped by the complex market structure of the economy. Nevertheless, it is possible to construct a model that provides an approximation of the residual value and assigns an error term to this approximated value. The error indicates how well a model performs in predicting residual values. A model with an acceptable performance might be used as an approximation for the actual residual value and is expected to value quite accurately the contract at hand. In the following, I would like to introduce some models predicting residual values, which are, to my best knowledge, the only simulations ever performed regarding this topic.

The first approach dates back to 1954 and was undertaken by Farrell (1954). He has developed a theoretical model in order to predict used car prices and, thus, residual values via demand and supply functions (Farrell, 1954, pp. 172-177). Both types of functions depend on consumer's income and prices of cars of different ages. Since he assumes that the supply functions of used cars are perfectly inelastic according to income and prices, the demand functions are solely relevant for the formation of prices. Hence, his approach concentrates on the estimation of demand functions. The inclusion of various assumptions yields that the demand for a car of age i is not affected from prices for cars of all age but only from the prices of adjacent cars aging $i-1$ and $i+1$ years. Moreover, the amount a consumer is willing to pay at most for a car of age i depends on his or her income and tastes.

Consequently, if we consider a certain consumer with a certain taste and income, he or she will afford a car of age i only if its price ranges in a certain interval. This interval has its lower boundary at the maximum price of a car of age $i-1$ which the consumer is willing to pay. The upper boundary is defined as the maximum price of a car of age i which he or she might be willing to pay. If the actual price is below the lower bound of the interval, the consumer will afford an $i-1$ year old car. If the actual price is above the upper limit, the consumer will buy an $i+1$ year old car. Hence, the demand for an i year old car can be derived by aggregating all demand functions of every consumer. Then, the aggregated demand function can be expressed in terms of the distribution of income and the distribution of tastes which is assumed to be independent of income. The aggregated demand function D_i for a car of age i can be written as

$$D_i = \int_0^\infty F(W,w)dw \int_{\frac{1}{w}G_i(P_i)}^{\frac{1}{w}G_{i-1}(P_{i-1})} f(u)du,$$

where $F(W,w)$ is the frequency function of the income w which is uniquely determined by the national income W, $f(u)$ is the frequency function of the variable u which indicates the tastes. $\frac{1}{w}G_i(P_i)$ and $\frac{1}{w}G_{i-1}(P_{i-1})$ assign the boundary of the intervals for the tastes of consumers which determine the buy decision for a car of age i and which depend on the actual price of a car of age i and $i-1$ via a function G_i and G_{i-1} and the income. The variable P_i determines the actual price of a car of age i. The latter integral specifies the individual demand function in relation to the income and the integration over w yields the aggregation of all individual demand functions. In order to derive the frequency function $f(u)$, a cross-sectional analysis is used for its estimation. A further simplifying assumption replaces the frequency function $F(W,w)$ by the distribution of income of a certain year, in the used dataset by the distribution of income of the year 1941. This approach and the estimate of the frequency function of tastes are used to determine $G_i(P_i)$. Then, knowing the demand for a car of age i, it is possible to estimate the price of a i year old car. The estimates are calculated for a dataset covering the years 1922 to 1941 for the American market. Then, the model is used to predict the prices of used cars for the period from 1947 to 1952. Irrespective of some exceptions, the forecasts are fairly inaccurate. Hence, the model's performance is rather poor.

An approach from the theoretical financial perspective evaluates residual values via option theory. This model is not exclusively constructed for automobile leasing but for a general leasing context where it is applicable to a variety of leased assets. Lee et al. (1982, pp. 34-35) describe the residual value S_T of a leased asset to the lessor with any price X as

$$S_T = \max(0, S_T - X) + X - \max(0, X - S_T).$$

The present value of the residual value is obtained by generating the present value of the single terms on the right side of the equation. Then, the present value of the residual value can be expressed as the sum of the value of a call option with exercise price X and the present value of the exercise price minor the value of a put option with exercise price X. The option pricing model of Black and Scholes (1973) is not applicable in this context as its assumptions are too restrictive for the market of leased assets. The authors solve this issue by using the option pricing model with stochastic dividend yield of Geske (1978). However, the practicability of the model of Lee et al. (1982) is yet to be proven. As an example in the appendix of Lee et al. (1982, p.41) shows, the application of the model of Geske (1978) requires the "continuous time- and risk-adjusted present value of the compounded rate of economic depreciation in S_0 over T periods" (Lee et al., 1982, p. 41). Hence, without evaluating the rate of economic depreciation, the prediction of the residual value cannot be completed.

There are a lot of assets where little or no data is available. In the automotive industry this might be the case for new products like the introduction of Sports Utility Vehicles (SUVs), hybrid cars or the production of new model series like the VW (Volkswagen) Phaeton. In those cases, there is a need to develop models not requiring a large dataset or no data at all. Such a model has been developed by Rode et al. (2002, pp. 7-19). Moreover, this model incorporates uncertainty which means that not only it forecasts residual values but also offers some statements about the probability of deviating from the predicted value.

For that purpose, the model has four components which influence the depreciation of an asset. These components are useful life, economic obsolescence (for example, by the rise of new regulation standards), technical obsolescence (like newer and more efficient technological advantages) and the correlation between these components. Useful life covers the depreciation period of an asset from a value of 100% to a value of zero percent. The value for useful life normally ranges between some values depending on level of usage or quality, which is why it must be estimated. If some data points are already established, an empirical distribution will give information about values of the automobile's useful life and probabilities of those values. A depreciation pattern is then predefined including only the age of the asset and its value for useful life. The authors use the linear depreciation pattern according to age for their explanations but alternatives are also provided.[16] Economic obsolescence is modelled as a time series of one single factor over the useful life of the leased asset illustrating all alterations of the depreciation pattern due to economic influences. The modelling of the technological obsolescence is analogous. In the case of an existing dataset, an autoregressive time series model is suggested for both factors. In a last step, the correlation between those three components is estimated in order to specify the direction and magnitude of the influence. Under the assumption of a linear depreciation pattern the model can be described as

$$V_t = V_0 \left(1 - \frac{t}{\tilde{n}}\right) \prod_{i=1}^{t} (1 + \kappa_i)(1 + \tau_i),$$

where V_t is the asset's value in percentage to the basis of its new price, t is time, $\tilde{n}$ is the random variable for the useful life and κ_t and τ_t is the economic and technological influence factor at time t. This model can now be used to simulate residual values and estimate a probability distribution function for these values. The paper at hand does not expand the

[16]See Rode et al. (2002, pp.11-12) for further information.

application of the model to automobile prices or other assets, which represents a general lack in the existing literature.

A system theoretical based approach is constructed by Jost and Franke (2005). Even though details of this model are not made available due to its sole practical purpose, I decided to include it in my literature overview in order to show the variety of approaches for assessing the problem of prediction of residual values. With the brief overview provided by the authors, the model consists of four interrelated major parts or subsystems. The first subsystem simulates vehicle flows and buyback volume. Both of them have an influence on used car prices as the vehicle flow describes the lifetime of the car to its scrappage date. The length of the lifetime influences the volume of traded (older) used cars. Moreover, buyback commitments influence the number of (younger) used cars on the second-hand car market. Another subsystem explains model cycles, which are related to vehicle attractiveness of used cars and, hence, affect used car prices. The authors also introduce a system simulating exogenous factors that influences the aforementioned two subsystems. Finally, the residual value formation is constructed where residual values are modelled via demand for younger used cars and their supply.

Cheng and Wu (2006) develop an econometric method to predict automobile prices of two year old vehicles. They claim that multicollinearity, i.e. used explanatory variables being highly correlated, cause a serious problem for the use of econometric models in predicting car prices.[17] The inclusion of too many independent variables according to the number of observations can be a reason for multicollinearity. One econometric model to account for this source of multicollinearity is the partial least squares regression. The idea behind this model is to extract the relevant information of the explanatory variables for the observations of the dependent variable (Cheng and Wu, 2006, p. 262). The relevant variables are identified

[17] Other authors, however, do not consider multicollinearity as a major threat in the context of forecasting with regressions if the sole purpose is to predict the value, see for instance Makridakis et al. (1998, p. 288). Thus, the necessity to correct for this issue is questionable to me.

according to their level of covariance with the observations of the dependent variable of two year old automobile prices. This value is supposed to indicate the strength of relationship between those variables.

The authors argue that variance and correlation are better indicators for the identification of relevant variables. The variance of the relevant variable measures hereby the significance of the certain influence whereas its correlation with the used car prices quantifies the relevance of this particular influence (Cheng and Wu, 2006, p. 262). Hence, Cheng and Wu (2006, p. 264) develop the so called modified partial least squares regression which identifies relevant variables according to both criteria: variance and correlation. The performance of this methodology is compared to the partial least squares regression and three other methodologies which all attempt to resolve the problem of multicollinearity.[18] The regression models are adjusted for prices of two year old cars which cover five models of the compact utility segment in the American market from January 1995 to June 1999. Prices are then forecasted for the period from June 1999 to December 2000. The fit of the partial least squares and modified partial least squares regression is superior to the other methods. Moreover, the model constructed by the authors performs on average better than the partial least squares regression.

In order to construct a model which simulates the performance of gains and losses on automobile leasing contracts, Smith and Jin (2007, pp. 256-257) uses a regression equation to forecast the residual value of a used car in percentage in terms of its manufacturer's suggested retail price. Unfortunately, as the deviation of residual values is indispensable to construct the superordinate risk model, the regression model is presented without its estimates or its performance. The model specifies average depreciation curves for ten market segments of the American market with monthly data ranging from 1994 to 1997. Furthermore, the used

[18]These methods are: variable subset selection method, ridge regression and principal components regression.

car prices in percentage are assumed only to depend on age. The depreciation model which is to be estimated via a regression analysis is then of the form

$$\log\left(\frac{\text{current market value}}{\text{MSRP}}\right) = \beta_0 + \beta_1(\text{model age}) + \beta_2(\text{model age})^2 + \sum md_i,$$

where $md_i,\ \ i = 1, ..., 11$ is a monthly dummy variable to indicate for monthly seasonal effects and MSRP is the manufacturer's suggested retail price.

A different approach to estimate used car prices arises from the computational methodology. Wu et al. (2009, pp. 7810-7814) apply two types of this methodology to assess the problem: the artificial neural network with back-propagation and an adaptive neuro-fuzzy inference system. The first one uses an artificial neural network and adjusts its parameters backwards by comparing the estimated used car price with the actual used car price. The second method divides the input variables into different sets according to the fuzzy logic or, simply into some 'if-then' rules. Then, an artificial neural network estimates the parameters for the predefined functions for each of those sets. Finally, it estimates the single output function constructed via the weighting of these predefined functions. In order to compare their performance, Wu et al. (2009) use four car models from the manufacturing years 2000 to 2005 to train their models in the Taiwanese second-hand car market. The chosen input factors are the brand of the car, the manufacturing year and the engine style. As a possible fourth input variable, they suggest to include an equipment index, which accounts for the anti-lock braking system, traction control system and supplement restraint system. The results indicate that both models perform better by including the fourth variable; both are effective in the prediction of used car prices and the performance of the adaptive neuro-fuzzy inference system is superior to the other methodologies.

2.6 Summary and Future Reasearch

The importance of leasing as a form to finance equipment has significantly increased over the past decades. In some sectors, leasing has even replaced the classical bank credit and has become a considerable part of the assortment of banks. The work at hand aims to provide insights on the questions how leasing evolved and thus why people lease, how lease contracts can be evaluated and how the risk structure of lease contracts respectively of leasing providers can be assessed.

I have set out to give an explanation of the term "lease" but the difficulty hereby is that its definition is subject to national legislation. Hence, a uniform definition does not exist at all, which is why I give a rough definition and differentiation of leasing. This classification is acknowledged in the scientific literature and, therefore, is also used for the work at hand.

I then turn to the question why it is reasonable to lease and provide answers with explanatory approaches from both the perspective of the lessee and the lessor. The explanations are manifold and range from tax benefits, cost considerations, implicit options, reduction of adverse selection in the second-hand market to simply the desire to afford a more expensive car.

Subsequently, I examine the valuation techniques of lease contracts that can be classified into two groups: the discounted cash flow methodology or the option pricing theory. The discounted cash flow approach is restricted to value mainly financial leases. This drawback is overcome by applying the option pricing theory that also offers the possibility to rate implicit options. The current literature thus mainly cites the valuation methods of the option pricing theory.

The last part deals with the examination of the risk structure of lease contracts. First, I give a brief distinction of the risk subject to the classification of the Basel Committee on Banking Supervision in liquidity, operational, credit and market risk. Then, a specific characteristic of the market risk of leases is examined in detail, being the residual value risk. In the first place, its determinants are analysed for automotive leases. The overview shows that most studies use the hedonic approach to identify the determinants. In this context, features of a car as well as its age essentially drive the residual value. The issue of forecasting residual values is considered next. I have discovered that there are only a small number of studies dealing with this topic and even fewer papers provide an empirical validation of their developed model.

From this literature overview implications for future research can be drawn. Especially in the context of residual value risk, there is a huge need for future research. First, it might be necessary to think of alternatives to the hedonic approach, which concentrates on the features of a car. These are however prone to consumers' tastes and may vary strongly over time. Hence, the question arises whether residual values may be determined by market factors describing the market environment of a car rather than consumers' tastes. In this context, the valuation of features by consumers is replaced by factors describing the market situation of a car. These variables may be rather measurable and, additionally, rather available compared to consumers' tastes. Moreover, it is useful to analyse residual values not in terms of ageing but as a series of fixed age over time. In general, lease contracts have a fixed maturity. The question is therefore how residual values of cars evolve over time and how influences pertain during different time periods. It will be thus of high importance to conduct an examination that focuses on price changes over time not affected by the aging of the car.

Furthermore, there is a lack of research regarding prediction models for residual values of cars. The literature covers this topic with only a few works that often fail to provide an empirical validation of their models. The discussion initiated in this chapter has clearly shown the importance of appropriate forecast models. A more elaborate and detailed handling of this issue may provide substantiated support for the risk management of lease contracts.

Chapter 3

Determinants of Residual Values

Abstract

Automotive lease contracts are remarkably influenced by the specification of residual values at completion of a lease contract. These predicted values represent a considerable source of risk for contracts due to their effects on pricing and sales of cars at maturity stage. Based on an analysis of 17 automobiles in the German used car market from 1992 to 2008, I identify ARMAX regression models which explain residual values over time. These regression models are defined by variables deriving from three categories which describe the market environment of used cars. The empirical results give evidence that the chosen factors influence the residual values of cars. A comparison of effects on residual values as well as between different brands and segments allows us to draw implications for the risk management of lease contracts and lease portfolios. Furthermore, I conduct a theoretical analysis in order to show how changes in the variance of an explanatory variable affect the valuation of lease contracts by using the results of the empirical study. Then, I proof that at its upper limit lease rates increase for changes in the standard deviation of an explanatory variable.

3.1 Introduction

The importance of the market segment of leasing has significantly increased over the last decades. In 2010, leasing accounted for 20.7 percent of investments in equipment (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 13) and for approximately 50 percent of equipment externally financed in Germany (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 14). In the same year, cars and estate vehicles formed hereby the largest product group of equipment leasing with about 53 percent (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 15). Thus, management of risk in automotive lease contracts is crucial for lease firms, banks and other financial institutions.

A specific feature in the risk structure of lease contracts is the *residual value risk*. The residual value is defined as the market price or value of the leased vehicle at the maturity of the lease contract. In lease contracts great importance is attached to residual values. The lessor is compensated via lease rates for the depreciation due to the use of the leased asset during maturity of the contract. Residual values therefore directly influence lease rates. Moreover, several forms of lease contracts contain implicit options. In this case, residual values may function as strike prices for these options and may influence the initial valuation of lease contracts. A survey from Dudenhöffer and Neuberger (2007) emphasizes this certain risk which is crucial to leasing providers. It points out that 90 percent of automobile dealers who also function as lessors expect a financial risk for their lease firm due to a decline in residual values (Dudenhöffer and Neuberger, 2007, p. 6). This is confirmed by an article published in Der Spiegel (2009) which reports among other reasons that a BMW dealer declared bankruptcy because of misspecified residual values. Thus, an analysis of determinants of automobiles' residual values is necessary to understand the risk structure and to determine as well as to manage the risk of lease contracts and entire lease portfolios.

The objective of this study is to find answers to the following questions:

1. What drives residual values of cars over time?
2. Which are the similarities between different cars and segments, if any?
3. Which implications result from this analysis for risk management and for valuation of automotive lease contracts in particular?

For this purpose, I develop an empirical model which explains the residual values of cars over time. I assume hereby that residual values are mainly driven by determinants which can be distinguished in three categories explaining changes in residual values based on various conditions in 1.) the economy, 2.) the used and new car market and 3.) a particular car model. Previous studies essentially rely on features of cars which, however, vary with consumers' tastes in order to identify determinants of residual values. Thus, the use of market factors instead of features evaluated by consumers seems reasonable since such factors are rather measurable and available.

As lease contracts generally have a fixed maturity, I concentrate on how the market environment influences residual values over time. This also gives an explanation on how the risk structure of lease contracts alters due to fluctuations in the market. Contrary to previous works that focused on changes in residual values caused during a car's ageing, I aim to analyse residual values in terms of depreciation and revaluation. To be more precise, Storchmann (2004, p. 373) distinguishes cars' price changes in depreciation which "reflects the change in net present value over time" and revaluation which "is the change in value or price of an asset that is caused by everything other than aging". Formally, depreciation and revaluation can be expressed as

$$P(t,s) - P(t+1,s+1) = [P(t,s) - P(t,s+1)] - [P(t+1,s+1) - P(t,s+1)]\,,$$

where $P(t,s)$ is the price of the asset at time t and for age s (Storchmann, 2004, p. 373). The term on the left side of this equation then shows the total price change of an asset over time. The first and second term on the right side of this equation denotes depreciation and revaluation. The focus of this study is on revaluation of cars' price changes. In conclusion, the objective of the chapter at hand is to determine an empirical model which explains the revaluation of automobile prices in the German market.

In a next step, I undertake a theoretical analysis to demonstrate how fluctuations in the explanatory variables affect lease rates by using the empirical results of the determined model. To my best knowledge, this is the first study that examines this part of cars' price changes and their impacts on lease contracts. For this reason, I collect a unique dataset of monthly used car prices of 17 different automobiles over the period from June 1992 to December 2008.

The chapter is structured as follows: In section 3.2 I will review related literature concerning determinants of used car prices. Then, I will describe my dataset and the explanatory variables which I need to develop the empirical model for the revaluation of cars' residual values in section 3.3.1 and 3.3.2. Section 3.3.2 concludes with a description of the research design and the methodology applied. The empirical results will be discussed in 3.3.3 while section 3.4 derives implications for risk management of lease contracts and lease portfolios. A summary in section 3.5 completes the study.

3.2 Related Work

Previous studies of the used car market are mainly dealing with the ageing effect of cars. Most of them use the hedonic approach to find factors that influence used car prices. This method defines a car as a bundle of characteristics. Each characteristic has a certain price whereas the sum of those characteristics eventually provides the price of the used car.

An early study of Ohta and Griliches (1976) analyses the impact of physical (e.g. horsepower, weight, length etc.) and performance factors (e.g. acceleration, handling, fuel economy etc.)

on used car prices; however, fails to find any advantages of using performance characteristics over physical ones to explain used car prices. Gordon (1990) contributes to this field by analysing a longer time period. Moreover, he introduces an additional variable for a car's trim which shows a negative significant effect. His study supports the results of Ohta and Griliches (1976) for his extended observation period. The German market on the other hand is examined in a study by Dexheimer (2003). She confirms the results of former studies by showing that the age of a car, its brand and driven mileage have a significant influence on used car prices. The relationship between market factors and used car prices is analysed by Storchmann (2004). He compares the influence of per-capita private consumption and petrol prices in OECD and non-OECD countries. According to Storchmann (2004) income leads to higher depreciation rates in both areas but an increase in petrol costs solely affects OECD countries. In another study by Prado (2009), four European countries are examined in his analysis using a set of different variables divided into four categories. The first category describes factors regarding the wear of the car, the second group defines the starting point of depreciation, the next group determines market situations for every country and the last category describes the physical characteristics of the car. While characteristics improving the used car's quality increase its price, other variables used in this study lack consistent results throughout the different markets.

All of the studies mentioned above try to explain price changes with the help of influencing factors. There are several papers failing to identify determinants which generally serve as an explanation for fluctuations in used car prices. The interest is rather on examining price effects caused by one special factor or event. Although the main objective of my study is to explain movements in used car prices, I would nevertheless like to outline additional factors and their effects to provide a complete picture of what may drive used car prices.

One of them is the effect of petrol prices as Ohta and Griliches (1986) examine. Later studies by Ohta (1987) and Kahn (1986) look at how consumers' expectations about petrol prices affect used car prices, while Busse et al. (2009) and Goodmann (1983) explore outcomes of the effect of petrol price changes on both more and less fuel-efficient cars. Effects on used car prices caused by a launch of a new car are examined in Purohit (1992). Further studies deal with a car's quality as described via brand effects in Betts and Taran (2004) as well as product recalls like in Hartmann (1987). Engers et al. (2009) approximates the net benefit of a car with annual driven miles and focuses his research on how the net benefit leads to a decline in used car prices when the car ages. The study of Dunham (1997) compares the effect of various regulatory sanctions on used car prices.

The study at hand contributes to the existing literature by being the first, solely focusing on price changes in used cars resulting from revaluation. I determine factors other than ageing that affect the price of used cars. Then, I apply these results to lease valuation and examine the impact of the empirical results on lease rates. This application has never been done in previous studies but promises to be highly interesting to financial institutions that offer automobile lease contracts. The study also shows how residual values can be explained by certain determinants and how changes of particular factors may alter the value of lease contracts or lease portfolios of respective providers.

3.3 Data and Empirical Analysis

3.3.1 Description of the Dataset

For this study, used car prices are collected from DAT[19] which are determined as dealers' average prices for the German market. Car dealers and manufacturers occupy 55% of the market making them the most important sales channel for lease contracts (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 19). As I expect both manufacturers and dealers to sell the returned car at retail price, I consider the use of those prices to be appropriate

[19]DAT Deutsche Automobil Treuhand GmbH, Hellmuth-Hirth-Strasse 1, 73760 Ostfildern.

for my analysis of residual values. Moreover, most lease contracts mature after 36 months, which is why basing the analysis on three year old cars seems plausible to me.

The time series is constructed based on the method of Giacotto et al. (2007, p. 425) and uses monthly retail prices of car models which were registered exactly three years ago. The definition of a k year old car is taken according to DAT. Then for instance, a car is exactly k years old in October 2007 if it was registered in November k years ago.[20] More precisely, the point of the time series of October 2007 is defined as a car registered in November 2004; the point November 2007 is defined as a model registered in December 2004 and so forth. Following this method, time series for a total of 17 cars ranging from June 1992 to December 2008 were collected.[21] The cars included in the sample are selected according to the following criteria: 1.) the model history of the car is at least 22 years old; 2.) only vehicles from the five major car segments (subcompact, compact, medium-class, upper medium-class and luxury) are taken; 3.) all cars are among the favourites (according to registration numbers) in their segment in the last five years. The car models included in the study are listed in table 3.1 according to their segments. All of them have a petrol engine.

Since models and equipment change after a certain time, predecessors respectively successors must be identified and adjusted in the time series. Contrary to Giacotto et al. (2007, p. 425), quality adjustments such as technical improvements (e.g. development of electronic stability program (esp) in the mid 90's) cannot be incorporated or lead to inconclusive model specifications (very expensive and unusual additional equipment especially in the subcompact segment leading to very uncommon high-priced cars) for such a long time range. Instead, I use for each car the minimum engine and minimum equipment that is available in the particular model years. This approach is applied because it addresses the same group of consumers during the whole observation period.

[20] I use the Europa Code by DAT for the cars' classification in order to ensure the correct specification of the car models and to trace them throughout the observation period.

[21] To exclude effects from the German reunification my time series starts in the middle of 1992.

Table 3.1: Car models in the sample

Subcompact	**Compact**	**Medium-class**	**Upper medium-class**	**Luxury**
VW Polo	VW Golf	BMW 3 Series	Mercedes-Benz E-Class	Mercedes-Benz S-Class
Opel Corsa	Opel Astra (formerly Opel Kadett)	Mercedes-Benz C-Class (formerly Mercedes 190)	BMW 5 Series	BMW 7 Series
Ford Fiesta	Ford Focus (formerly Ford Escort)	VW Passat	Audi A6 (formerly Audi 100)	Audi A8 (formerly Audi V8)
Peugeot Series 205, 206		Audi A4 (formerly Audi 80)		

All models are adjusted for mileage. As assumed mileage I use the average driven kilometres (km) suggested for a car of three years by the DAT. Those values change according to different segments. Hence, mileage of a car included in the subcompact segment is 36 000 km, 45 000 km in the compact segment, 54 000 km in medium-class, 63 000 km in upper medium-class and 72 000 km in the luxury segment.

In a final step, I divide the used car retail prices by the latest manufacturer's suggested retail price (MSRP) (since the latest prices are only reported by DAT from 1985 to 2008) in the year the car was registered the first time. The residual value is then defined as the percentage of the used car retail price by its latest MSRP in the year the car was first registered. This ensures comparability of the residual values of the same car over time and between different automotive models.

3.3.2 Research Design and Explanatory Variables

I start with a definition of the variables used in my study to describe movements in residual values. I assume that residual values are influenced by variables which can be grouped into the following three main categories:

1. Variables specifying the economy,
2. variables characterising the used and new car market and
3. variables describing a specific car model.

The variables of the first category illustrate the economic climate nationwide. The decision to buy a car strongly depends on the financial situation of the consumer. If the financial outlook is bad, consumers may keep their old car and delay their decision to buy another car to some future point in time. Potential buyers of a new car may also decide to buy a used car instead. To account for this possible influence, I look at two perspectives of the financial situation of consumers. The first perspective observes private households as consumers. For this purpose, the financial situation of private households is described as the price-adjusted quarterly private consumer spending (pcs). In order to adopt the perspective of the industry as a consumer, I use the price-adjusted quarterly gross domestic product to measure its financial situation (gdp). Moreover, gdp serves as an indicator for the overall situation of the German economy. Another independent variable included in my study is the unemployment rate. The ownership of a car respectively the ability to buy a car strongly depends on the employment situation. It determines whether people can afford to purchase a new or used car, or a car of higher or lower segments. Thus, I take the impact of the labour market situation into account. As the unemployment rate is not stationary during the observation period, I use the monthly change in percentage of the unemployment rate as my explanatory variable ($chur$). In some cases, consumers will rely on financing to purchase a used car. Conclusively, the level of financing costs may influence the buying decision of a car. The financing costs are determined by the money market rates. To modify a proxy variable for these costs, I use monthly quotations of the rates of the EURIBOR three-month fund for the period between January 1999 and December 2008 and of the rates of the FIBOR three-month fund before 1999 (*euribor3*).

The variables of the second category describe both fluctuations in the new and used car markets. Those fluctuations are a result of the different consumers' behaviours in these markets. The first variable which I will examine more closely for the used car market can be understood as the "trading volume". This variable measures the absolute number of cars that change ownership within one month (*com*). *com* explains how each car in the analysis responds to the activity in the used car market, thus being a proxy for the size of this market. A similar variable is the absolute number of cars first registered in a month (*frcm*) which also offers insights into the size and activity or "trading volume"; however, in that case for the new car market. Together these two variables give an impression about the situation in the car markets and the behaviour of the consumers acting in them. The last variable I consider in this second category describes fluctuations in petrol prices. Petrol prices are probably the most noted and transparent costs related to the ownership of a car. Whereas the level of petrol price might not influence the buying decision itself, it will possibly affect the choice of the car model. That is why I include a measure for petrol prices in my analysis. For this purpose, I use the monthly petrol price for normal benzine (measured in Euro Cent).[22,23] As petrol prices have been fluctuating more and more in recent history, I use the logarithm of petrol prices to avoid including a heteroscedastic time series (*lnpp*).

[22] Premium benzine is not considered in this study because its time series just started in 1999.

[23] As data was missing in the source for the years 1996, 1997 and 1998, I approximate those values by using the consumer price index for normal benzine. The values are then generated by using the benzine price from January 1999 to calculate backwards by multiplying the index with exactly this price. The benzine price from December 1995 is used afterwards to calculate forward according to the same methodology. In the final step, the average value between these two calculated prices is used to approximate the missing values.

The third category includes variables which describe the underlying car model more precisely. Car models which have been on sale for a while in the used car market may be less attractive than used cars with a short model history. Hence, residual values may alter with the topicality of a car. For this reason, I construct a variable which measures the number of months the car model has already been available in the used car market (*modern*). The variable equals zero for any three year old car that first enters the used car market. For example, a car model with a model cycle of 36 month is launched in the new car market in January 2000. Three years later, December 2002 will then mark its first appearance in the used car market. In that case, *modern* equals zero in December 2002, grows up to 36 in December 2005 and finally equals zero again in January 2006 when the next model is launched. I use dummy variables to define the model cycles which equal one if the model belongs to the cycle and zero if not. For instance, in February 1998 another car model of VW Golf is launched in the used car market for three year old cars. This means that one dummy is used for the times series of VW Golf which equals zero from June 1992 to January 1998 and equals one from February 1998 to December 2008. In case of k model changes in the observation period, k dummy variables have to be established $(d_1, ..., d_k)$. Since some car models' residual values do not satisfy the stationarity assumption I have to use first differences for these cars (I will deal with this point in the following). With the example at hand, I also establish a dummy variable for price changes which equals one respectively zero depending on whether a new model is launched or not (*mc*). This variable indicates the price changes which appear for model changes and is used instead of the dummy variables d_i for those cars with first-differenced residual values. During a model cycle some car models might undergo a rework process for which I implement the variable called *facelift* equalling one if a facelift is launched in the used car market or zero if otherwise.

Data for the variables of the first category are taken from the German Federal Bureau of Statistics[24] and from the German Central Bank (Deutsche Bundesbank)[25].[26] All the variables of the second category were collected from the VDA[27] annual reports from 1989 to 2009.

The analysis of the different variables above and their impact on residual values indicates a serial correlation for the error terms. To overcome this issue, I first include a lagged dependent variable and conduct a linear OLS time series regression. If serial correlation continues to remain in the error term, I use an ARMAX time series regression instead (without a lagged dependent variable) which is a linear regression model with ARMA error terms. The coefficients are estimated by a maximum likelihood estimation. In order to identify the appropriate ARMA model for the error term, I analyse both the autocorrelations and the partial autocorrelations of this particular error. To verify that the properties of the error term hold, I test the stationarity of the residuals of the structural equation (which I will refer to as N_t in the following) by using a Phillips-Perron test and examine the white noise property of the errors (which I will denote as ϵ_t in the following) with a Portmanteau (Q) test.

As dependent variable I use the residual values of the different car models over time ($value_t$, June 1992 $\leq t \leq$ December 2008) or respectively their first difference ($dvalue_t$, June 1992 $\leq t \leq$ December 2008). The decision of which dependent variable to use depends on the stationarity assumption. Except for the Ford Fiesta, the VW Polo and the Audi A6, all other cars are stationary at least at the ten percent significance level according to the Phillips-Perron test. The already mentioned exceptions are first-order stationary at the one percent significance level. The factors of the three categories explained above define the independent

[24]Statistisches Bundesamt, Gustav-Stresemann-Ring 11, 65189 Wiesbaden, http://www.destatis.de.

[25]Deutsche Bundesbank, Wilhelm-Epstein-Str. 14, 60431 Frankfurt, http://www.bundesbank.de

[26]The consumer price index for petrol which I need to calculate the missing observations of the petrol price is taken from the German Federal Bureau of Statistics as well.

[27]Verband der Automobilindustrie e.V. (VDA), Behrenstr. 35, 10117 Berlin.

variables. All independent variables are stationary or trend-stationary at least at the ten percent significance level according to the Phillips-Perron test.[28]

In order to mirror the information available to consumers, I use data that is observable in the market. For example, private consumer spending figures are calculated at the end of each quarter. Hence, I use those figures to test for instance how the value of the first quarter influence the dependent variable in April, May and June. The value of the second quarter is then publicly available and applied to test for the influences on the dependent variable in July, August, September and so forth. Analogical, I use lagged monthly explanatory variables to test the relationship between the dependent and independent variables. Exceptions are the proxy for the financing costs and the number of first registered cars. Changes in interest rates are not immediately incorporated in financing costs which is why I allow a lag of three months. For the number of first registrations I use a lag of 36 months as I am interested in observing market movements when the leased cars were new. I wish to examine whether a strong activity in the new car market has an effect on supply and demand for these cars in the used car market. In addition, the employed approach of lagged independent variables avoids endogenity.

I check the correlations between the explanatory variables which indicate no multicollinearity. Furthermore, I estimate robust standard errors for every car model. The descriptive statistics for the variables used in my analysis are reported in Panel A of table 3.2 for the car models and in Panel B for the explanatory variables. Additionally, I report in table 3.2 the results of the Phillips-Perron test for each used variable.

[28] Trend-stationary variables are *pcs*, *gdp*, *lnpp*.

Table 3.2

Descriptive Statistics for the observation period from

June 1992 to December 2008

This table reports the descriptive statistics for the car models and the explanatory variables which are used in the analysis of this chapter for the observation period from June 1992 to December 2008. Therefore, $value_t$ denotes the residual value, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the monthly unemployment rate, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three month, gdp_{t-1} the lagged price-adjusted quarterly gross domestic product, pcs_{t-1} the lagged price-adjusted quarterly private consumer spending and $lnpp_{t-1}$ denotes the lagged logarithm of monthly petrol prices. A d before a variable denotes its first difference. The variable in parentheses behind the car models denotes whether I use the residual value or its first difference. The value in parentheses concerning the Phillips-Perron test denotes the corresponding probability. For trending variables I perform the Phillips-Perron test including a trend.

Panel A: Descriptive statistics for the car models

variables	**number of observations**	**mean**	**standard deviation**	**Phillips Perron test**
VW Polo ($dvalue_t$)	199	-0.1654	1.2213	-15.485
				(0.00)
Opel Corsa ($dvalue_t$)	199	60.0855	4.3004	-2.830
				(0.05)
Ford Fiesta ($dvalue_t$)	199	-0.1483	1.5737	-14.075
				(0.00)
Peugeot ($value_t$)	199	60.9366	5.0128	-2.656
				(0.08)
VW Golf ($value_t$)	199	62.1573	3.4887	-2.983
				(0.04)
Opel Astra ($value_t$)	199	57.1499	5.8711	-2.762
				(0.06)
Ford Focus ($value_t$)	199	57.3644	3.5761	-2.717
				(0.07)
BMW 3 Series ($value_t$)	199	61.5210	3.8092	-2.627
				(0.09)
Mercedes-Benz C-Class	199	60.2564	38595	-3.228
($value_t$)				(0.02)
VW Passat ($value_t$)	199	54.9977	4.0890	-3.661
				(0.00)
Audi A4 ($value_t$)	199	59.2798	3.6331	-2.594
				(0.09)
Mercedes-Benz E-Class	199	-0.0728	1.1784	-14.936
($dvalue_t$)				(0.00)
BMW 5 Series ($value_t$)	199	55.0126	3.6148	-3.350
				(0.01)

variables	**number of observations**	**mean**	**standard deviation**	**Phillips Perron test**
Audi A6 ($dvalue_t$)	199	0.0086	1.3640	-15.013 (0.00)
Mercedes-Benz S-Class ($dvalue_t$)	199	-0.0286	2.0452	-13.577 (0.00)
BMW 7 Series ($dvalue_t$)	199	-0.0279	1.6488	-13.709 (0.00)
Audi A8 ($value_t$)	199	45.5626	5.9358	-2.621 (0.09)
Panel B: Descriptive statistics for the explanatory variables				
com_{t-1}	199	592638	64361.03	-8.870 (0.00)
$dcom_{t-1}$	199	-1025.995	67392.81	-28.163 (0.00)
$frcm_{t-36}$	199	285476.7	54615.53	-8.918 (0.00)
$dfrcm_{t-36}$	199	48.8694	57754.6	-22.073 (0.00)
$euribor3_{t-3}$	199	4.0878	1.8141	-3.432 (0.01)
$deuribor3_{t-3}$	199	-0.0231	0.1624	-9.293 (0.00)
$chur_{t-1}$	199	0.0333	3.7312	-8.144 (0.00)
gdp_{t-1}	199	97.8284	7.2978	with trend -5.259 (0.00)
$dgdp_{t-1}$	199	0.3859	2.1657	-7.142 (0.00)
pcs_{t-1}	199	97.0801	6.0430	with trend -6.166 (0.00)
$dpcs_{t-1}$	199	0.2767	4.4115	-7.788 (0.00)
$lnpp_{t-1}$	199	4.5571	0.2247	with trend -3.933 (0.01)
$dlnpp_{t-1}$	199	0.0034	0.0273	-13.462 (0.00)

Since I include the variables *modern* and the dummies $d_1, ..., d_k$ in my regressions, I can also take into account a deterministic time trend shown by some independent variables for the observation period. To examine the robustness of my results to the inclusion of those trending variables, I also report robustness tests in section 3.3.3. Here, I perform the analysis with trend-adjusted independent variables to proof that the results are stable.

3.3.3 Results

In this section I will present the findings of the empirical analysis. I identified the ARMA models for the error term by analysing its autocorrelations and partial autocorrelations. To check for white noise errors I use the Portmanteau (Q) test statistic. A summary of all models for each car type can be found in table 3.3. As the residuals of the structural equation of the Mercedes-Benz E-Class, the Mercedes-Benz S-Class and the BMW 7 Series are not stationary, I have to differentiate the variables and perform the same analysis for their first differences. The evaluation of the dynamic and ARMAX regression models for the cars without differentiated variables are listed in table 3.4, the one for models in need of differentiating in table 3.5. The robustness tests are reported in table 3.6. In the case where I can conduct an OLS regression, I report the F-statistic instead of the χ^2-statistic.[29]

By analysing the results I observe that the modernity factor has a highly significant negative impact on a wide majority of the car models. I thus obtain supporting evidence that residual values decrease the longer a certain type of car model is available in the used car market.

[29]For the Audi A6 I do not report the results of the OLS regression but of the maximum likelihood estimation. This is due to the fact that for the OLS regression no F statistic can be reported due to the variable facelift which is unequal to zero for exactly one observation. This, however, does not change the evidence of the results. The differences in values of the standard deviation and coefficients are minor and can thus be neglected.

Table 3.3

Selected ARMAX models for the cars of the sample

This table shows the selected ARMAX regression models for the cars of the sample. In this context, $value_t$ denotes the residual value, d_i denotes the dummy for the i-th successor since June 1992, $modern$ the variable for modernity, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the quarterly unemployment rate, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three month, gdp_{t-1} the lagged price-adjusted quarterly gross domestic product, pcs_{t-1} the lagged price-adjusted quarterly private consumer spending, $lnpp_{t-1}$ denotes the lagged logarithm of monthly petrol price and mc the dummy for a model change. A d before a variable denotes its first difference. N_t denotes the error term and ϵ_t a white noise series. B is the backward shift operator. α is the intercept and β_i the regression coefficients of the independent variables. ϕ_i is the coefficient of the AR term, Φ_i the one of the seasonal AR term and θ_i the one of the MA term.

car model	**ARMAX model**	**error term**
Opel Corsa	$value_t = \alpha + \beta_1 d_1 + \beta_2 d_2 + \beta_3 modern + \beta_4 com_{t-1} + \beta_5 frcm_{t-36} + \beta_6 euribor3_{t-3} + \beta_7 chur_{t-1} + \beta_8 gdp_{t-1} + \beta_9 pcs_{t-1} + \beta_{10} lnpp_{t-1} + N_t$	$(1 - \phi_1 B - \phi_2 B^2)N_t = \epsilon_t$
VW Polo	$dvalue_t = \alpha + \beta_1 mc + \beta_2 modern + \beta_3 dcom_{t-1} + \beta_4 dfrcm_{t-36} + \beta_5 deuribor3_{t-3} + \beta_6 chur_{t-1} + \beta_7 dgdp_{t-1} + \beta_8 dpcs_{t-1} + \beta_9 dlnpp_{t-1} + N_t$	$(1 - \phi_1 B^{12})N_t = (1 - \theta_1 B^{12})\epsilon_t$
Peugeot Series 205, 206	$value_t = \alpha + \beta_1 value_{t-1} + \beta_2 d_1 + \beta_3 modern + \beta_4 com_{t-1} + \beta_5 frcm_{t-36} + \beta_6 euribor3_{t-3} + \beta_7 chur_{t-1} + \beta_8 gdp_{t-1} + \beta_9 pcs_{t-1} + \beta_{10} lnpp_{t-1} + N_t$	$N_t = \epsilon_t$
Ford Fiesta	$dvalue_t = \alpha + \beta_1 mc + \beta_2 modern + \beta_3 dcom_{t-1} + \beta_4 dfrcm_{t-36} + \beta_5 deuribor3_{t-3} + \beta_6 chur_{t-1} + \beta_7 dgdp_{t-1} + \beta_8 dpcs_{t-1} + \beta_9 dlnpp_{t-1} + N_t$	$(1 - \phi_1 B^{12})N_t = \epsilon_t$
VW Golf	$value_t = \alpha + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 modern + \beta_5 com_{t-1} + \beta_6 frcm_{t-36} + \beta_7 euribor3_{t-3} + \beta_8 chur_{t-1} + \beta_9 gdp_{t-1} + \beta_{10} pcs_{t-1} + \beta_{11} lnpp_{t-1} + N_t$	$(1-\phi_1 B-\phi_2 B^2)(1-\Phi_1 B^{12})N_t = \epsilon_t$
Ford Focus	$value_t = \alpha + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 modern + \beta_5 com_{t-1} + \beta_6 frcm_{t-36} + \beta_7 euribor3_{t-3} + \beta_8 chur_{t-1} + \beta_9 gdp_{t-1} + \beta_{10} pcs_{t-1} + \beta_{11} lnpp_{t-1} + N_t$	$(1 - \phi_1 B - \phi_2 B^2)N_t = \epsilon_t$
Opel Astra	$value_t = \alpha + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 modern + \beta_5 com_{t-1} + \beta_6 frcm_{t-36} + \beta_7 euribor3_{t-3} + \beta_8 chur_{t-1} + \beta_9 gdp_{t-1} + \beta_{10} pcs_{t-1} + \beta_{11} lnpp_{t-1} + N_t$	$(1 - \phi_1 B)(1 - \Phi_1 B^{12})N_t = \epsilon_t$

Table 3.3 (continued)

Selected ARMAX models for the cars of the sample

car model	**model**	**error term**
BMW 3 Series	$value_t = \alpha + \beta_1\, value_{t-1} + \beta_2\, d_1 + \beta_3\, d_2 + \beta_4\, d_3 + \beta_5\, modern + \beta_6\, com_{t-1} + \beta_7\, frcm_{t-36} + \beta_8\, euribor3_{t-3} + \beta_9\, chur_{t-1} + \beta_{10}\, gdp_{t-1} + \beta_{11}\, pcs_{t-1} + \beta_{12}\, lnpp_{t-1} + N_t$	$N_t = \epsilon_t$
Mercedes-Benz C-Class	$value_t = \alpha + \beta_1\, d_1 + \beta_2\, d_2 + \beta_3\, modern + \beta_4\, com_{t-1} + \beta_5\, frcm_{t-36} + \beta_6\, euribor3_{t-3} + \beta_7\, chur_{t-1} + \beta_8\, gdp_{t-1} + \beta_9\, pcs_{t-1} + \beta_{10}\, lnpp_{t-1} + N_t$	$(1 - \phi_1 B)(1 - \Phi_1 B^{12})N_t = \epsilon_t$
VW Passat	$value_t = \alpha + \beta_1\, d_1 + \beta_2\, d_2 + \beta_3\, d_3 + \beta_4\, d_4 + \beta_5\, modern + \beta_6\, com_{t-1} + \beta_7\, frcm_{t-36} + \beta_8\, euribor3_{t-3} + \beta_9\, chur_{t-1} + \beta_{10}\, gdp_{t-1} + \beta_{11}\, pcs_{t-1} + \beta_{12}\, lnpp_{t-1} + N_t$	$(1 - \phi_1 B)N_t = \epsilon_t$
Audi A4	$value_t = \alpha + \beta_1\, d_1 + \beta_2\, d_2 + \beta_3\, d_3 + \beta_4\, facelift + \beta_5\, modern + \beta_6\, com_{t-1} + \beta_7\, frcm_{t-36} + \beta_8\, euribor3_{t-3} + \beta_9\, chur_{t-1} + \beta_{10}\, gdp_{t-1} + \beta_{11}\, pcs_{t-1} + \beta_{12}\, lnpp_{t-1} + N_t$	$(1 - \phi_1 B)N_t = \epsilon_t$
Mercedes-Benz E-Class	$dvalue_t = \alpha + \beta_1\, mc + \beta_2\, modern + \beta_3\, dcom_{t-1} + \beta_4\, dfrcm_{t-36} + \beta_5\, deuribor3_{t-3} + \beta_6\, chur_{t-1} + \beta_7\, dgdp_{t-1} + \beta_8\, dpcs_{t-1} + \beta_9\, dlnpp_{t-1} + N_t$	$N_t = \epsilon_t$
BMW 5 Series	$value_t = \alpha + \beta_1\, d_1 + \beta_2\, modern + \beta_4\, com_{t-1} + \beta_5\, frcm_{t-36} + \beta_6\, euribor3_{t-3} + \beta_7\, chur_{t-1} + \beta_8\, gdp_{t-1} + \beta_9\, pcs_{t-1} + \beta_{10}\, lnpp_{t-1} + N_t$	$(1 - \phi_1 B)N_t = \epsilon_t$
Audi A6	$dvalue_t = \alpha + \beta_1\, mc + \beta_2\, facelift + \beta_3\, modern + \beta_4\, dcom_{t-1} + \beta_5\, dfrcm_{t-36} + \beta_6\, deuribor3_{t-3} + \beta_7\, chur_{t-1} + \beta_8\, dgdp_{t-1} + \beta_9\, dpcs_{t-1} + \beta_{10}\, dlnpp_{t-1} + N_t$	$N_t = \epsilon_t$
Mercedes-Benz S-Class	$dvalue_t = \alpha + \beta_1\, mc + \beta_2\, modern + \beta_3\, dcom_{t-1} + \beta_4\, dfrcm_{t-36} + \beta_5\, deuribor3_{t-3} + \beta_6\, chur_{t-1} + \beta_7\, dgdp_{t-1} + \beta_8\, dpcs_{t-1} + \beta_9\, dlnpp_{t-1} + N_t$	$(1 - \phi_1 B)N_t = \epsilon_t$
BMW 7 Series	$dvalue_t = \alpha + \beta_1\, mc + \beta_2\, facelift + \beta_3\, modern + \beta_4\, dcom_{t-1} + \beta_5\, dfrcm_{t-36} + \beta_6\, deuribor3_{t-3} + \beta_7\, chur_{t-1} + \beta_8\, dgdp_{t-1} + \beta_9\, dpcs_{t-1} + \beta_{10}\, dlnpp_{t-1} + N_t$	$(1 - \phi_1 B)N_t = \epsilon_t$

Table 3.3 (continued)

Selected ARMAX models for the cars of the sample

car model	model	error term
Audi A8	$value_t = \alpha + \beta_1\, d_1 + \beta_2\, d_2 + \beta_3\, modern + \beta_4\, com_{t-1} + \beta_5\, frcm_{t-36} + \beta_6\, euribor3_{t-3} + \beta_7\, chur_{t-1} + \beta_8\, gdp_{t-1} + \beta_9\, pcs_{t-1} + \beta_{10}\, lnpp_{t-1} + N_t$	$(1 - \phi_1 B - \phi_2 B^2) N_t = \epsilon_t$

Table 3.4

Empirical results of the ARMAX model estimation for the cars with stationary residual values

This table reports the results of the ARMAX regression models for those cars where the residual value is the independent variable. d_i denotes the dummy for the i-th successor since June 1992, $modern$ the variable for modernity, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the monthly unemployment rate, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three month, gdp_{t-1} the lagged price-adjusted quarterly gross domestic product, pcs_{t-1} the lagged price-adjusted quarterly private consumer spending, $lnpp_{t-1}$ denotes the lagged logarithm of monthly petrol prices and α the intercept. The values in parentheses with the coefficients denote the standard deviations. The values in parentheses with the χ^2 respectively F test statistic, the Phillips-Perron test and the Portmanteau (Q) test denote the corresponding probabilities. N is the number of observations. $\hat{\sigma}$ is the estimated standard deviation of the white noise disturbance. All estimated standard errors are robust standard errors.

variable	**Opel Corsa**	**Peugeot**	**VW Golf**	**Ford Focus**	**Opel Astra**	**BMW 3 Series**	**Mercedes C-Class**	**VW Passat**	**Audi A4**	**BMW 5 Series**	**Audi A8**
d_1	-7.592***	4.479**	-8.129***	-4.825***	-10.58***	-1.569	-7.899*	-8.585**	-4.162***	1.577	7.762***
	(2.66)	(2.217)	(1.719)	(.9384)	(1.873)	(1.966)	(4.716)	(3.739)	(.9767)	(1.306)	(1.499)
d_2	-13.08***	–	-10.4***	-4.976**	-18.36***	-2.077	-11.56*	-3.82	2.933*	-2.368	5.285
	(4.869)		(2.916)	(2.256)	(3.684)	(2.998)	(6.989)	(5.866)	(1.7)	(2.765)	(3.486)
d_3	–	–	-15.94***	-13.13***	-19.99***	-1.47	–	-11.07	.6627	–	–
			(4.167)	(3.528)	(4.96)	(3.951)		(9.057)	(2.881)		
d_4	–	–	–	–	–	–	–	-14.15	–	–	–
								(12.29)			
$value_{t-1}$	–	.6879***	–	–	–	.7802***	–	–	–	–	–
		(.171)				(.0808)					
$facelift$	–	–	–	–	–	–	–	–	2.445*	–	–
									(1.383)		
$modern$	-.1397***	-.006	-.1962***	-.1339***	-.2518***	-.0327	-.164***	-.2475***	-.13***	-.1438***	-.1679***
	(.0227)	(.0099)	(.019)	(.0177)	(.0219)	(.02)	(.0306)	(.0625)	(.017)	(.0163)	(.0195)
com_{t-1}	$-4.2 \cdot 10^{-7}$	$-4.9 \cdot 10^{-6}$	$6.1 \cdot 10^{-7}$	$-2.3 \cdot 10^{-7}$	$5.6 \cdot 10^{-7}$	$5.9 \cdot 10^{-6}$*	$7.8 \cdot 10^{-7}$	$6.5 \cdot 10^{-7}$	$1.1 \cdot 10^{-6}$	$4.8 \cdot 10^{-7}$	$-7.1 \cdot 10^{-7}$
	$(6.9 \cdot 10^{-7})$	$(3.3 \cdot 10^{-6})$	$(5.2 \cdot 10^{-7})$	$(5.6 \cdot 10^{-7})$	$(7.8 \cdot 10^{-7})$	$(3.3 \cdot 10^{-6})$	$(9.3 \cdot 10^{-7})$	$(5.5 \cdot 10^{-7})$	$(1.1 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$	$(7.8 \cdot 10^{-7})$
$frcm_{t-36}$	$1.4 \cdot 10^{-6}$	$1.6 \cdot 10^{-6}$	$1.7 \cdot 10^{-6}$**	$7.7 \cdot 10^{-7}$	$8.1 \cdot 10^{-7}$	$-1.8 \cdot 10^{-6}$	$-1.2 \cdot 10^{-8}$	$1.9 \cdot 10^{-6}$*	$-5.1 \cdot 10^{-8}$	$4.6 \cdot 10^{-7}$	$-8.5 \cdot 10^{-7}$
	$(1.2 \cdot 10^{-6})$	$(1.6 \cdot 10^{-6})$	$(8.1 \cdot 10^{-7})$	$(7.4 \cdot 10^{-7})$	$(9.2 \cdot 10^{-7})$	$(2.0 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$	$(7.8 \cdot 10^{-7})$	$(9.0 \cdot 10^{-7})$	$(8.7 \cdot 10^{-7})$

Table 3.4 (continued)

Empirical results of the ARMAX model estimation for the cars with stationary residual values

variable	**Opel Corsa**	**Peugeot**	**VW Golf**	**Ford Focus**	**Opel Astra**	**BMW 3 Series**	**Mercedes C-Class**	**VW Passat**	**Audi A4**	**BMW 5 Series**	**Audi A8**
$euribor3_{t-3}$	.5784	.2007	-.0253	-.0373	.2907	-.1075	-.0403	-.5101	.4823*	.0653	.4568
	(.7443)	(.1447)	(.3301)	(.26)	(.2366)	(.1501)	(.6067)	(1.116)	(.2912)	(.2317)	(.2936)
$chur_{t-1}$	.0375**	.0836**	.037**	.0207*	-.0012	-.0462	.0196	.0172	-.007	.0213	.0107
	(.0174)	(.0382)	(.0148)	(.0125)	(.0154)	(.0446)	(.0222)	(.0173)	(.014)	(.0135)	(.0145)
gdp_{t-1}	-.0298	.2186**	.0031	.0417	.0545	.1203	.0274	.0466	-.0486	-.0161	.0081
	(.0586)	(.1029)	(.0625)	(.0499)	(.0569)	(.1019)	(.0725)	(.0501)	(.0591)	(.0462)	(.0621)
pcs_{t-1}	-.0213	-.3171**	-.0294	-.0697**	-.0301	.0722	-.017	-.0571	-.0011	-.046	-.0246
	(.0491)	(.1475)	(.0363)	(.0282)	(.0418)	(.0662)	(.0501)	(.0427)	(.0343)	(.0329)	(.0321)
$lnpp_{t-1}$	1.365	-7.098**	-.6852	-1.296	-2.191	-4.845**	.2135	1.809	.5266	-1.587	-1.496
	(2.731)	(3.114)	(1.328)	(2.384)	(1.354)	(2.412)	(1.954)	(1.34)	(1.305)	(1.917)	(1.221)
α	71.17***	60.67**	83.81***	76.36***	85.95***	17.39*	74.24***	62.04***	62.97***	73.18***	55.34***
	(12.25)	(29.77)	(6.886)	(9.8)	(7.603)	(9.107)	(10.12)	(14.88)	(7.828)	(8.888)	(6.985)
ARMA term											
ar(1)	1.1***	–	1.156***	1.22***	.9449***	–	.8806***	.965***	.9379***	.938***	1.247***
	(.0681)		(.0686)	(.0788)	(.0206)		(.0861)	(.0844)	(.0322)	(.0287)	(.1091)
ar(2)	-.1795***	–	-.2269***	-.2814***	–	–	–	–	–	–	-.3013**
	(.0669)		(.0696)	(.0807)							(.1196)
ar(12)	–	–	.3925***	–	.5051***	–	.2268*	–	–	–	–
			(.1206)		(.1377)		(.1239)				
$\hat{\sigma}$	.7842***	–	.5881***	.5839***	.6097***	–	.8662***	.7056***	.6444***	.6787***	.6286***
	(.1064)		(.0665)	(.0544)	(.0512)		(.1295)	(.1211)	(.0709)	(.1016)	(.0666)
N	199	199	199	199	199	199	199	199	199	199	199

Table 3.4 (continued)

Empirical results of the ARMAX model estimation for the cars with stationary residual values

variable	Opel Corsa	Peugeot	VW Golf	Ford Focus	Opel Astra	BMW 3 Series	Mercedes C-Class	VW Passat	Audi A4	BMW 5 Series	Audi A8
χ^2/F	3779.56	442.33	5330.57	4375.87	28459.75	515.79	5489.72	71368.67	8278.62	7598.36	32312.71
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Phillips-	-2.7983	-12.832	-2.887	-2.966	-2.922	-11.772	-4.360	-2.749	-2.867	-2.709	-3.147
Perron test	(0.06)	(0.00)	(0.05)	(0.04)	(0.04)	(0.00)	(0.00)	(0.07)	(0.05)	(0.07)	(0.00)
Portmanteau	34.73	28.73	34.35	35.13	29.41	22.39	40.20	50.50	45.95	19.89	35.24
(Q) test	(0.71)	(0.91)	(0.72)	(0.69)	(0.89)	(0.99)	(0.46)	(0.12)	(0.24)	(0.99)	(0.68)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.5

Empirical results of the ARMAX model estimation for the cars with first-differenced residual values

This table reports the results of the ARMAX regression models for those cars which need first differences of the residual values for the analysis. mc denotes the dummy for a model change, $modern$ the variable for modernity, $dcom_{t-1}$ the lagged first difference of the total monthly number of change of ownership, $dfrcm_{t-36}$ the first difference of the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the monthly unemployment rate, $deuribor3_{t-3}$ the lagged first difference of the three-month EURIBOR interest rate lagged three month, $dgdp_{t-1}$ the lagged first difference of the price-adjusted quarterly gross domestic product, $dpcs_{t-1}$ the lagged first difference of the price-adjusted quarterly private consumer spending, $dlnpp_{t-1}$ denotes the lagged first difference of the logarithm of monthly petrol prices and α the intercept. The values in parentheses with the coefficients denote the standard deviations. The values in parentheses with the χ^2 respectively F test statistic, the Phillips-Perron test and the Portmanteau (Q) test denote the corresponding probabilities. N is the number of observations. $\hat{\sigma}$ is the estimated standard deviation of the white noise disturbance. All estimated standard errors are robust standard erros.

variable	**VW Polo**	**Ford Fiesta**	**Mercedes E-Class**	**Audi A6**	**Mercedes S-Class**	**BMW 7 Series**
mc	7.27***	9.564***	9.31***	9.211***	14.74***	14.46***
	(1.895)	(2.035)	(.4607)	(2.182)	(2.596)	(1.238)
$facelift$	–	–	–	-4.518**	–	5.912***
				(2.225)		(.2337)
$modern$	$-3.0 \cdot 10^{-4}$	-.0018	.0021	$-2.8 \cdot 10^{-4}$	-.0012	.0014
	(.0014)	(.0029)	(.0014)	(.0017)	(.0013)	(.002)
$dcom_{t-1}$	$8.3 \cdot 10^{-7}$	.5081*	$1.4 \cdot 10^{-6}$*	$1.1 \cdot 10^{-6}$**	$1.5 \cdot 10^{-6}$*	$8.5 \cdot 10^{-7}$
	$(7.7 \cdot 10^{-7})$	(.3027)	$(8.8 \cdot 10^{-7})$	$(5.2 \cdot 10^{-7})$	$(8.8 \cdot 10^{-7})$	$(6.4 \cdot 10^{-7})$
$dfrcm_{t-36}$	$5.7 \cdot 10^{-7}$	$2.1 \cdot 10^{-6}$*	$-7.2 \cdot 10^{-7}$	$1.6 \cdot 10^{-7}$	$1.2 \cdot 10^{-10}$	$3.5 \cdot 10^{-7}$
	$(1.2 \cdot 10^{-6})$	$(1.2 \cdot 10^{-6})$	$(6.9 \cdot 10^{-7})$	$(6.0 \cdot 10^{-7})$	$(8.8 \cdot 10^{-7})$	$(6.4 \cdot 10^{-7})$
$deuribor3_{t-3}$	-.574	-1.301**	-.4763*	.2057	.0277	-.0464
	(.6898)	(.603)	(.2489)	(.4649)	(.3939)	(.2929)
$chur_{t-1}$	-.0219	.0329	.005	-.0129	-.003	.0085
	(.0223)	(.0262)	(.0177)	(.0161)	(.0194)	(.0168)
$dgdp_{t-1}$	-.0926	.0634	-.0018	-.0269	-.031	.0135
	(.072)	(.0715)	(.0478)	(.0436)	(.0481)	(.0468)
$dpcs_{t-1}$	.0437	-.051	-.0117	.0092	.0197	-.0189
	(.0355)	(.0417)	(.027)	(.0263)	(.0311)	(.0288)

Table 3.5 (continued)

Empirical results of the ARMAX model estimation for cars with first-differenced residual values (continued)

variable	**VW Polo**	**Ford Fiesta**	**Mercedes E-Class**	**Audi A6**	**Mercedes S-Class**	**BMW 7 Series**
$dlnpp_{t-1}$	.8062	-4.631	-1.686	-.7756	2.63	-3.633**
	(2.14)	(4.116)	(1.713)	(1.36)	(2.207)	(1.706)
α	-.0544	-.1113	-.2757***	-.1248	-.1841**	-.2531**
	(.1335)	(.1393)	(.0832)	(.0831)	(.0905)	(.1103)
ARMA term						
ar(1)	–	–	–	–	.1235*	.1351**
					(.0651)	(.0659)
ar(12)	.5004***	.2217*	–	–	–	–
	(.1443)	(.1183)				
ma(12)	-.3581***	–	–	–	–	–
	(.1275)					
$\hat{\sigma}$	.9574***	.9841***	–	.7075***	0.9072	.6671***
	(.1479)	(.1198)		(.1119)	(0.1287)	(.0563)
N	199	199	199	199	199	199
χ^2/F	32.78	67.46	47.66	22539.93	68.10	1430.61
	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Phillips-Perron test	-14.615	-13.706	-12.855	-12.474	-12.519	-12.274
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Portmanteau (Q) test	26.36	23.88	33.28	16.70	48.60	37.22
	(0.75)	(0.98)	(0.76)	(0.99)	(0.17)	(0.60)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.6

Robustness tests

This table reports the robustness test to the inclusion of trending explanatory variables in the ARMAX regression. d_i denotes the dummy for the i-th successor since June 1992, $modern$ the variable for modernity, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the monthly unemployment rate, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three month, $gdpta_{t-1}$ the lagged trend-adjusted price-adjusted quarterly gross domestic product, $pcsta_{t-1}$ the lagged trend-adjusted price-adjusted quarterly private consumer spending, $lnppta_{t-1}$ denotes the lagged trend-adjusted logarithm of monthly petrol prices and α the intercept. The values in parentheses with the coefficients denote the standard deviations. The values in parentheses with the χ^2 respectively F test statistic, the Phillips-Perron test and the Portmanteau (Q) test denote the corresponding probabilities. N is the number of observations. $\hat{\sigma}$ is the estimated standard deviation of the white noise disturbance. All estimated standard errors are robust standard errors.

variable	**Opel Corsa**	**Peugeot**	**VW Golf**	**Ford Focus**	**Opel Astra**	**BMW 3 Series**	**Mercedes C-Class**	**VW Passat**	**Audi A4**	**BMW 5 Series**	**Audi A8**
d_1	-7.641***	-.3929	-8.595***	-5.124***	-10.95***	-1.285	-7.551*	-8.14**	-4.406***	.547	7.266***
	(2.053)	(.5179)	(1.56)	(.7435)	(1.743)	(.8833)	(4.102)	(3.681)	(.9016)	(.9674)	(1.4)
d_2	-13.16***	–	-11.22***	-5.786***	-19.09***	-1.519*	-10.99*	-3.11	2.544	-4.489**	4.045
	(3.865)		(2.64)	(1.588)	(3.416)	(.8761)	(5.975)	(5.782)	(1.613)	(1.944)	(3.223)
d_3	–	–	-17.08***	-14.42***	-20.98***	-.6769	–	-10	-.0394	–	–
			(3.748)	(2.42)	(4.594)	(1.485)		(8.934)	(2.693)		
d_4	–	–	–	–	–	–	–	-12.71	–	–	–
								(12.13)			
$value_{t-1}$	–	.6879***	–	–	–	.7802***	–	–	–	–	–
		(.171)				(.0808)					
$facelift$	–	–	–	–	–	–	–	–	2.447*	–	–
									(1.383)		
$modern$	-.1401***	-.0347*	-.201***	-.14***	-.2561***	-.0298**	-.1614***	-.2401***	-.1341***	-.1559***	-.1748***
	(.018)	(.0187)	(.017)	(.0121)	(.0202)	(.0119)	(.026)	(.0616)	(.0157)	(.0118)	(.0179)
com_{t-1}	$-4.2 \cdot 10^{-7}$	$-4.9 \cdot 10^{-6}$	$6.1 \cdot 10^{-7}$	$-2.3 \cdot 10^{-7}$	$5.6 \cdot 10^{-7}$	$5.9 \cdot 10^{-6}$*	$7.7 \cdot 10^{-7}$	$6.5 \cdot 10^{-7}$	$1.1 \cdot 10^{-6}$	$4.8 \cdot 10^{-7}$	$-7.1 \cdot 10^{-7}$
	$(6.9 \cdot 10^{-7})$	$(3.3 \cdot 10^{-6})$	$(5.2 \cdot 10^{-7})$	$(5.6 \cdot 10^{-7})$	$(7.8 \cdot 10^{-7})$	$(3.3 \cdot 10^{-6})$	$(9.3 \cdot 10^{-7})$	$(5.5 \cdot 10^{-7})$	$(1.1 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$	$(7.8 \cdot 10^{-7})$
$frcm_{t-36}$	$1.4 \cdot 10^{-6}$	$1.6 \cdot 10^{-6}$	$1.7 \cdot 10^{-6}$**	$7.7 \cdot 10^{-7}$	$8.1 \cdot 10^{-7}$	$-1.8 \cdot 10^{-6}$	$-1.3 \cdot 10^{-8}$	$1.9 \cdot 10^{-6}$*	$-5.1 \cdot 10^{-8}$	$4.6 \cdot 10^{-7}$	$-8.5 \cdot 10^{-7}$
	$(1.2 \cdot 10^{-6})$	$(1.6 \cdot 10^{-6})$	$(8.1 \cdot 10^{-7})$	$(7.4 \cdot 10^{-7})$	$(9.2 \cdot 10^{-7})$	$(2.0 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$	$(7.8 \cdot 10^{-7})$	$(9.0 \cdot 10^{-7})$	$(8.7 \cdot 10^{-7})$

Table 3.6 (continued)
Robustness test

variable	**Opel Corsa**	**Peugeot**	**VW Golf**	**Ford Focus**	**Opel Astra**	**BMW 3 Series**	**Mercedes C-Class**	**VW Passat**	**Audi A4**	**BMW 5 Series**	**Audi A8**
$euribor3_{t-3}$	.5779	.2007	-.0251	-.0372	.2913	-.1075	-.0402	-.5102	.4822*	.0657	.4568
	(.7449)	(.1447)	(.3301)	(.26)	(.2366)	(.1501)	(.6069)	(1.115)	(.2913)	(.2317)	(.2936)
$chur_{t-1}$	.0376**	.0836**	.037**	.0207*	-.0012	-.0462	.0195	.0172	-.007	.0213	.0108
	(.0174)	(.0382)	(.0148)	(.0125)	(.0154)	(.0446)	(.0222)	(.0173)	(.014)	(.0135)	(.0145)
$gdpta_{t-1}$	-.0298	.2186**	.0031	.0416	.0544	.1203	.0274	.0466	-.0486	-.0161	.0081
	(.0586)	(.1029)	(.0625)	(.0499)	(.0569)	(.1019)	(.0725)	(.0501)	(.0591)	(.0462)	(.0621)
$pcsta_{t-1}$	-.0213	-.3171**	-.0294	-.0697**	-.03	.0722	-.0169	-.0571	-.0011	-.046	-.0246
	(.0491)	(.1475)	(.0363)	(.0282)	(.0418)	(.0662)	(.0501)	(.0427)	(.0343)	(.0329)	(.0321)
$lnppta_{t-1}$	1.367	-7.098**	-.6848	-1.297	-2.191	-4.845**	.2147	1.812	.5264	-1.587	-1.491
	(2.731)	(3.114)	(1.328)	(2.384)	(1.354)	(2.412)	(1.954)	(1.34)	(1.305)	(1.917)	(1.221)
α	72.47***	23.72*	83.81***	68.55***	79.04***	13.57***	75.78***	68.52***	61.04***	61.19***	55.34***
	(6.28)	(13.34)	(6.886)	(2.427)	(4.2)	(4.932)	(8.063)	(14.74)	(3.684)	(2.355)	(6.985)
ARMA term											
ar(1)	1.1***	–	1.155***	1.22***	.9449***	–	.8806***	.9651***	.9379***	.938***	1.247***
	(.0681)		(.0686)	(.0788)	(.0206)		(.0861)	(.0843)	(.0322)	(.0287)	(.109)
ar(2)	-.1795***	–	-.2268***	-.2814***	–	–	–	–	–	–	-.3012**
	(.0669)		(.0696)	(.0807)							(.1195)
ar(12)	–	–	.3925***	–	.5051***	–	.2267*	–	–	–	–
			(.1206)		(.1377)		(.1239)				
$\hat{\sigma}$	.7842***	–	.5881***	.5839***	.6097***	–	.8661***	.7056***	.6444***	.6787***	.6286***
	(.1064)		(.0665)	(.0544)	(.0512)		(.1295)	(.1211)	(.0709)	(.1016)	(.0666)
N	199	199	199	199	199	199	199	199	199	199	199

Table 3.6 (continued)
Robustness test

variable	Opel Corsa	Peugeot	VW Golf	Ford Focus	Opel Astra	BMW 3 Series	Mercedes C-Class	VW Passat	Audi A4	BMW 5 Series	Audi A8
χ^2/F	3772.39	442.33	5329.02	4375.87	28401.66	515.79	5493.56	71338.41	8281.32	7615.10	32313.38
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Phillips-	-2.7983	-12.832	-2.887	-2.966	-2.924	-11.772	-4.358	-2.747	-2.868	-2.709	-3.147
Perron test	(0.06)	(0.00)	(0.05)	(0.04)	(0.04)	(0.00)	(0.00)	(0.07)	(0.05)	(0.07)	(0.00)
Portmanteau	34.73	28.73	34.35	35.13	29.41	22.39	40.20	50.50	45.95	19.89	35.24
(Q) test	(0.71)	(0.91)	(0.72)	(0.69)	(0.89)	(0.99)	(0.46)	(0.12)	(0.24)	(0.99)	(0.68)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Additionally, the analysis shows that model changes or a rework of the car model have a highly significant impact on its residual value causing jumps in its pattern. Furthermore, I find that fluctuations in the used and new car market rather influence residual values than changes in determinants describing the overall economy. Each variable for the number of new registered cars as well as the number of cars changing hands shows a positive significant influence on numerous cars. This holds true even for those vehicles not showing any significant reaction. Thus, I conclude that an increase in both factors yields a rising demand which results in higher residual values. Interestingly, changes in gross domestic product or private consumer spending only significantly affect a very small number of cars. Consequently, the main reasons for purchasing a car are not caused by changes in the economic and financial environment. An explanation for this observation might lie in the nature of a car being a good not many people want to waive. That is why a change in their financial situation may not primarily affect cars' residual values. Another surprising observation is that only three cars show a negative significant reaction when tested for fluctuations in petrol prices. This is another case where the explanation like the one for the missing significant reaction to changes in the economic factors may apply. Although these costs may increase, people's dependency on cars or their decision not to waive them fails to trigger a significant reaction. However, the empirical analysis shows there are no particular underlying factors which prevail throughout all car models. As a result, it is necessary to identify the influencing factors for each car individually supporting my applied approach.

In addition to the analysis above, I can derive characteristics for a certain segment. The subcompact and compact segment seem to be dependent on gross domestic product and the private consumers' behaviour whereas all other segments remain unchanged – in terms of statistical significance – towards these economic factors. I explain this observation by assuming that consumers of the lower segments are more receptive to changes in the financial situation than upper segments. The better people are off financially, the more likely they will buy a new car or choose a car from a higher segment. This assumption may explain therefore why a few cars of the subcompact and compact segment are significantly negative influenced by the variable private consumer spending. There again, consumers of the upper segments are less sensitive to changes in the financial situation which results in no significant reaction in the residual values. Additionally, consumers of the upper segments may also consider their cars as status symbols. They have a great interest in maintaining this status especially when the financial situation gets worse. Furthermore, the unemployment situation has a remarkable influence on both of these lower segments. Here, I observe a significant positive effect. My explanation is that the more people are unemployed, the more often people are forced to purchase either used cars or cars of lower segments. The other segments seem to be rather sensitive to changes in the used car market. With an increasing number of cars changing their ownership, these movements in the used car market spillover to the higher segments forcing up car prices there. Thus, I observe that cars of the higher segments benefit from an increasing trading activity in the used car market.

Finally, I examine the results on the basis of the cars' brands. To my surprise, cars of Opel and Audi hardly seem to be influenced by the chosen variables. On the contrary, strong reactions for the cars of Ford can be recorded. Although both Ford vehicles show the same signs regarding all independent variables except for *com*, the results differ highly in terms of statistical significance for each determinant. While the Ford Fiesta is influenced by the variables of the new and used car market, the Ford Focus reacts to changes in the economic situation. Cars of the Volkswagen brand seem to be rather impacted by fluctuations in the new car market which lead to increasing residual values. This finding may underline the fact that Volkswagen is a very popular brand in Germany. For years, the company has claimed the highest rate of new registrations in Germany compared to other car manufacturers. New registrations lead to a boost in popularity for the brand resulting in more consumers willing to purchase a Volkswagen. Interestingly, the cars of BMW are very sensitive to changes in petrol prices whereas this factor is of no significant interest to its competitor Mercedes-Benz. The latter cars are affected by changes in the used car market. Mercedes-Benz is considered as a high end brand standing for extremely high prestige. Thus, cars of Mercedes-Benz benefit from a high demand and yield increasing residual values when activities such as changes in ownership increase in the used car market.

3.4 Implications for the Risk Management and Valuation of Automotive Lease Contracts

The previous analysis illustrated the impact of different factors found in car markets and the economy. Now, the question arises how these results can be used by leasing institutions?

Firstly, from the discussion in section 3.3.3 one can assess how leasing portfolios may react to changes in the market factors. It is now possible to identify potential risks in the leasing portfolio by assessing the fluctuations in the market variables used in this study. For example, a leasing provider for BMW cars should be aware of changes in the price of petrol. Furthermore, leasing providers with a focus on cars in the subcompact and compact segment may encounter fluctuations in their portfolio due to changes in the overall economic situation. The latter observation derives from my analysis of those two segments being significantly influenced by economic variables (i.e. unemployment rate, gross domestic product and private consumer spending) than by movements in the car markets. The analysis in section 3.3.3 offers similar conclusions to different classifications such as brands, segments or further combinations and should sensitise the leasing provider to potential risk inherent in its leasing portfolio. Based on these findings the risk management may be improved and the leasing portfolio may be hedged against certain influences.

Additionally, changes in the residual values affect the valuation of leasing contracts. In the following, I will examine theoretically how changes in residual values influence the leasing rate by using the empirical analysis of section 3.3. For this purpose, I apply the valuation model of McConnell and Schallheim (1983) to rate automobile lease contracts. I can hereby fall back on operating lease contracts as financial lease contracts are simply a special case of operating leases.[30] McConnell and Schallheim (1983) model the standard operating lease – a lease contract which may be cancelled at any time during the contract period – by using a compound option approach. By doing so, the lessee purchases the right to use the asset until the next payment. Every payment of the leasing rate includes an option to make the next lease payment which again contains an option (a compound option) to extend the lease at the next time of the contractual payment and so forth.[31] Then, the equilibrium lease rate L for a n-period standard operating lease contract with maturity T can be derived as

$$L = \sum_{i=0}^{n-1} \lambda^i (1-\lambda) S_0 \cdot N_i(h_i + \sigma\sqrt{i}) - L \sum_{i=1}^{n-1} (1+r_f)^{-i} \cdot N_i(h_i), \qquad (3.1)$$

with

$$h_i = \frac{\ln(\lambda^i A_0/\bar{A}_i) + (\ln(1+r_f) - \sigma^2/2)i}{\sigma\sqrt{i}} \quad \text{and} \quad \lambda = \frac{1 - \mathbb{E}\left((A_i - A_{i-1})/A_{i-1}\right)}{1+r_f} \cdot e^{\sigma_{ly}},$$

where A_i is the market value of the leased asset at time i, $\bar{A}_i$ is the boundary at time i above which the lessee will choose to make the lease payment, r_f is the risk-free interest rate, σ_{ly} is the covariance between $\ln(\tilde{A}_i/A_{i-1})$ ($\tilde{\cdot}$ denotes a random variable) and the 'market factor' y[32], σ^2 is the variance of the logarithm of the rate of change of the leased asset (i.e. $\text{Std}[\ln(\tilde{A}_i/A_{i-1})](= \text{Std}[\ln(\tilde{\delta}_i])$ compare Rubinstein (1976, p. 418), Geske (1977, p. 544) and McConnell and Schallheim (1983, p. 244, footnote 7)) and $N_i(\cdot)$ is the i-dimensional multivariate normal distribution function.

The empirical analysis of section 3.3.3 shows that residual values are influenced by different variables. Consequently, a fluctuation in these influencing variables leads to a variation in

[30] In the context of McConnell and Schallheim (1983, p. 242, p. 251) a financial lease is an operating lease with a non-cancellation period.

[31] The complete derivation of the valuation formula can be found in McConnell and Schallheim (1983, pp. 242-247).

[32] The 'market factor' derives from the valuation technique of Rubinstein (1976) and is required to value uncertain income streams. For its derivation and definition in this context I refer to the explanations in Rubinstein (1976).

the residual value. To measure the magnitude of this impact, I take the variance of a certain influencing factor and observe how alterations in the variance of a leased car caused by changes in this certain influencing variable affect the lease rate. McConnell and Schallheim (1983) analyse the sensitivity of the lease rate to changes in the variance of the leased asset (McConnell and Schallheim, 1983, pp. 252-253). They obtain a purely positive relationship for changes in the variance on the lease rate of a standard operating lease. Thus, changes in the variance of the leased asset generally lead to increasing residual values.

Over the next paragraphs, I would like to examine the question how the lease rate is affected by fluctuations in the determinants of section 3.3.2. This effect of changes in a certain influencing factor i on the lease rate L is theoretically explained by its partial derivation, i.e.

$$\frac{\partial L}{\partial \sigma_i^2} = \frac{\partial L}{\partial \sigma^2} \cdot \frac{\partial \sigma^2}{\partial \sigma_i^2}.$$

Since $\partial L/\partial \sigma^2$ was proved by McConnell and Schallheim (1983, p. 252) to be strictly positive (as mentioned above), I hereby have then to calculate the change in the variance resulting from changes in a certain factor, i.e. $\partial \sigma^2/\partial \sigma_i^2$, by holding all other factors constant. For the empirical analysis I assumed for lease contracts a maturity of 36 months and calculated the influences on A_{36}/A_0. The variance rate σ^2 in equation (3.1) is defined as the variance of the logarithm of the changes in value between the values of the leased asset at the time of the contractual payments. If I perform the empirical analysis for $\ln(A_{36}/A_0)$,[33] I can derive the variance σ^2 from the stationarity assumption (A.7)[34] in McConnell and Schallheim (1983, p. 243). Hence, dividing the variance of $\ln(A_{36}/A_0)$ by the number of contractual payments n provides the variance σ^2.

[33] Actually, I perform the analysis for the term $\ln(A_{36}/A_0 \cdot 100)$. However, I can neglect the multiplication with 100 for the calculation of the variance since according to the logarithmic rules this term may be expressed as the sum of the applied term and a constant which does not add to the calculation of the variance. This approach thus not alters the results.

[34] This assumption states that "the distribution of the rate of economic depreciation of the leased asset is stationary over time" (McConnell and Schallheim, 1983, p. 243).

In order to illustrate the effect of fluctuations in the influencing variables on lease rates, I choose the model of table 3.3 as an example which includes a lagged dependent variable. Hereby, I assume formally that

$$z_t = \alpha + \beta_1 z_{t-1} + \beta_2 x_t^1 + \beta_3 x_t^2 + \cdots + \beta_{k+1} x_t^k + \epsilon_t,$$

where $z_t = \ln(A_{36}/A_0)_t$, x_t^i is the ith independent variable ($1 \leq i \leq k$) and ϵ_t is the white noise error term (for each i x_t^i and ϵ_t are stochastic processes and x^i are the independent variables of section 3.3.2). Then, by using the white noise property of ϵ_t and for simplicity I assume strictly stationary explanatory variables for the regression, the σ^2 of a n-period operating lease can be estimated as

$$\sigma^2 < n^{-1} \cdot \left(\sum_{j=1}^{k} \frac{\beta_{j+1}^2 \sigma_j^2}{1-\beta_1^2} + \left| \sum_{\substack{j,m=1 \\ j \neq m}}^{k} \frac{\beta_{j+1}\beta_{m+1}\sigma_j\sigma_m}{(1-\beta_1)^2} \right| + \frac{\sigma_\epsilon^2}{1-\beta_1^2} \right),$$

and simultaneously, holding all other factors constant I obtain

$$\frac{\partial \sigma^2}{\partial \sigma_i^2} < n^{-1} \cdot \left(\frac{\beta_{i+1}^2}{1-\beta_1^2} + \frac{1}{\sigma_i} \cdot C \right), \qquad \text{with } C = \left| \sum_{\substack{j=1 \\ j \neq i}}^{k} \frac{\beta_{j+1}\beta_{i+1}\sigma_j}{(1-\beta_1)^2} \right|, \tag{3.2}$$

where σ_i is the standard deviation of the independent variable i ($1 \leq i \leq k$) and σ_ϵ^2 the variance of the white noise error.

Proof:

I want to show the relationship

$$\frac{\partial \sigma^2}{\partial \sigma_i^2} < n^{-1} \cdot \left(\frac{\beta_{i+1}^2}{1-\beta_1^2} + \frac{1}{\sigma_i} \cdot C \right), \qquad \text{with } C = \left| \sum_{\substack{j=1 \\ j \neq i}}^{k} \frac{\beta_{j+1}\beta_{i+1}\sigma_j}{(1-\beta_1)^2} \right|,$$

by assuming that

$$z_t = \alpha + \beta_1 z_{t-1} + \beta_2 x_t^1 + \beta_3 x_t^2 + \cdots + \beta_{k+1} x_t^k + \epsilon_t,$$

where $z_t = \ln(A_{36}/A_0)_t$, x_t^m ($1 \leq m \leq k$) is the mth independent variable, ϵ_t is the white noise error term (x_t^m and ϵ_t are stochastic processes) and $i \in \mathbb{N} \cap [1, k]$ fixed.

By using the recursive representation of z_t and the limit of the infinite geometric series ($|\beta_1| < 1$ in my sample which allows to apply the limit of the infinite geometric series) it follows

$$\begin{aligned} z_t &= \alpha + \beta_1 z_{t-1} + \beta_2 x_t^1 + \beta_3 x_t^2 + \cdots + \beta_{k+1} x_t^k + \epsilon_t \\ &= \alpha\left(1 + \beta_1 + \beta_1^2 + \ldots\right) + \beta_2\left(x_t^1 + \beta_1 x_{t-1}^1 + \beta_1^2 x_{t-2}^1 + \ldots\right) + \cdots + \\ &\quad \beta_{k+1}\left(x_t^k + \beta_1 x_{t-1}^k + \beta_1^2 x_{t-2}^k + \ldots\right) + \epsilon_t + \beta_1 \epsilon_{t-1} + \beta_1^2 \epsilon_{t-2} + \ldots \\ &= \frac{\alpha}{1-\beta_1} + \beta_2 \sum_{j=0}^{\infty} \beta_1^j x_{t-j}^1 + \cdots + \beta_{k+1} \sum_{j=0}^{\infty} \beta_1^j x_{t-j}^k + \sum_{j=0}^{\infty} \beta_1^j \epsilon_{t-j}. \end{aligned}$$

Hence, it is

$$\begin{aligned} \text{var}(z_t) &= \text{var}\left(\frac{\alpha}{1-\beta_1} + \beta_2 \sum_{j=0}^{\infty} \beta_1^j x_{t-j}^1 + \cdots + \beta_{k+1} \sum_{j=0}^{\infty} \beta_1^j x_{t-j}^k + \sum_{j=0}^{\infty} \beta_1^j \epsilon_{t-j}\right) \\ &= \beta_2^2 \text{var}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^1\right) + \cdots + \beta_{k+1}^2 \text{var}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^k\right) + \text{var}\left(\sum_{j=0}^{\infty} \beta_1^j \epsilon_{t-j}\right) \\ &\quad + 2\beta_2\beta_3 \text{cov}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^1, \sum_{j=0}^{\infty} \beta_1^j x_{t-j}^2\right) + 2\beta_2\beta_4 \text{cov}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^1, \sum_{j=0}^{\infty} \beta_1^j x_{t-j}^3\right) \\ &\quad + \cdots + 2\beta_k\beta_{k+1} \text{cov}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^{k-1}, \sum_{j=0}^{\infty} \beta_1^j x_{t-j}^k\right) \\ &\quad + 2\beta_2 \text{cov}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^1, \sum_{j=0}^{\infty} \beta_1^j \epsilon_{t-j}\right) + \cdots + 2\beta_{k+1} \text{cov}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^k, \sum_{j=0}^{\infty} \beta_1^j \epsilon_{t-j}\right) \\ &= \sum_{n=1}^{k} \beta_{n+1}^2 \text{var}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^n\right) + \sum_{\substack{n,l=1 \\ n \neq l}}^{k} \beta_{n+1}\beta_{l+1} \text{cov}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^n, \sum_{j=0}^{\infty} \beta_1^j x_{t-j}^l\right) \\ &\quad + \text{var}\left(\sum_{j=0}^{\infty} \beta_1^j \epsilon_{t-j}\right) + 2\sum_{n=1}^{k} \beta_{n+1} \text{cov}\left(\sum_{j=0}^{\infty} \beta_1^j x_{t-j}^n, \sum_{j=0}^{\infty} \beta_1^j \epsilon_{t-j}\right). \end{aligned} \tag{3.3}$$

In the following steps, I determine the terms of equation (3.3) individually. For simplicity, I assume hereby strictly stationary independent variables x_t^m $(1 \leq m \leq k)$.

Then, I obtain:

1. term: var $\left(\sum\limits_{j=0}^{\infty}\beta_1^j x_{t-j}^m\right)$

$$\text{var}\left(\sum_{j=0}^{\infty}\beta_1^j x_{t-j}^m\right) = \sum_{j=0}^{\infty}\beta_1^{2j}\text{var}\left(x_{t-j}^m\right) = \frac{\sigma_m^2}{1-\beta_1^2},$$

because of strictly stationary explanatory variables and applying the limit of the infinite geometric series.

2. term: cov $\left(\sum\limits_{j=0}^{\infty}\beta_1^j x_{t-j}^m, \sum\limits_{j=0}^{\infty}\beta_1^j x_{t-j}^n\right)$ with $1 \leq m, n \leq k$ and $n \neq m$

$$\begin{aligned}
\text{cov}\left(\sum_{j=0}^{\infty}\beta_1^j x_{t-j}^m, \sum_{j=0}^{\infty}\beta_1^j x_{t-j}^n\right) &= \text{cov}\left(x_t^m + \beta_1 x_{t-1}^m + \beta_1^2 x_{t-2}^m + \ldots, x_t^n + \beta_1 x_{t-1}^n + \ldots\right) \\
&= \sum_{j=0}^{\infty}\beta_1^j \text{cov}\left(x_t^m, x_{t-j}^n\right) + \beta_1 \sum_{j=0}^{\infty}\beta_1^j \text{cov}\left(x_{t-1}^m, x_{t-j}^n\right) + \ldots \\
&= \sum_{j=0}^{\infty}\beta_1^j \sigma_m \sigma_n \text{corr}\left(x_t^m, x_{t-j}^n\right) \\
&\quad + \beta_1 \sum_{j=0}^{\infty}\beta_1^j \sigma_m \sigma_n \text{corr}\left(x_{t-1}^m, x_{t-j}^n\right) + \ldots.
\end{aligned}$$

using the strict stationarity of the independent variables. As the correlation of any two random variables is between -1 and 1 and I apply the strict relationship (i.e. $-1 <$ correlation< 1, otherwise I would have collinear variables in the time series regression which contradicts its assumptions), I estimate by using the limit of the infinite geometric series

$$\begin{aligned}
\text{cov}\left(\sum_{j=0}^{\infty}\beta_1^j x_{t-j}^m, \sum_{j=0}^{\infty}\beta_1^j x_{t-j}^n\right) &< \sum_{j=0}^{\infty}\beta_1^j \sigma_m \sigma_n + \beta_1 \sum_{j=0}^{\infty}\beta_1^j \sigma_m \sigma_n + \beta_1^2 \sum_{j=0}^{\infty}\beta_1^j \sigma_m \sigma_n + \ldots \\
&< \frac{\sigma_m \sigma_n}{1-\beta_1} + \beta_1 \frac{\sigma_m \sigma_n}{1-\beta_1} + \beta_1^2 \frac{\sigma_m \sigma_n}{1-\beta_1} + \ldots \\
&< \sum_{j=0}^{\infty}\beta_1^j \frac{\sigma_m \sigma_n}{1-\beta_1} \\
&< \frac{\sigma_m \sigma_n}{(1-\beta_1)^2}
\end{aligned}$$

and analogous

$$\text{cov}\left(\sum_{j=0}^{\infty}\beta_1^j x_{t-j}^m, \sum_{j=0}^{\infty}\beta_1^j x_{t-j}^n\right) > \frac{-\sigma_m \sigma_n}{(1-\beta_1)^2}.$$

3. term: var $\left(\sum\limits_{j=0}^{\infty}\beta_1^j\epsilon_{t-j}\right)$

$$\operatorname{var}\left(\sum_{j=0}^{\infty}\beta_1^j\epsilon_{t-j}\right) = \sum_{j=0}^{\infty}\beta_1^{2j}\operatorname{var}\left(\epsilon_{t-j}\right) = \frac{\sigma_\epsilon^2}{1-\beta_1^2},$$

by using the limt of the infinite geometric series and the white noise property of ϵ_t, where σ_ϵ^2 is the variance of the white noise error term.

4. term: cov $\left(\sum\limits_{j=0}^{\infty}\beta_1^j x_{t-j}^m, \sum\limits_{j=0}^{\infty}\beta_1^j\epsilon_{t-j}\right)$
For $0 \leq n \leq t$, because of the assumption of strict stationarity of the independent variables and the contemporaneous exogeneity of ϵ_t it follows

$$\operatorname{cov}\left(x_{t-j}^m, \epsilon_{t-n}\right) = \mathbb{E}\left(x_{t-j}^m\epsilon_{t-n}\right) = \mathbb{E}\left(\mathbb{E}\left(x_{t-j}^m\epsilon_{t-n}|x_{t-n}^m\right)\right) = \mathbb{E}\left(x_{t-j}^m\mathbb{E}\left(\epsilon_{t-n}|x_{t-n}^m\right)\right) = 0.$$

Regrading the result above (and, again, the contemporenous exogenity of ϵ_t) it follows

$$\operatorname{cov}\left(\sum_{j=0}^{\infty}\beta_1^j x_{t-j}^m, \sum_{j=0}^{\infty}\beta_1^j\epsilon_{t-j}\right) = 0.$$

Thus, I finally achieve

$$\sum_{j=1}^{k}\frac{\beta_{j+1}^2\sigma_j^2}{1-\beta_1^2} - \sum_{\substack{j,m=1\\ j\neq m}}^{k}\frac{\beta_{j+1}\beta_{m+1}\sigma_j\sigma_m}{(1-\beta_1)^2} + \frac{\sigma_\epsilon^2}{1-\beta_1^2} < \operatorname{var}(z_t) < \sum_{j=1}^{k}\frac{\beta_{j+1}^2\sigma_j^2}{1-\beta_1^2} + \sum_{\substack{j,m=1\\ j\neq m}}^{k}\frac{\beta_{j+1}\beta_{m+1}\sigma_j\sigma_m}{(1-\beta_1)^2} + \frac{\sigma_\epsilon^2}{1-\beta_1^2}.$$

By analogously following the steps of above and holding all other factors constant, I can derive

$$\frac{\beta_{i+1}^2}{1-\beta_1^2} - \frac{1}{\sigma_i}\cdot\sum_{\substack{j=1\\ j\neq i}}^{k}\frac{\beta_{j+1}\beta_{i+1}\sigma_j}{(1-\beta_1)^2} < \frac{\partial\operatorname{var}(z_t)}{\partial\sigma_i^2} < \frac{\beta_{i+1}^2}{1-\beta_1^2} + \frac{1}{\sigma_i}\cdot\sum_{\substack{j=1\\ j\neq i}}^{k}\frac{\beta_{j+1}\beta_{i+1}\sigma_j}{(1-\beta_1)^2}.$$

Applying the stationarity assumption (A.7) in McConnell and Schallheim (1983, p. 243), I obtain

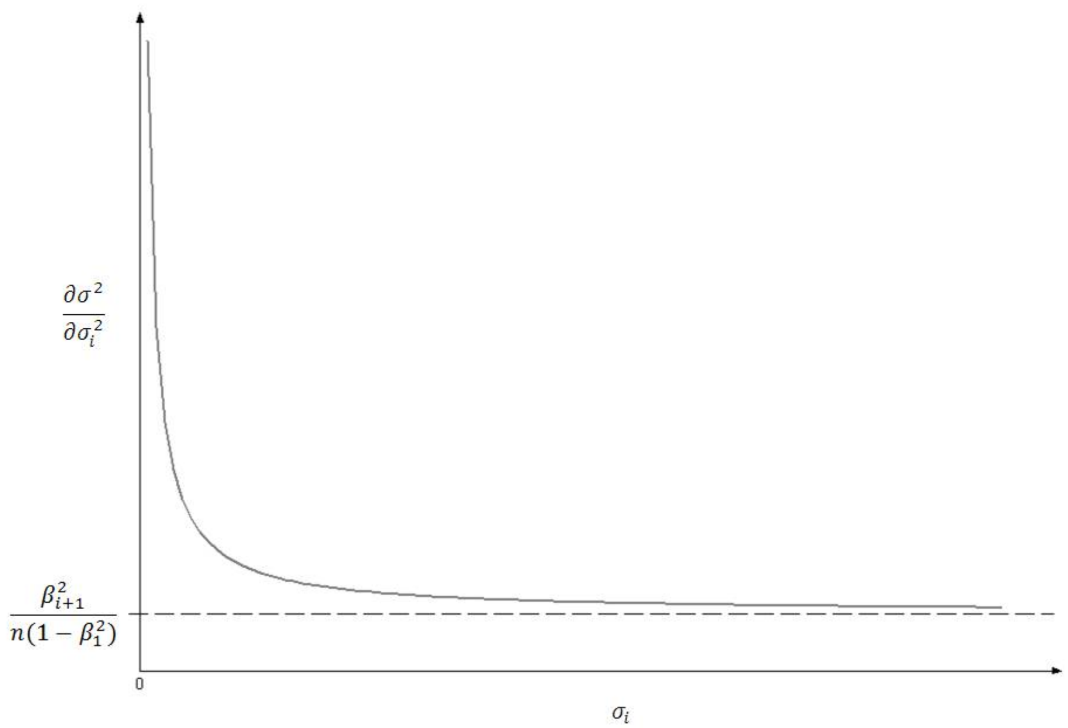
$$n^{-1}\cdot\left(\frac{\beta_{i+1}^2}{1-\beta_1^2} - \frac{1}{\sigma_i}\cdot\sum_{\substack{j=1\\ j\neq i}}^{k}\frac{\beta_{j+1}\beta_{i+1}\sigma_j}{(1-\beta_1)^2}\right) < \frac{\partial\sigma^2}{\partial\sigma_i^2} < n^{-1}\cdot\left(\frac{\beta_{i+1}^2}{1-\beta_1^2} + \frac{1}{\sigma_i}\cdot\sum_{\substack{j=1\\ j\neq i}}^{k}\frac{\beta_{j+1}\beta_{i+1}\sigma_j}{(1-\beta_1)^2}\right)$$

which proofs the relationship.

□

The examination above shows that the partial derivation of the variance is a function of the standard deviation of the influencing factor of interest. In case $C \equiv 0$, the lease rate augments with the constant proportionality factor $\beta_{i+1}^2/[n(1-\beta_1^2)]$ for changes in σ_i^2. Otherwise, I can estimate the upper limit for $\partial\sigma^2/\partial\sigma_i^2$. Equation (3.2) shows very high proportionality factors for very small σ_i which converge asymptotically to $\beta_{i+1}^2/[n(1-\beta_1^2)]$ for an increasing standard deviation of the influencing factor i. This point is visualised in figure 3.1. Using a more descriptive explanation of this finding, the theoretical result simply states that the lease rate increases the more exactly one of the underlying factors fluctuates (and the others remain constant). Moreover, in case of a settled market situation of this particular underlying factor (i.e. the σ_i is low), the increase in the lease rate is considerably stronger if the fluctuations of this factor tend to augment. On the other hand, if the market situation of this factor has already been turbulent (i.e. σ_i is high), a further augmentation of the fluctuations do not lead to a faster increase in the lease rate. To conclude, my observations show that

Figure 3.1: Upper limit for changes of the variance σ^2 for changes in σ_i^2



the upper limit for changes in the variance of the leased asset due to changes in a certain influencing factor is at least $\beta_{i+1}^2/[n(1-\beta_1^2)]$. The smaller the volatility of the influencing factor, the higher is the upper limit. Hence, I can estimate the maximal effect of changes in the volatility of a certain influencing factor which yields higher lease payments with a proportionality factor approaching an upper limit of at least $\beta_{i+1}^2/[n(1-\beta_1^2)]$.

By using Peugeot as an example I will illustrate my findings mentioned above. First, I have to estimate the coefficients for the regression model with $\ln(A_{36}/A_0)$ as dependent variable. The empirical results can be found in table 3.7. By using equation (3.2) I determine the upper limit for the petrol price as influencing factor i as

$$\frac{\partial\sigma^2}{\partial\sigma_i^2} < n^{-1}\left(0.0319 + \frac{0.0071}{\sigma_i}\right).$$

Hence, at its upper limit a change in the variance of the logarithm of the petrol price leads to a change in variance of Peugeot in the amount of at least $0.0319/n$ where n are the number of lease payments. This result implies that at its maximum the lease rate for a Peugeot increases for a change in the variance of the petrol price by a proportionality factor of at least $0.0319/n$ holding all other factors constant.

Table 3.7

Regression results for the logarithm of the residual value of the Peugeot

This table reports the results of the ARMAX regression models for the logarithm of the residual value of Peugeot. d_i denotes the dummy for the i-th successor since June 1992, $modern$ the variable for modernity, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the monthly unemployment rate, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three month, gdp_{t-1} the lagged price-adjusted quarterly gross domestic product, pcs_{t-1} the lagged price-adjusted quarterly private consumer spending, $lnpp_{t-1}$ denotes the lagged logarithm of monthly petrol prices and α the intercept. The values in parentheses with the F test statistic, the Phillips-Perron test and the Portmanteau (Q) test denote the corresponding probabilities. N is the number of observations. All estimated standard errors are robust standard errors.

variables	**coefficient**	**standard error**
$lnvalue_{t-1}$	.6826***	.1812
$d1$	.0796*	.0405
$modern$	$-1.2 \cdot 10^{-4}$	$1.8 \cdot 10^{-4}$
com_{t-1}	$-9.7 \cdot 10^{-8}$	$6.2 \cdot 10^{-8}$

variables	**coefficient**	**standard error**
$frcm_{t-36}$	$2.8 \cdot 10^{-8}$	$2.8 \cdot 10^{-8}$
$euribor3_{t-3}$	.0028	.0022
$chur_{t-1}$	.0016**	$7.6 \cdot 10^{-4}$
gdp_{t-1}	.004**	.002
pcs_{t-1}	-.006**	.0029
$lnpp_{t-1}$	-.1306**	.0592
α	2.092*	1.109
N	199	
F	371.35	
	(0.00)	
Phillips-Perron test	-12.810	
	(0.00)	
Portmanteau (Q) test	31.20	
	(0.84)	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.5 Summary

Residual value risk is a special risk concerning lease contracts. In order to access and understand this risk, one has to determine the factors that drive residual values. As automobile lease contracts form the largest group of equipment leasing, I focus my study on residual values of cars. In contrast to previous works, I neglect factors concerning the ageing of a car but concentrate my analysis on revaluation of automobile prices. The aim of this study is to explain influences on residual values over time.

For this purpose, I specify a set of explanatory variables and analyse their effects on residual values of cars. These variables are distinguished in three categories which reflect the market environment of used cars by describing influences from the overall economy, the used and new car market and characteristics of a specific car model. The analysis is performed for a dataset of 17 cars from the five major segments in the German automobile market. For this purpose, I collect monthly used car prices from DAT for an observation period from June 1992 to December 2008.

The empirical results give evidence of changing automobiles' residual values due to effects of the selected variables. Thus, factors related to the market environment of a used car can explain fluctuations in residual values. From this analysis I examine how different cars respond to certain influences and which similarities and differences between different brands and segments result. Based on this discussion, implications for risk management of lease contracts and lease portfolios can be derived. On the one hand, those implications result from the identification of various sources of risk inherent in residual values of automotive lease contracts. On the other hand, based on the development of an empirical model for residual values I look at the effect of changes in the variance of a certain influencing variable on lease rates. As an example, I use a regression model with a lagged dependent variable. My results show that one can estimate an upper limit for the proportionality factor which indicates the magnitude of change on the overall variance. This upper limit is positive which demonstrates that lease rates increase at their upper limit. This limit increases even more for a small standard deviation of the explanatory variable. From this observation it follows that higher lease rates are obtained as they approach their upper limit for very small variance rates of the influencing variables. These results show the impact of fluctuations in cars' residual values on lease contracts as well as entire lease portfolios which are of high relevance to risk management of residual value risk in automobile lease contracts.

Chapter 4

Prediction of Residual Values

Abstract

Residual values are of substantial importance in the context of lease contracts as they determine the lease rate. Because they are not known in advance, their prediction becomes necessary at completion of lease contracts. The aim of this study is to develop a prediction model for residual values of automobiles. In order to achieve this, I employ an ARMAX regression approach by using independent variables which can be classified into three main groups all describing the market environment of used cars. Hence, I adjust the empirical model for three cars of the German market in the time period from June 1992 to December 2005. The testing method for the performance of the models spans from January 2006 to December 2008. The results are highly satisfying with deviations from the actual residual value in December 2008 of approximately one percent of the original manufacturer's suggested retail price and an overall moderate deviation of at most three percent throughout the whole prediction period. Furthermore, I conduct a theoretical analysis using the empirical results on how fluctuations in the underlying factors influence the lease rate and the net advantage to leasing. I provide evidence that changes in the independent variables affect

both the lease rate and the net advantage to leasing with a constant proportionality factor reversely directed than the influence on the residual value.

4.1 Introduction

Residual values are of major importance within the scope of lease contracts. As they are understood as the value of the leased asset at maturity of the contract, they directly affect the valuation of lease contracts. This circumstance arises from the conception of leases which allows for a primary compensation to the lessor for the leased asset's depreciation during duration of the contract resulting from the relinquishment of the asset's usage. In this context, the difference between the asset's value at conclusion of the contract and its residual value determines the proportion of depreciation compensating the lessor. Besides this major relevance of residual values they are also used for additional purposes. Implicit options for instance represent another frequent application of residual values. Many lease contracts contain options on either lessee's or lessor's side such as call options which give the lessee the opportunity to purchase the leased asset at maturity of the contract. Residual values are often defined as strike prices for the purposes of implicit options determining by this definition the values of the latter ones.

The difficulty in dealing with residual values lies in the dilemma of not knowing them in advance but requiring their value at completion of the lease contract. Thus, it is necessary to predict residual values for each contract. The aim of this study is to find a model to forecast as accurately as possible the residual values of cars. I focus hereby on the prediction of automobiles' residual values in Germany as cars and estate vehicles form with 53 percent the largest product group of equipment leasing in the German market in 2010 (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 15). I follow a common duration of three years for automotive lease contracts and develop an ARMAX regression model for the time series of residual values of a three year old VW Golf, Mercedes-Benz C- and E-Class based on a dataset ranging from June 1992 to December 2008. Residual values are then predicted for a period of 36 months. I specify the prediction models for an in-sample period from June 1992 to December 2005 and determine their performance out-of-sample from January 2006 to December 2008. The applied research design does not account for the loss in values due to the ageing of cars. Instead, I focus solely on the change in residual values resulting from external factors which describe the market environment of the leased car over time. For this purpose, I identify influences classified into three main categories which are the overall economy, the market conditions of new and used cars and the characteristics of a specific car model. In a next step, I analyse how different assumptions about the underlying market conditions affect the equilibrium lease rate and the value of the lease contract. This is assessed firstly from a theoretical perspective by applying the developed forecast models and secondly by illustrating these theoretical results with a numerical example by applying the empirical results of the study. From this analysis I can draw conclusions for the management of residual value risk in automotive lease contracts.

The study at hand is, to my best knowledge, the first one ever which uses an ARMAX regression approach to forecast residual values of cars. However, I extend the literature not only by using an alternative approach but also by providing empirical results of the performance of the methodology employed, which represents a considerable lack in the existing literature. Moreover, this study is also the first which develops a prediction model based on a dataset of the German automobile market. Another novelty is the time frame of almost twenty years which exceeds the observation periods of a wide majority of former studies. These two aspects, length and local market, further add to the scientific foundation whereas the application to the valuation literature and thus the risk management emphasize the practical implications. This link between valuation and forecast model is also not accounted for in the context of other studies.

The rest of this chapter is structured as follows: First, I review the already existing literature focusing on the prediction of residual values of cars. I continue then in section 4.3 by describing the dataset of residual values and the influencing variables used in this study before discussing the applied methodology and the prediction results in section 4.4. I first develop a proper forecast model by making use of the explanatory variable in section 4.4.1. Then, I predict the explanatory variables with the help of ARIMA models in 4.4.2 and forecast the residual values in 4.4.3 by using the predicted values of the explanatory variables. In section 4.5 the practical consequences are discussed which determine the impact on the valuation process of automotive leases. Section 4.6 finishes by summarising the results and offering an outlook for future research.

4.2 Related Work

The existing literature concerning the prediction of residual values is relatively poor. Besides little theoretical foundation, empirical evidence is hardly available. In the following I give a brief overview of the existing scientific literature dealing with the issue of predicting residual values.

The first approach dates back to Farrell (1954). He develops a theoretical model which uses supply and demand functions to predict used car prices and, hence, residual values. Both functions depend on consumer's income and prices for cars of different ages. Since he assumes perfectly inelastic supply functions, his approach is reduced to estimates of the demand functions. The demand function for a car of a certain age, however, depends according to aggregation on consumers' tastes, income and the price of a car. With a cross sectional analysis and further simplifying assumptions he estimates used car prices in the U.S. market for the observation period from 1922 to 1941. Based on this analysis, he predicts used car prices for the years 1947 to 1952 but the forecasts are fairly inaccurate yielding a poor performance of the prediction model.

An entirely theoretical approach is documented by Lee et al. (1982) who use option pricing theory to calculate the residual value of any leased asset. By doing so, they subtract a put option from a call option for the leased asset with the same exercise price and finally add the present value of this very price. The result of this equation is the present value of the leased asset. The valuation of these options requires the rate of economic depreciation until maturity of the lease contract. This rate, however, is unknown in advance which only shifts the problem to the issue of predicting the rate of economic depreciation making this approach unsuitable in practice.

Another theoretical model without practical application is constructed by Rode et al. (2002). They focus on forecasts of cars for which either no or only few data is available. For the construction of their model they use the following four factors: useful life of the leased asset, economic obsolescence, technical obsolescence and the correlation between these indicators. For the factor useful life they assume a linear depreciation of the asset. Under this assumption they derive an explicit representation for the residual value. Since no practical application has been constructed, a performance evaluation of the model is not available.

Cheng and Wu (2006) develop an econometric method to predict automobile prices of two year old cars. Hereby, they modify the partial least squares regression, a method dealing with multicollinearity. They identify the relevant variables for prediction by using their variance and correlation with the dependent variable instead of their covariance. Cheng and Wu (2006) then test the performance of their "modified partial least squares regression" for five cars of the compact utility segment in the American market. They adjust their model for the observation period from January 1995 to June 1999 and forecast used car prices for the following months up to December 2000. They compare their findings with the results of a partial least squares regression, a variable subset selection method, ridge regression and principal components regression to conclude that the modified model is superior to the other empirical models.

Smith and Jin (2007) use a regression equation to predict residual values. The equation solely consists of a linear and a quadratic term of the model age as well as monthly dummy variables as explanatory variables. The main purpose of the model is to simulate gains and losses of automobile lease contracts which is why it lacks a performance report. Thus an evaluation of its prediction quality is not possible.

An approach from the computational perspective is given by Wu et al. (2009). They compare artificial neural networks with back-propagation and an adaptive neuro-fuzzy inference system. The chosen input factors are the brand of the car, the manufacturing year and the engine style and a possible fourth variable called the equipment index. Both models are trained for a dataset of four cars in the Taiwanese used car market for the manufacturing years from 2000 to 2005. The overall performance for these models is good with even better results when including the fourth variable. In summary, the adaptive neuro-fuzzy inference system is superior to the artificial neural network.

The present chapter contributes to the existing literature by developing a prediction model based on the ARMAX regression methodology which has not yet been applied in this sector of research. In this context, I forecast residual values by simulating the economic environment for used cars. Hereby, I do not restrict my analysis on specific characteristics of a particular automobile but consider the overall market situation. I also extend the empirical literature by testing the forecast ability of my model on an actual dataset. Hence, I do not only develop a prediction model based on a different methodology but I further provide empirical evidence of the forecast performance which is neglected in the majority of previous studies.

4.3 Description of the Dataset

4.3.1 Description of the Automobile Data

For this study, used car prices are collected from DAT[35] which are determined as dealers' average prices for the German market. Car dealers and manufacturers occupy 55% of the market making them the most important sales channel for lease contracts (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 19). As I expect both manufacturers and dealers to sell the returned car at retail price, I consider the use of those prices to be appropriate for my analysis of residual values. Moreover, most lease contracts mature after 36 months, which is why basing the analysis on three year old cars seems plausible to me.

The time series is constructed based on the method of Giacotto et al. (2007, p. 425) and uses monthly retail prices of car models which were registered exactly three years ago. The definition of a k year old car is taken from DAT. Then for instance, a car is exactly k years old in October 2007 if it was registered in November k years ago.[36] More precisely, the point of the time series of October 2007 is defined as a car registered in November 2004; the point November 2007 is defined as a model registered in December 2004 and so forth. Following this method, time series ranging from June 1992 to December 2008 were collected.[37] In my analysis for predicting residual values of cars, I focus on three cars: VW Golf, Mercedes-Benz C-Class and Mercedes-Benz E-Class. I restrict my study in this chapter only on these cars because of their statistical properties. By using the shortened in-sample period the stationarity assumption of the time series of the residual values holds only for very few cars. The analysis of chapter 3 shows, however, that the stationarity assumption is not an issue the more observations are available. Nearly all car models show stationary residual values

[35]DAT Deutsche Automobil Treuhand GmbH, Hellmuth-Hirth-Strasse 1, 73760 Ostfildern.

[36]I use the Europa Code by DAT for the cars' classification in order to ensure the correct specification of the car models and to trace them throughout the observation period.

[37]To exclude effects from the German reunification my time series starts in the middle of 1992.

for the complete observation period. Extending the in-sample period, however, results in the problem that there is no opportunity to test the performance of the forecast models due to the lack of data after December 2008. This would leave doubts on the validity of the applied approach. Hence, I use only these three cars for my study since the application to the other car models is not an issue if using a longer in-sample period. The choice of the car models, however, is reasonable: These cars show the highest popularity (measured as the absolute registration number) in the three main German car segments over the majority of the observation period. All car models exhibit a model history of at least 22 years and have a petrol engine.

Since models and equipment change after a certain time, predecessors respectively successors must be identified and adjusted in the time series. Contrary to Giacotto et al. (2007, p. 425), quality adjustments such as technical improvements (e.g. development of electronic stability program (esp) in the mid 90's) cannot be incorporated or lead to inconclusive model specifications (very expensive and unusual additional equipment leading to very uncommon high-priced cars) for such a long time range. Instead, I use for each car the minimum engine and minimum equipment that is available in the particular model years. This approach is applied because it addresses the same group of consumers during the whole observation period.

All models are also adjusted for mileage. As assumed mileage I use the average kilometres (km) driven for a car of three years suggested by the DAT. Those values change according to different segments. Hence, mileage for the VW Golf is 45 000 km, for the Mercedes-Benz C-Class it is 54 000 km and for the Mercedes-Benz E-Class it is 63 000 km.

In a final step, I divide the used car retail prices by the latest manufacturer's suggested retail price (MSRP) (as only the most recent prices are reported by DAT from 1989 to 2008) in the year the car was registered the first time. The residual value is then defined as the percentage of the used car retail price by its latest MSRP in the year the car was first registered. This approach ensures comparability of the residual values of the same car over time and between different automotive models.

4.3.2 Description of the Explanatory Variables

In chapter 3, I find evidence that the residual values of cars are influenced over time by variables which can be grouped into the following three main categories:

1. Variables specifying the economy,
2. variables characterising the used and new car market and
3. variables describing a specific car model.

I use the same influences classified in those categories to develop a prediction model. Additionally, I define further variables to describe these influences with alternative proxy variables. The prediction model is then constructed by combining the proxy variables from these categories with each impact included which is described by exactly one of the possible indicators.[38] In the following paragraphs, I describe the influences and variables which I apply to establish the prediction model.

The variables of the first category illustrate the economic climate nationwide. The decision to buy a car strongly depends on the financial situation of the consumer. If the financial outlook is bad, consumers may keep their old car and delay their decision to buy another car to some future point in time. Potential buyers of a new car may also decide to buy a used car instead. To account for this possible influence, I look at two perspectives of the financial situation of consumers. The first perspective observes private households as consumers. For this purpose, the financial situation of private households may be described by using two

[38] I refer to section 4.4.1 for the precise description of the model's development.

different variables. One possibility is to use the price-adjusted quarterly private consumer spending (*pcs*). An alternative is to describe this influence by using the quarterly disposable income (*di*, measured in thousand millions Euro).

In order to adopt the perspective of the industry as a consumer and to indicate the overall situation of the German economy, I apply proxy variables which meet these requirements. One of them is the price-adjusted quarterly gross domestic product as a first possibility (*gdp*). Alternatively, I can analyse these effects by including the rate of change of the gross domestic product in my study. In this case, I can either use the quarterly rate of change related to the previous quarter (*gdppq*) or the quarterly rate of change related to the quarter of the previous year (*gdppyq*). Moreover, I also use indices which exhibit the economic climate in Germany to describe these influences. In Germany, there are two major indices which monitor the economic climate. The ifo business climate index is the most popular one and therefore considered in my study.[39] Another index is the ZEW Indicator of Economic Sentiment which I also include in my study.[40] As both indexes violate the stationarity assumption of time series, I use their monthly rate of change in percentage for my analysis (*chifo* and *chzew*).

Another independent variable included in my study is the unemployment rate. The ownership of a car respectively the ability to buy a car strongly depends on the employment situation. It determines whether people can afford to purchase a new or used car, or a car of a higher or lower segment. Thus, I take the impact of the labour market situation into account. As the unemployment rate is not stationary during the observation period, I use

[39]The ifo business climate index is constructed by the ifo Institute for Economic Research e.V. at the University of Munich and surveys 7 000 firms in manufacturing, construction, wholesaling and retailing about their actual and expected economic situation. For further information I refer to http://www.cesifo-group.de/portal/page/portal/ifoHome.

[40]The ZEW Indicator is constructed by the Centre of European Economic Research and surveys up to 350 financial experts about their expectations concerning the economic development. For further information I refer to http://www.zew.de/.

the monthly change in percentage of the unemployment rate as explanatory variable (*chur*). In some cases, consumers will rely on financing to purchase a used car. Conclusively, the level of financing costs may influence the buying decision of a car. The financing costs are determined by the money market rates. To modify a proxy variable for these costs I use monthly quotations of the rates of the EURIBOR three-month fund for the period between January 1999 and December 2008 and of the rates of the FIBOR three-month fund before 1999 (*euribor3*).

The variables of the second category describe both fluctuations in the new and used car markets. Those fluctuations are a result of the different consumers' behaviours in these markets. The first variable which I will examine more closely for the used car market can be understood as the "trading volume". This variable measures the absolute number of cars that change ownership within one month (*com*). *com* explains how each car in the analysis responds to the activity in the used car market, thus being a proxy for the size of this market. A similar variable is the absolute number of cars first registered in a month (*frcm*) which also offers insights into the size and activity or "trading volume"; however, in that case for the new car market. Together these two variables give an impression about the situation in the car markets and the behaviour of the consumers acting in them. The last variable I consider in this second category describes fluctuations in petrol prices. Petrol prices are probably the most noted and transparent costs related to the ownership of a car. Whereas the level of petrol price might not influence the buying decision itself, it will possibly affect the choice of the car model. That is why I include a measure for petrol prices in my analysis. For this purpose I use the monthly petrol price for normal benzine (measured in Euro Cent).[41,42] As

[41]Premium benzine is not considered in this study because its time series just started in 1999.

[42]As data was missing in the source for the years 1996, 1997 and 1998, I approximate those values by using the consumer price index for normal benzine. The values are then generated by using the benzine price from January 1999 to calculate backwards by multiplying the index with exactly this price. The benzine price from December 1995 is used afterwards to calculate forward according to the same methodology. In the final step, the average value between these two calculated prices is used to approximate the missing values.

petrol prices have been fluctuating more and more in recent history, I use the logarithm of petrol prices to avoid the inclusion of a heteroscedastic time series (*lnpp*).

The third category includes variables which describe the underlying car model more precisely. Car models which have been on sale for a while in the used car market may be less attractive than used cars with a short model history. Hence, residual values may alter with the topicality of a car. For this reason, I construct a variable which measures the number of months the car model has already been available in the used car market (*modern*). The variable equals zero for any three year old car that first enters the used car market. For example, a car with a model cycle of 36 months is launched in the new car market in January 2000. Three years later, December 2002 will then mark its first appearance in the used car market. In that case, *modern* equals zero in December 2002, grows up to 36 in December 2005 and finally equals zero again in January 2006 when the next model is launched. I use dummy variables to define the model cycles which equal one if the model belongs to the cycle and zero if not. For instance, in February 1998 another car model of VW Golf is launched in the used car market for three year old cars. This means that one dummy is used for the times series of VW Golf which equals zero from June 1992 to January 1998 and equals one from February 1998 to December 2008. In case of k model changes in the observation period, k dummy variables have to be established ($d_1, ..., d_k$).

Data for the variables of the first category are taken from the German Federal Bureau of Statistics[43], from the German Central Bank (Deutsche Bundesbank)[44] and the Ifo Institute for Economic Research[45] as well as the ZEW Centre of European Economic Research[46].[47]

[43] Statistisches Bundesamt, Gustav-Stresemann-Ring 11, 65189 Wiesbaden, http://www.destatis.de.

[44] Deutsche Bundesbank, Wilhelm-Epstein-Str. 14, 60431 Frankfurt, http://www.bundesbank.de.

[45] Ifo Institute for Economic Research e.V. at the University of Munich, Poschingerstr. 5, 81679 Munich, http://www.cesifo-group.de/portal/page/portal/ifoHome.

[46] ZEW Centre of European Economic Research GmbH Mannheim, L 7, 1, 68161 Mannheim, http://www.zew.de/.

[47] The consumer price index for petrol which I will need to calculate the missing observations of the petrol price is also taken from the German Federal Bureau of Statistics.

All the variables of the second category are collected from the annual reports of the VDA[48] for 1989 until 2009.

4.4 Methodology and Prediction Results

4.4.1 Identification of the Prediction Model

The previous section specifies in total eleven sources of possible influences for residual values of cars. Among them are two influences which I describe in short as the *financial situation of private and industrial consumers* whereas the latter one is also an indicator for the economic climate. For each of the two influences I specify various indicator variables to approximate these impacts. In the following, I will use all of the eleven types of influences as mentioned in section 4.3.2 to develop a prediction model by applying an ARMAX regression approach. Hereby, I use one possible proxy variable for each influence. The detailed description of the applied procedure to develop and to identify the prediction models is described below.

The application of the ARMAX approach allows me to account for the serial correlation in the error terms. The models are estimated by using a maximum likelihood estimation. As I aim to predict residual values for a lease contract with a three-year duration, I use a forecast horizon of 36 months. Thus, I adjust the empirical model based on the observation period June 1992 to December 2005 and test its prediction ability for the period January 2006 to December 2008.

Since the time series of all three automotive models are stationary at least on the ten percent significance level according to the Phillips-Perron test, I use as dependent variable the residual values of the different car models over time ($value_t$, June 1992 $\leq t \leq$ December 2005). As independent variables I define the factors of the three categories explained in

[48] Verband der Automobilindustrie e.V. (VDA), Behrenstr. 35, 10117 Berlin.

section 4.3.2. All independent variables are stationary or trend-stationary at least at the ten percent significance level according to the Phillips-Perron test.[49]

In order to mirror the information available to consumers, I use data that is observable in the market. For example, private consumer spending figures are calculated at the end of each quarter. Hence, I use those figures to test for instance how the value of the first quarter influences the dependent variable in April, May and June. The value of the second quarter is then publicly available and applied to predict the dependent variable in July, August, September and so forth. Analogical, I use lagged monthly explanatory variables to model the relationship between the dependent and independent variables. Exceptions are the proxy for the financing costs, the number of first registered cars and the indices monitoring the economic climate. Changes in interest rates are not immediately incorporated in financing costs which is why I allow a lag of three months. For the number of first registrations I use a lag of 36 months as I am interested in observing market movements when the leased cars were new. I expect a strong activity in the new car market to have an effect on supply and demand for these cars in the used car market. The ifo and the ZEW index show the future expectations about the economic climate of the surveyed firms and financial specialists. While the ifo index usually covers a shorter time horizon of about three month, the time horizon of the ZEW index is up to six months. I therefore incorporate the *chifo* with a lag of three months and respectively *chzew* with a lag of five months. Employing this approach of lagged independent variables also avoids endogenity. The descriptive statistics for the variables used in my analysis are reported in Panel A of table 4.1 for the car models and in Panel B for the explanatory variables. Additionally, I list in table 4.1 the results of the Phillips-Perron test for each used variable.

[49] Trend-stationary variables are *pcs*, *di*, *gdp* and *lnpp*.

Table 4.1

Descriptive Statistics for the observation period from

June 1992 to December 2005

This table reports the descriptive statistics for the car models and the explanatory variables which are used in the analysis of the study at hand for the in-sample period from June 1992 to December 2008. Therefore, $value_t$ denotes the residual value, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the monthly unemployment rate, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three months, gdp_{t-1} the lagged price-adjusted quarterly gross domestic product, $chifo_{t-3}$ the monthly rate of change of the ifo index in percentage lagged three months, $chzew_{t-5}$ the monthly rate of change of the ZEW indicator in percentage lagged five months, pcs_{t-1} the lagged price-adjusted quarterly private consumer spending, di_{t-1} the lagged quarterly disposable income and $lnpp_{t-1}$ denotes the lagged logarithm of monthly petrol prices. The value in parentheses concerning the Phillips-Perron test denotes the corresponding probability. For trending variables I perform the Phillips-Perron test including a trend.

variables	**number of observations**	**mean**	**standard deviation**	**Phillips Perron test**
Panel A: Descriptive statistics for the car models				
VW Golf ($value_t$)	163	62.903	3.2090	-2.709 (0.07)
Mercedes-Benz C-Class ($value_t$)	163	60.7170	4.1014	-3.067 (0.03)
Mercedes-Benz E-Class ($value_t$)	163	57.866	3.4639	-3.125 (0.03)
Panel B: Descriptive statistics for the explanatory variables				
com_{t-1}	163	605351.1	59979.84	-8.968 (0.00)
$frcm_{t-36}$	163	287852.5	57735.8	-7.961 (0.00)
$euribor3_{t-3}$	163	4.0060	1.8150	-3.937 (0.00)
$chur_{t-1}$	163	0.3181	3.7799	-7.369 (0.00)
gdp_{t-1}	163	95.5504	5.8892	with trend -4.928 (0.00)
$gdppyq_{t-1}$	163	1.3442	1.3666	-3.793 (0.00)
$gdppq_{t-1}$	163	0.3190	.5841	-5.554 (0.00)
$chifo_{t-3}$	163	0.0079	1.4941	-9.774 (0.00)
$chzew_{t-5}$	163	0.3305	3.9135	-13.006 (0.00)

variables	**number of observations**	**mean**	**standard deviation**	**Phillips Perron test**
pcs_{t-1}	163	95.8263	5.8546	with trend -5.921 (0.00)
di_{t-1}	163	322.8131	30.0192	with trend -4.188 (0.00)
$lnpp_{t-1}$	163	4.4836	0.1749	with trend -3.146 (0.09)

For every car model I estimate robust standard errors. Since I include the variables *modern* and the dummies $d_1, ..., d_k$ in my regressions, I can also take into account a deterministic time trend shown by some independent variables for the observation period. To examine the robustness of my results to the inclusion of those trending variables, I report robustness tests in table 4.5. Therefore, I perform the analysis with trend-adjusted independent variables to prove that the results are stable. The issue of multicollinearity can be neglected, since I am solely interested in forecasting residual values.[50]

In order to find the best forecast model of my approach for each car, I start by constructing all possible prediction models based on the inclusion of each of the eleven sources of impacts as discussed in the previous section and describe them with the different variables of this section 4.3.2. For those influences which offer more than one possible explanatory variable (see the financial situation of private and industrial consumers), I create an empirical model for each possible explanatory variable. Hence, this procedure specifies in total ten possible prediction models which are listed in table 4.2.

[50]Compare for instance Makridakis et al. (1998, p. 189).

Table 4.2: Forecast model specifications

This table shows all possible forecast model specifications by including all influences. In this context $value_t$ denotes the residual value, d_i denotes the dummy for the i-th successor since June 1992, $modern$ the variable for modernity, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the lagged total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change of the monthly unemployment rate in percentage, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three months, $gdppyq_{t-1}$ the lagged quarterly rate of change of the gross domestic product related to the previous year quarter, $gdppq_{t-1}$ the lagged quarterly rate of change of the gross domestic product related to the previous quarter, $chifo_{t-3}$ the monthly rate of change of the ifo index in percentage lagged three months, $chzew_{t-5}$ the monthly rate of change of the ZEW indicator in percentage lagged five months, gdp_{t-1} the price-adjusted quarterly gross domestic product, pcs_{t-1} the lagged price-adjusted quarterly private consumer spending, di_{t-1} the lagged quarterly disposable income and $lnpp_{t-1}$ denotes the lagged logarithm of monthly petrol prices. α is the intercept and β_i the regression coefficients. N_t denotes the (ARMA) error term.

Model	Model definition
1	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, gdppyq_{t-1} + \beta_{k+7}\, pcs_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
2	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, gdppq_{t-1} + \beta_{k+7}\, pcs_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
3	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, chifo_{t-3} + \beta_{k+7}\, pcs_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
4	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, chzew_{t-5} + \beta_{k+7}\, pcs_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
5	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, gdp_{t-1} + \beta_{k+7}\, pcs_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
6	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, gdppyq_{t-1} + \beta_{k+7}\, di_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
7	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, gdppq_{t-1} + \beta_{k+7}\, di_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
8	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, chifo_{t-3} + \beta_{k+7}\, di_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
9	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, chzew_{t-5} + \beta_{k+7}\, di_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$
10	$value_t = \alpha + \sum_{i=1}^{k} \beta_i\, d_i + \beta_{k+1}\, modern + \beta_{k+2}\, com_{t-1} + \beta_{k+3}\, frcm_{t-36} + \beta_{k+4}\, euribor3_{t-3} + \beta_{k+5}\, chur_{t-1} + \beta_{k+6}\, gdp_{t-1} + \beta_{k+7}\, di_{t-1} + \beta_{k+8}\, lnpp_{t-1} + N_t$

A graphic examination of the time series of the residual values in my sample does not yield a clear linear trend for the modernity factor for every car. This non-linearity especially becomes apparent when a new model cycle begins with the launch of a new car model in the used car market. For this reason, I specify a quadratic ($modern^2$) and a cubic term ($modern^3$) to deal with this issue. I take the non-linearity into account by further considering the models of table 4.2 with these two terms. I hereby add either the variable $modern^2$ or $modern^3$ to each of the ten models. According to this procedure, I receive in total 30 possible model specifications: ten models deriving from table 4.2, another ten models by adding $modern^2$ and finally ten models by applying $modern^3$.

I then identify the best model based on the observation period June 1992 to December 2005 and test its prediction ability for the period January 2006 to December 2008. The selection of the best model based on the in-sample estimation requires the use of a selection criterion where I apply the popular Akaike information criterion (AIC). According to this approach, I have to select the best model with the smallest AIC. The appropriate ARMA error term is selected according to the analysis of the autocorrelation function and the partial autocorrelation function. To check whether the properties of the error term hold, I test the stationarity of the residuals of the structural equation (which I will denote as N_t in the following) by using a Phillips-Perron test and verify the white noise property of the errors (which I will denote as ϵ_t in the following) with a Portmanteau (Q) test. If I have to incorporate a seasonal ARMA term, I will compare the empirical model with the seasonal ARMA term with the same model including monthly dummy variables (md_i, $1 \leq i \leq 11$) modelling the seasonality instead of the seasonal ARMA term. Based on the smallest AIC, I then select again the best empirical model estimated for the time period from June 2005 to December 2008.

The next paragraph reports the selected ARMAX regression models for each car of the sample following the methodology described above. To support the selection procedure, I

Table 4.3

Selection of the empirical models

This table shows the value of the Akaike information criterion for each of the possible forecast models of table 4.2 and by adding the squared and cubic modernity factor $modern^2$ and $modern^3$ for each car of the sample. The smallest value is framed.

information criteria	**model 1**	**model 2**	**model 3**	**model 4**	**model 5**	**model 6**	**model 7**	**model 8**	**model 9**	**model 10**
VW Golf										
AIC	334.7773	334.9891	323.2033	333.2714	334.9932	335.5623	335.6791	323.6031	333.9975	335.5735
quadratic term added										
AIC	328.5879	328.6171	317.4241	326.9069	328.637	329.2686	329.1713	317.7676	327.5321	329.2585
cubic term added										
AIC	325.1836	325.1668	314.1577	323.4874	325.2074	325.7866	325.6449	314.459	324.0651	325.8352
Mercedes-Benz C-Class										
AIC	448.2898	448.2755	447.3015	447.7986	448.1418	448.0169	447.5527	447.0222	447.2685	446.5784
quadratic term added										
AIC	446.386	446.5024	445.5659	446.0346	446.1388	446.4882	446.1777	445.6176	445.68	444.8223
cubic term added										
AIC	447.6892	447.7516	446.7588	447.2689	447.3347	447.6221	447.3017	446.7233	446.9855	445.6677
Mercedes-Benz E-Class										
AIC	381.4793	381.343	374.0345	381.5052	381.5004	382.2921	382.0358	374.4138	382.2766	381.5078
quadratic term added										
AIC	379.7463	379.646	372.382	379.8063	379.7519	380.9143	380.652	373.097	380.9042	379.845
cubic term added										
AIC	378.3904	378.303	371.0128	378.4546	378.384	379.6125	379.3589	371.7779	379.6023	378.4651

list the AIC for each car and all 30 empirical models in table 4.3. According to this approach the best model for the VW Golf is identified as

$$\begin{aligned} value_t &= \alpha + \beta_1\, d_1 + \beta_2\, d_2 + \beta_3\, modern + \beta_4\, modern^3 + \beta_5\, ckm_{t-1} + \beta_6\, frcm_{t-36} \\ &\quad + \beta_7\, euribor3_{t-3} + \beta_8\, chur_{t-1} + \beta_9\, chifo_{t-3} + \beta_{10}\, pcs_{t-1} + \beta_{11}\, lnpp_{t-1} \\ &\quad + N_t, \quad \text{with } (1-\phi_1 B - \phi_2 B^2)(1-\Phi_1 B^{12})N_t = \epsilon_t, \end{aligned} \tag{4.1}$$

where B is the Backwardshift operator, ϕ_i is the coefficient of the AR-term, Φ_i the one of the seasonal AR-term and θ_i the one of the MA-term.[51] Analogously, I specify the prediction model for the other two cars. In the case of the Mercedes-Benz C-Class, the prediction model with an ARMA(1,0) error term[52] is identified as

$$\begin{aligned} value_t &= \alpha + \beta_1\, d_1 + \beta_2\, d_2 + \beta_3\, modern + \beta_4\, modern^2 + \beta_5\, ckm_{t-1} + \beta_6\, frcm_{t-36} \\ &\quad + \beta_7\, euribor3_{t-3} + \beta_8\, chur_{t-1} + \beta_9\, gdp_{t-3} + \beta_{10}\, di_{t-1} + \beta_{11}\, lnpp_{t-1} \\ &\quad + \sum_{i=1}^{11} \beta_{11+i}\, md_i + N_t, \quad \text{with } (1-\phi_1 B)N_t = \epsilon_t, \end{aligned} \tag{4.2}$$

and for the Mercedes-Benz E-Class the empirical model with an ARMA(1,0) error term is

$$\begin{aligned} value_t &= \alpha + \beta_1\, d_1 + \beta_2\, d_2 + \beta_3\, modern + \beta_4\, modern^3 + \beta_5\, ckm_{t-1} + \beta_6\, frcm_{t-36} \\ &\quad + \beta_7\, euribor3_{t-3} + \beta_8\, chur_{t-1} + \beta_9\, chifo_{t-3} + \beta_{10}\, pcs_{t-1} + \beta_{11}\, lnpp_{t-1} \\ &\quad + N_t, \quad \text{with } (1-\phi_1 B)N_t = \epsilon_t. \end{aligned} \tag{4.3}$$

Interestingly, all models contain either a quadratic or a cubic term. This observation supports my assumption that the decay caused by a decreasing actuality of the car is not captured by a pure linear pattern. Moreover, I find that the applied procedure selects the same empirical models for both the VW Golf and the Mercedes-Benz E-Class regarding the used independent

[51] Since the AIC is lower for the insertion of the seasonal autoregressive term in comparison to monthly dummy variables (with monthly dummies the AIC is 324.0815), I choose the model with the ARMA(2,0)$(1,0)_{12}$ error term.

[52] In this case, I use monthly dummy variables to account for seasonality as the inclusion of a seasonal autoregressive term results in a higher AIC of 456.1237.

variables. These two car models show a cubic term and the impacts of the financial situation of consumers are best described by the ifo index as well as private consumer spending. The only difference can be found in the specification of the ARMA model of the error terms.

The estimated coefficients of the specified ARMAX regression are documented in table 4.4. The robustness test to the inclusion of trending variables can be found in table 4.5.

Table 4.4: Empirical results

This table reports the results of the ARMAX regression models for the cars of the sample. d_i denotes the dummy for the i-th successor since June 1992, $modern$ the variable for modernity, $modern^2$ and $modern^3$ the squared and cubic modernity factor, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the monthly unemployment rate, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three months, gdp_{t-1} the lagged price-adjusted quarterly gross domestic product, $chifo_{t-3}$ the monthly rate of change of the ifo index in percentage lagged three months, pcs_{t-1} the lagged price-adjusted quarterly private consumer spending, di_{t-1} the lagged quarterly disposable income, $lnpp_{t-1}$ denotes the lagged logarithm of monthly petrol prices, md_i the dummy variable for month i and α the intercept. The values in parentheses with the coefficients denote the standard deviations. The values in parentheses with the χ^2 test statistic, the Phillips-Perron test and the Portmanteau (Q) test denote the corresponding probability. N is the number of observations. $\hat{\sigma}$ is the estimated standard deviation of the white noise disturbance. All estimated errors are robust standard errors.

Variable	**VW Golf**	**Mercedes-Benz C-Class**	**Mercedes-Benz E-Class**
$d1$	-12.78***	-6.712	-3.144
	(1.586)	(6.234)	(3.037)
$d2$	-13.97***	-7.649	-9.582**
	(2.29)	(8.319)	(4.864)
$modern$	-.0902***	-.0526	-.2358***
	(.0316)	(.0542)	(.0399)
$modern^2$	–	$-8.0 \cdot 10^{-4}$	–
		$(6.0 \cdot 10^{-4})$	
$modern^3$	$-1.7 \cdot 10^{-5}$ ***	–	$9.2 \cdot 10^{-6}$ ***
	$(4.1 \cdot 10^{-6})$		$(2.7 \cdot 10^{-6})$
com_{t-1}	$7.4 \cdot 10^{-8}$	$5.9 \cdot 10^{-7}$	$-2.0 \cdot 10^{-6}$ **
	$(9.2 \cdot 10^{-7})$	$(1.3 \cdot 10^{-6})$	$(8.2 \cdot 10^{-7})$
$frcm_{t-36}$	$-1.6 \cdot 10^{-6}$	$-2.8 \cdot 10^{-6}$	$-8.3 \cdot 10^{-7}$
	$(1.4 \cdot 10^{-6})$	$(2.7 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$
$euribor3_{t-3}$	.0369	-.3896	-.0109
	(.235)	(.5469)	(.3464)
$chur_{t-1}$	-.0491**	-.0497	.0124
	(.0191)	(.0498)	(.0179)
gdp_{t-1}	–	.1829	–
		(.1805)	
$chifo_{t-1}$	.0019	–	-.0681*
	(.0217)		(.0399)

Table 4.4: Empirical results (continued)

Variable	**VW Golf**	**Mercedes-Benz C-Class**	**Mercedes-Benz E-Class**
di_{t-1}	–	-.0567	–
		(.0469)	
pcs_{t-1}	-.0058	–	-.0539**
	(.0271)		(.0213)
$lnpp_{t-1}$	-.6543	-3.586	-.9828
	(1.599)	(3.049)	(1.845)
md_1	–	.0014	–
		(.2694)	
md_2	–	.0934	–
		(.5123)	
md_3	–	-.2871	–
		(.6279)	
md_4	–	.675	–
		(1.033)	
md_5	–	.778	–
		(1.105)	
md_6	–	.9154	–
		(1.104)	
md_7	–	.8901	–
		(.7588)	
md_8	–	.7001	–
		(.8178)	
md_9	–	.478	–
		(.8734)	
md_{10}	–	.0652	–
		(.7252)	
md_{11}	–	.9716**	–
		(.4471)	
α	83.56***	90.94***	81.37***
	(7.737)	(13.33)	(9.379)
ARMA term			
ar(1)	1.032***	.8326***	.9308***
	(.0649)	(.1253)	(.0448)
ar(2)	-.1552**	–	–
	(.0626)		
ar(12)	.3915***	–	–
	(.133)		
$\hat{\sigma}$	.5895***	.8136***	.6888***
	(.0627)	(.1065)	(.0806)

Table 4.4: Empirical results (continued)

Variable	**VW Golf**	**Mercedes-Benz C-Class**	**Mercedes-Benz E-Class**
N	163	163	163
χ^2	11988.11	3834.16	21444.40
	(0.00)	(0.00)	(0.00)
Phillips-Perron	-3.018	-4.348	-3.105
test	(0.03)	(0.00)	(0.03)
Portmanteau	28.3997	42.5237	35.5854
(Q) test	(0.92)	(0.36)	(0.67)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4.5: Robustness tests for the forecast models

This table reports the robustness test to the inclusion of trending variables in the ARMAX regression models for the cars of the sample. d_i denotes the dummy for the i-th successor since June 1992, $modern$ the variable for modernity, $modern^2$ and $modern^3$ the squared and cubic modernity factor, com_{t-1} the lagged total monthly number of change of ownership, $frcm_{t-36}$ the total monthly number of first registrations exactly 3 years ago, $chur_{t-1}$ the lagged rate of change in percentage of the monthly unemployment rate, $euribor3_{t-3}$ the three-month EURIBOR interest rate lagged three months, $gdpta_{t-1}$ the lagged trend-adjusted price-adjusted quarterly gross domestic product, $chifo_{t-3}$ the monthly rate of change of the ifo index in percentage lagged three months, $pcsta_{t-1}$ the lagged trend-adjusted price-adjusted quarterly private consumer spending, $dita_{t-1}$ the lagged trend adjusted quarterly disposable income, $lnppta_{t-1}$ denotes the lagged trend adjusted logarithm of monthly petrol prices, md_i the dummy variable for month i and α the intercept. The values in parentheses with the coefficients denote the standard deviations. The values in parentheses with the χ^2 test statistic, the Phillips-Perron test and the Portmanteau (Q) test denote the corresponding probability. N is the number of observations. $\hat{\sigma}$ is the estimated standard deviation of the white noise disturbance. All estimated standard errors are robust standard errors.

Variable	**VW Golf**	**Mercedes-Benz C-Class**	**Mercedes-Benz E-Class**
$d1$	-12.78***	-10.3**	-4.273
	(1.586)	(4.708)	(3.077)
$d2$	-13.97***	-13.5**	-11.51**
	(2.29)	(5.454)	(4.86)
$modern$	-.0902***	-.0796	-.2453***
	(.0316)	(.0485)	(.0388)
$modern^2$	–	$-8.0 \cdot 10^{-4}$	–
		$(6.0 \cdot 10^{-4})$	
$modern^3$	$-1.7 \cdot 10^{-5}$ ***	–	$9.2 \cdot 10^{-6}$ ***
	$(4.1 \cdot 10^{-6})$		$(2.7 \cdot 10^{-6})$
com_{t-1}	$7.4 \cdot 10^{-8}$	$5.9 \cdot 10^{-7}$	$-2.0 \cdot 10^{-6}$ **
	$(9.2 \cdot 10^{-7})$	$(1.3 \cdot 10^{-6})$	$(8.2 \cdot 10^{-7})$
$frcm_{t-36}$	$-1.6 \cdot 10^{-6}$	$-2.8 \cdot 10^{-6}$	$-8.3 \cdot 10^{-7}$
	$(1.4 \cdot 10^{-6})$	$(2.7 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$
$euribor3_{t-3}$	.0369	-.3899	-.0134
	(.235)	(.547)	(.3464)

Table 4.5: Robustness test (continued)

Variable	**VW Golf**	**Mercedes-Benz C-Class**	**Mercedes-Benz E-Class**
$chur_{t-1}$	-.0491**	-.0497	.0124
	(.0191)	(.0498)	(.0179)
$gdpta_{t-1}$	–	.1829	–
		(.1805)	
$chifo_{t-1}$	.0019	–	-.0681*
	(.0217)		(.0399)
$dita_{t-1}$	–	-.0567	–
		(.0469)	
$pcsta_{t-1}$	-.0058	–	
	(.0271)		-.0539**
			(.0213)
$lnppta_{t-1}$	-.6546	-3.586	-.9895
	(1.599)	(3.049)	(1.844)
md_1	–	.0014	–
		(.2694)	
md_2	–	.0933	–
		(.5123)	
md_3	–	-.2873	–
		(.6279)	
md_4	–	.6747	–
		(1.033)	
md_5	–	.7777	–
		(1.105)	
md_6	–	.9151	–
		(1.104)	
md_7	–	.89	–
		(.7589)	
md_8	–	.7001	–
		(.8178)	
md_9	–	.4778	–
		(.8734)	
md_{10}	–	.0651	–
		(.7252)	
md_{11}	–	.9715**	–
		(.4471)	
α	80.5***	78.38***	72.98***
	(3.416)	(6.22)	(4.19)
ARMA term			

Table 4.5: Robustness test (continued)

Variable	VW Golf	Mercedes-Benz C-Class	Mercedes-Benz E-Class
ar(1)	1.032***	.8326***	.931***
	(.0649)	(.1253)	(.0445)
ar(2)	-.1552**	–	–
	(.0626)		
ar(12)	.3914***	–	–
	(.133)		
$\hat{\sigma}$	.5895***	.8137***	.6888***
	(.0627)	(.1065)	(.0806)
N	163	163	163
χ^2	11997.83	3833.21	21428.88
	(0.00)	(0.00)	(0.00)
Phillips-Perron	-3.018	-4.347	-3.100
test	(0.03)	(0.00)	(0.03)
Portmanteau	28.3961	42.5254	35.5623
(Q) test	(0.92)	(0.36)	(0.67)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.4.2 Prediction of the Explanatory Variables

The prediction of the residual values by using the empirical models according to section 4.4.1 involves future values of the explanatory variables. However, these values are also unknown in advance and must therefore be forecasted as well. I predict future values of the explanatory variables by using ARIMA models. These models are rather basic compared to more sophisticated ones that may yield better forecast values. For my analysis, however, I use a wide majority of determinants for which a variety of forecast models exists from other research institutions, though all of their results are only available for purchase. This is why I do not focus on the development of more precise prediction models for the explanatory variables but adhere to the use of ARIMA models.

To forecast the residual values of the three car models from my analysis, I have to find future values for the variables *com*, *euribor3*, *chur*, *chifo*, *gdp*, *pcs*, *di* and *lnpp* as those are part of equation (4.1), (4.2) and (4.3). The modernity factor and the total number of newly registered cars in my models are known in advance and need not to be forecasted (the variable *frcm* is incorporated with a lag of 36 months).

In order to identify the best ARIMA model for the variables of interest, I follow a very similar approach to the one of section 4.4.1. Like before, I specify the model for the observation period June 1992 to December 2005 and forecast the values of the explanatory variables up to December 2008. I start by analysing the autocorrelation and partial autocorrelation functions of the desired variables. These functions indicate the possible structure of the ARIMA model. As the pattern of the autocorrelation and partial autocorrelation functions may lead to more than one suitable ARIMA model, I identify the most appropriate one with the help of the AIC. To test the stationarity and white noise property of the errors I perform the Phillips-Perron and Portemanteau (Q) test. In the case the explanatory variables are trend-stationary, I specify an ARMAX regression model that includes a deterministic linear time trend as the only explanatory variable. According to this aforementioned approach, I specify the ARIMA models listed in table 4.6 for the explanatory variables.

Table 4.6: ARIMA models for the explanatory variables

This table shows the selected ARIMA models for the explanatory variables where com denotes the total monthly number of change of ownership, $frcm$ the total monthly number of first registrations, $chur$ the rate of change in percentage of the monthly unemployment rate, $euribor3$ the three-month EURIBOR interest rate, gdp the price-adjusted quarterly gross domestic product, $chifo$ the monthly rate of change of the ifo index in percentage, pcs the price-adjusted quarterly private consumer spending, di the quarterly disposable income, $lnpp$ denotes the logarithm of monthly petrol prices. In this context, N_t denotes the ARIMA error term, ϵ_t the white noise error term, B denotes the Backwardshift operator and t the time in months indicating the deterministic linear time trend. α is the intercept, β the regression coefficient, ϕ_i is the coefficient of the AR term, Φ_i the one of the seasonal AR term, θ_i the coefficient of the MA term and Θ_i the one of the seasonal MA term.

Variable	**Specified ARIMA model**	**Definition**	Philips-Perron test	Portmanteau (Q) test
com	ARIMA(3,0,3)(1,0,1)$_{12}$	$(1-\phi_1 B-\phi_2 B^2-\phi_3 B^3)(1-\Phi_1 B^{12})\, com_t = (1-\theta_1 B-\theta_2 B^2-\theta_3 B^3)(1-\Theta_1 B^{12})\epsilon_t$	-13.608 (0.00)	28.1312 (0.9208)
euribor3	AR(2)	$(1-\phi_1 B-\phi_2 B^2)\, euribor3_t = \epsilon_t$	-30.578 (0.00)	16.9474 (0.9995)
chur	ARIMA(2,0,0)(1,0,1)$_{12}$	$(1-\phi_1 B-\phi_2 B^2)(1-\Phi_1 B^{12})\, chur_t = (1-\Theta_1 B^{12})\epsilon_t$	-12.636 (0.00)	39.6864 (0.4842)
gdp	ARIMA(1,0,0)(1,0,0)$_4$ with a time trend	$gdp_t = \alpha+\beta\, t+N_t$ with $(1-\phi_1 B)(1-\Phi_1 B^4)N_t = \epsilon_t$	-8.387 (0.00)	22.1691 (0.6794)
chifo	AR(3)	$(1-\phi_1 B-\phi_2 B^2-\phi_3 B^3)\, chifo_t = \epsilon_t$	-12.367 (0.00)	25.0202 (0.9692)
pcs	ARIMA(1,0,1)(1,0,1)$_4$ with a time trend	$pcs_t = \alpha+\beta\, t+N_t$ with $(1-\phi_1 B)(1-\Phi_1 B^4)N_t = (1-\theta_1 B)(1-\Theta_1 B^4)\epsilon_t$	-8.172 (0.00)	18.6231 (0.8519)
di	ARIMA(1,0,1) with a time trend	$di_t = \alpha+\beta\, t+N_t$ with $(1-\phi_1 B)N_t = (1-\theta_1 B)\epsilon_t$	-7.487 (0.00)	32.0433 (0.1917)
lnpp	ARIMA(1,0,0)(1,0,1)$_{12}$ with a time trend	$lnpp_t = \alpha+\beta\, t+N_t$ with $(1-\phi_1 B)(1-\Phi_1 B^{12})N_t = (1-\Theta_1 B^{12})\epsilon_t$	-12.222 (0.00)	46.8067 (0.2132)

4.4.3 Prediction of the Residual Values

After having completed the various steps of the previous sections, I am able to forecast the residual values of the VW Golf, Mercedes-Benz C-Class and Mercedes-Benz E-Class for January 2006 to December 2008. I compare the predicted values with the actual data for the observation period in order to evaluate the performance of the prediction models. Additionally, I estimate a 95% prediction interval to exhibit a range for the potential future residual values. This interval may be used to narrow down certain values of a lease contract or the lease rate. As discussed in Makridakis et al. (1998, p. 401), I neglect the prediction errors from forecasting the explanatory variables but use the mean squared errors of the ARMAX regression models in equation (4.1), (4.2) and (4.3) to calculate the confidence intervals. In general, this procedure leads to prediction intervals which are too narrow, this disadvantage is pointed out by Makridakis et al. (1998, p. 402). If, however, the forecasts of the explanatory variables are purchased, the prediction errors of each variable are generally not available. Hence, this approach reflects the situation of the risk management of leasing institutions and is thus reasonable.

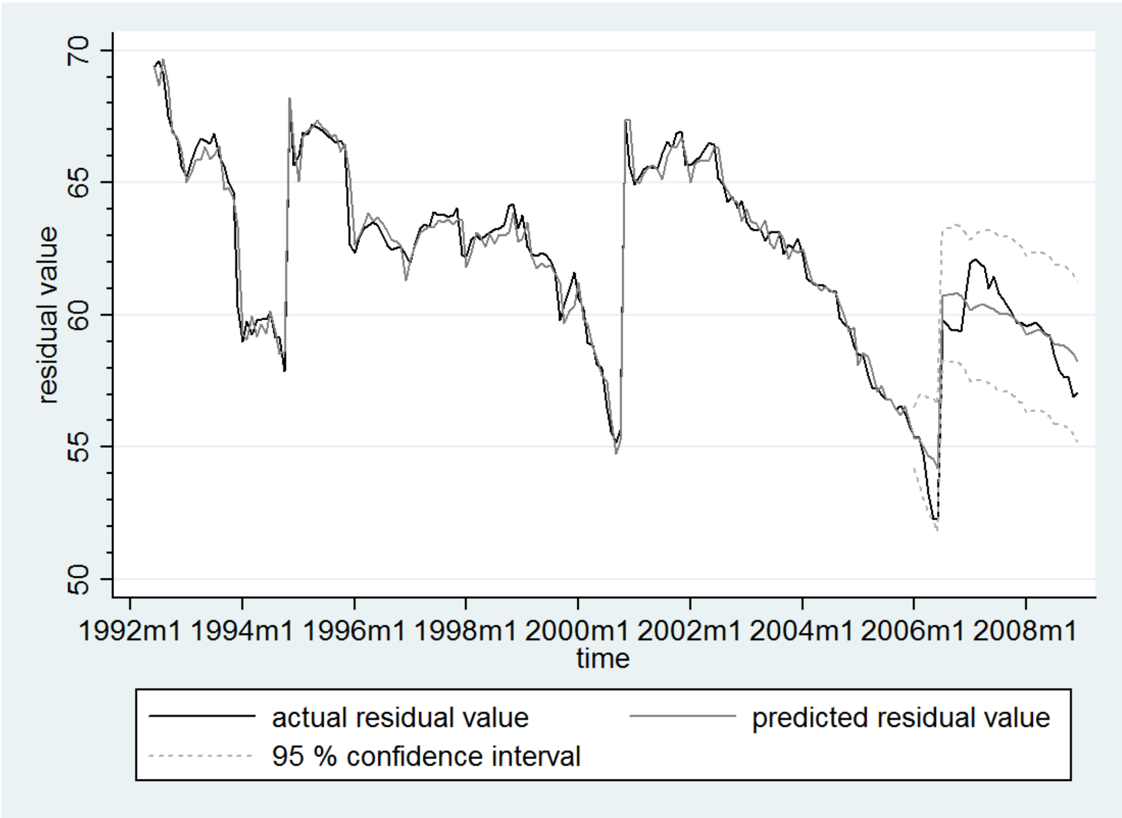
I begin by analysing the forecast values for the VW Golf. This is a special case as a model change has occurred during the prediction period. In July 2006, the VW Golf V (successor of the VW Golf IV) is available for the first time in the used car market for three year old cars. In my analysis, I include model cycles by using the dummy variables d_i $(1 \leq i \leq k)$. Since a new model cycle begins in July 2006, the dummy for this model cycle is not included in the estimation period from June 1992 until December 2005. Therefore, no estimated coefficient is available for this model cycle. Thus, I have to estimate the launch impact of this model in the used car market.

I solve this issue by analysing historical data of the time series for a three year old VW Golf and a two year old VW Golf during the observation period. First, I determine the effect of the launch of VW Golf III regarding the time series for two and three year old cars. The last value of a two year old VW Golf II was 69.55% while the first value of a three year old VW Golf III is 68.21%. Similarly, the last value of a two year old VW Golf III is 68.15% while the first value of a three year old VW Golf IV is 67.31%. If a new VW Golf model is launched in the used car market for three year old cars, I observe that consumers are willing to pay about as much as the latest value of its two year old predecessor. I document a difference of approximately one percent between these residual values. From this examination I expect the value of a three year old VW Golf V launched to be roughly 60.71%, since the latest value for the two year old Golf IV calculated in June 2005 is 61.71%. I proceed as follows: I predict the residual values according to my empirical model in equation (4.1). By doing so, I observe that the residual value in July 2006 is 78.71% without accounting for the new model cycle. Hence, I subtract 18 from the predicted values from July 2006 to December 2008. As a conclusion, I obtain a residual value of approximately 60.71% in July 2006.

The results for the VW Golf according to this procedure are illustrated graphically in figure 4.1. The graph shows a slower decay of the empirical model than of the actual data. Thus, my empirical model underestimates the decline in residual values even though the actual data is in the 95% prediction interval during the entire forecast period. Looking at the end of the observation period, I have predicted a residual value of 58.24% which weighs against the actual value of 57.05%. Due to the slower decay my model overestimates this value by approximately 1%. In order to compare the predicted values with the actual data, I calculate the prediction error by subtracting the actual residual values from the predicted ones. The prediction error for the out-of-sample forecast is in the interval [-1.83%,2.27%]. Consequently, I have a deviation from the actual data of at most 2.27% which is very moderate. In general, I expect a deviation from the predicted to the actual values with a mean of 0.18% and a standard deviation of 1.06%. Conclusively, my model overestimates the actual residual values in the mean by 0.18%.

In contrast, the empirical model in equation (4.2) for the Mercedes-Benz C-Class delivers satisfying results for the decay of the actual data. The graph of the actual and predicted

Figure 4.1: Residual value forecasts for VW Golf



residual values can be found in figure 4.2. However, the empirical model underestimates the actual fluctuations in the residual values. Even the limits of the prediction interval are exceeded three times which may be also caused by the too tight calculation of the confidence intervals. Another explanation for this observation might be quality differences, with the Mercedes-Benz cars fluctuating more during this time period than others. These strong fluctuations result in a larger interval and standard deviation of the prediction error compared to the VW Golf. The prediction error for the Mercedes-Benz C-Class is in the interval [-2.57%,3.34%] and its standard deviation is at about 1.69%. Its mean, however, is very low with a value of -0.02%. Thus, I underestimate the actual residual value in the mean by only 0.02%. At the end of the 36 months prediction period, my model gives a considerable good forecast of 55.03% percent compared to an actual value of 55.51%. With a difference of about 0.5%, I derive a relatively precise forecast of the residual value for the Mercedes-Benz C-Class.

Figure 4.2: Residual value forecasts for Mercedes-Benz C-Class

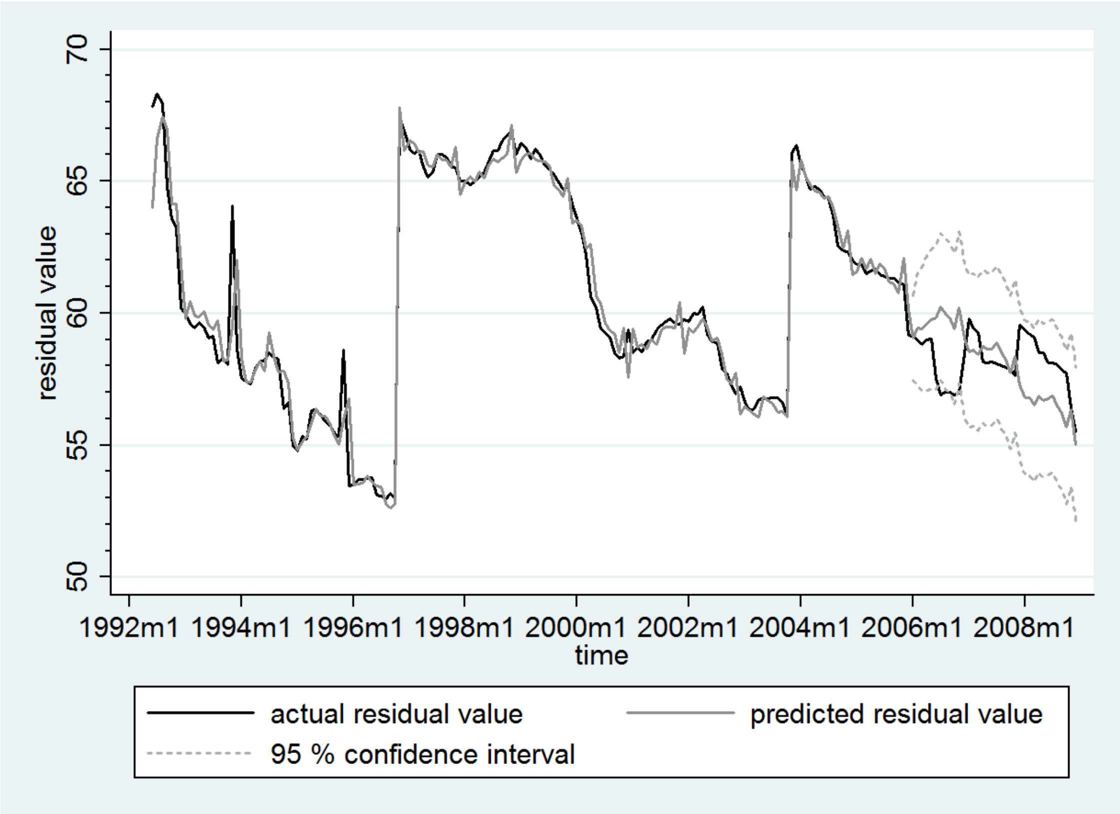
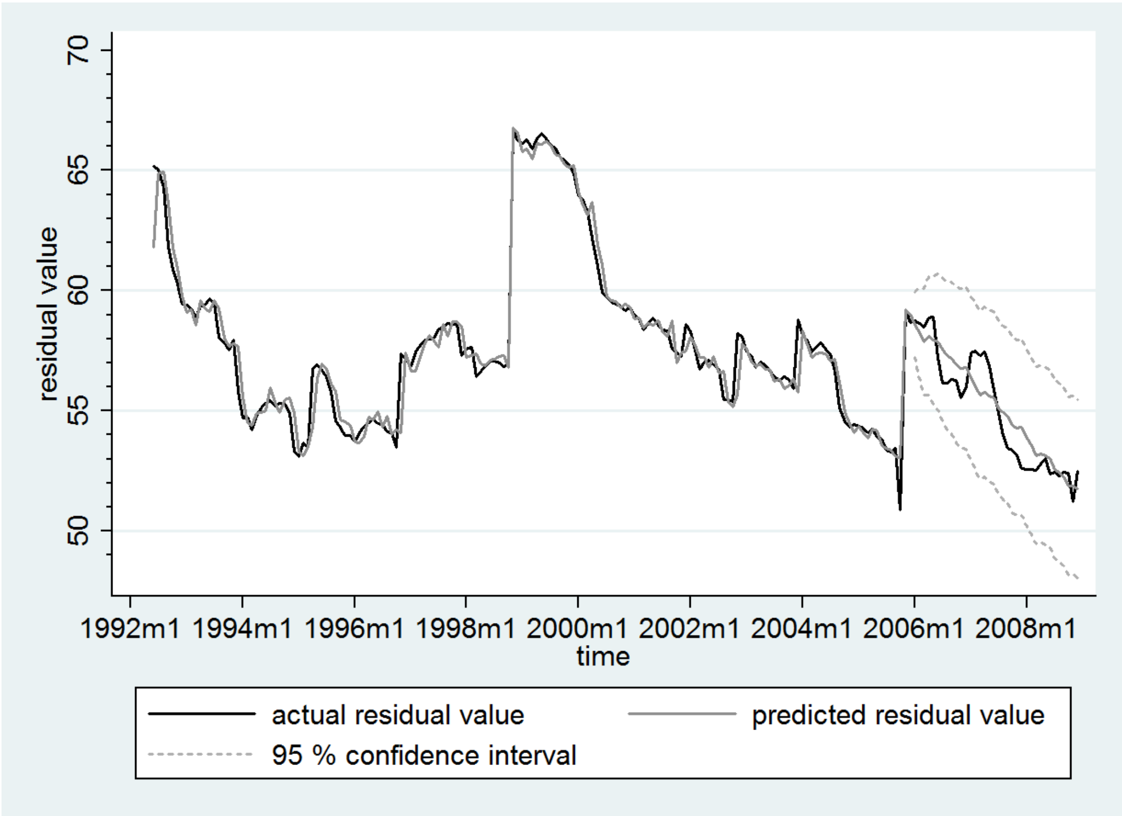


Figure 4.3 shows the results for the Mercedes-Benz E-Class. The prediction model in equation (4.3) simulates accurately the decline in residual values. Although the fluctuations in the actual data are stronger than predicted, the deviations from the predicted values are moderate. The actual data does not even reach the limits of the confidence interval, being always far within it. With 51.76%, the forecast for December 2008 differs only less than 1% compared to the original value of 52.50%. This observation strengthens the good performance of the model. The analysis of the prediction error confirms this picture. The deviations from the actual residual value are very small with all errors occurring within -1.67% and 1.70% and the standard deviation ranging as low as 0.95%. Like the VW Golf, the prediction model overestimates the residual value in the mean by 0.18%.

In general, I observe a good performance of the prediction models for the observation period from January 2006 to December 2008. The Mercedes-Benz C-Class has the largest deviations from the actual values with up to 3.34% overestimation. However, the prediction errors of

Figure 4.3: Residual value forecasts for Mercedes-Benz E-Class



the other car models do not exceed 2%. For the predicted residual value in December 2008 – which is necessary for the valuation of a 36 month lease contract signed in December 2005 – I observe a good forecasting performance of all three models. The difference between the actual and the predicted residual value is at most 1%. In summary, the deviation from the actual data throughout the car models is moderate and the residual value at the end of the prediction period can be forecasted quite accurately. Conclusively, I find a very satisfying performance during my out-of-sample period of the empirical models for each car of the study at hand. Hence, the application of the developed prediction models to evaluate automobile lease contracts seems to be appropriate.

4.5 Effects on the Risk Management of Automotive Lease Contracts

By using the ARMAX regression methodology, I developed an approach to determine residual values which are a central element in the valuation of lease contracts. While this issue is the aim of the study at hand, I am able to draw conclusions from this analysis that will offer further guidance for the risk management of lease institutions. This results from the opportunity to ascribe changes in residual values to fluctuations in certain underlying market factors by using the identified forecast models. As residual values determine lease rates or the value of lease contracts, I am able to link specific market situations to the level of this rate or value. The application of the forecast models developed in the previous section allows us to determine how changes in the underlying factors influence the equilibrium lease rate and, moreover, the value of the lease contract. This is of particular interest to leasing providers in various ways. First, the predicted residual values depend on forecast values of the explanatory variables. If values for those variables are specified wrongly, this will certainly alter the lease rate and the value of the lease contract. Lessors should be aware of the potential impact from a misspecification of the explanatory variables on lease contracts and the lease rate as this might considerably change their profit margin. Secondly, market conditions may fluctuate during the duration of lease contracts. If the market environment turns out to evolve in a different way than expected at completion of the contract, lessors are interested in how this development affects their gains or losses. It is vital for risk management of lease institutions to take these relations into account.

In the next paragraphs, I will analyse the impact of changes in the underlying factors on the equilibrium lease rate and the value of the lease contract. Before I apply the empirical results of this study, I determine the lease rate and the value of the lease contract according to the approach of McConnell and Schallheim (1983). For simplicity reasons, I concentrate my analysis on financial leases. This also reflects reality since 64% of all lease contracts in Germany in 2010 were financial leases (Bundesverband Deutscher Leasing-Unternehmen, 2011, p. 19) which covers the majority of leasing arrangements.

McConnell and Schallheim (1983, p. 251) determine the equilibrium lease rate L^{FL} of a financial lease with n lease payments by using a compound option approach as

$$L^{FL} = \frac{A_0}{\sum\limits_{i=0}^{n-1}(1+r_f)^{-i}} - \frac{S_0^n}{\sum\limits_{i=0}^{n-1}(1+r_f)^{-i}}, \tag{4.4}$$

where A_0 is the current market value of the asset, S_0^n is the present value of the asset's residual value at maturity date of the contract and r_f is the risk-free interest rate. The prediction models developed in section 4.4.1 with the ARMAX regression approach use a linear relationship between the residual values and the influencing variables defined in section 4.3.2. In general, those models can be represented as

$$value_t = \alpha + \beta_1 x_t^1 + \beta_2 x_t^2 + \cdots + \beta_k x_t^k + N_t, \tag{4.5}$$

where $value_t$ is the percentage of the residual value of a 36 month old car related to its MSRP when new (i.e. $A_{36}/A_0 \cdot 100$), x_t^i is the ith independent variable ($1 \leq i \leq k$, $k \in \mathbb{N}$) and N_t is the error term ($value_t$, x_t^i and N_t are stochastic processes). By using the notation of (4.5), the equilibrium lease rate in equation (4.4) can be represented as

$$L^{FL} = \frac{A_0}{\sum\limits_{i=0}^{n-1}(1+r_f)^{-i}} - value_t \cdot \frac{\ddot{A}_0}{\sum\limits_{i=0}^{n-1}(1+r_f)^{-i}}, \tag{4.6}$$

where $\ddot{A}_0$ is the present value of $A_0/100$ compounded at maturity of the contract.

Equation (4.6) allows us to examine how changes in the underlying factors of the residual value affect the lease rate. Therefore, I determine the sensitivity of the lease rate to changes in one of the explanatory variables x_t^i holding all other factors constant. Mathematically, this proposal is expressed by the deviation

$$\frac{\partial L^{FL}}{\partial x_t^i} = -\beta_i \cdot \frac{\ddot{A}_0}{\sum\limits_{i=0}^{n-1}(1+r_f)^{-i}}.$$

As one can see, the equilibrium lease rate alters with a constant proportionality factor for changes in the residual value which are caused by fluctuations in a particular market factor. The direction of changes in the lease rate, however, is opposite to the direction of changes in the residual value caused by the influencing variable.

In order to get an impression about the magnitude of the effect on lease rates, I use a numerical example to illustrate this in the following. I use the empirical results of table 4.4 to determine the sensitivity of the lease rate of all three car models to changes in the logarithm of petrol price. To compare the results, I assume the same MSRP for all three car models which I define as €30 000. Additionally, I assume monthly lease payments during the 36 month duration period and a risk-free interest rate of 3%. With this information at hand it becomes apparent that the monthly lease rate of a VW Golf increases by €0.03 for an increase in the logarithm of the petrol price of 0.01 (which is equal to an increase in petrol prices of approximately 1%). I note respectively an increase in the lease rate of €0.17 for the Mercedes-Benz C-Class and of €0.05 for the Mercedes-Benz E-Class.

So far, I have examined the impact of changes in the underlying factors on the equilibrium lease rate. The effects on the value of a lease contract are of equal interest to lessors. I define the value of a lease contract according to Myers et al. (1976, p. 801) who describe it as the advantage of leasing over financing. This is a very common definition in the leasing literature and is known as the *net advantage to leasing (NAL)*. Applied to the used valuation approach for financial leases in this study, the *NAL* is defined according to McConnell and Schallheim (1983, p. 251) as

$$\begin{aligned} NAL &= A_0 - \sum_{i=0}^{n-1} \frac{\bar{L}^{FL}}{(1+r_f)^i} - S_0^n \\ &= A_0 - \sum_{i=0}^{n-1} \frac{\bar{L}^{FL}}{(1+r_f)^i} - value_t \cdot \ddot{A}_0, \end{aligned} \tag{4.7}$$

with the contractual lease rate $\bar{L}^{FL}$. If leasing according to the contractual specifications is preferable, the *NAL* is positive. Under these circumstances a positive *NAL* implies a higher equilibrium lease rate in comparison to the contractual lease rate. In contrary, a negative

NAL implies that the contractual specifications are unfavourable and the car should not be leased but rather financed according to these conditions. In short, one can say that the *NAL* describes the value of the lease contract from the lessee's perspective. A positive *NAL* states that the specifications of the lease contract are profitable for the lessee while a negative one states that those are profitable for the lessor.

Like the equilibrium lease rate, the net advantage to leasing also alters for changes in the residual value. By using the same approach as above, I am able to determine the sensitivity of changes in the *NAL* for alterations in the underlying factors of the residual value. Assuming all other factors are held constant, this sensitivity is calculated as

$$\frac{\partial NAL}{\partial x_t^i} = -\beta_i \cdot \ddot{A}_0.$$

Again, the proportionality factor is constant and the direction of the influence is opposite to the direction of the coefficient of the analysed influence. The comprehension of this result is not so obvious at first sight. If the regression coefficient of the particular influence is negative, the residual value will decrease for an increase of the figures of this particular influence. Consequently, lease rates go up in order to compensate the lessor for the additional depreciation. Thus, one would initially think that the value of the lease contract should also fall. I have determined, however, that in this case the *NAL* goes up. To explain this result I have to examine the calculation of the *NAL* (which calculates the value of the contract from the lessee's perspective). In equation 4.7 I use the fixed contractual lease rate and compare it with the equilibrium lease rate. The equilibrium lease rate, however, will increase due to the decreasing residual value. This is why a decrease in the residual value makes leasing more favourable according to the originally predefined conditions (before the decrease in the residual value) compared to a leasing contract with the new (and higher) equilibrium lease rate. In order to illustrate this result, I use the previous example and obtain an increase in the net advantage to leasing of €0.68 for the VW Golf, of €3.71 for the Mercedes-Benz C-Class and of €1.02 for an increase of 0.01 in the logarithm of petrol prices. This analysis shows that the *NAL* increases for an approximate 1% rise in petrol prices. This results in a loss on lessors side of at least €0.68 for a VW Golf and up to €3.71 for a Mercedes-Benz C-Class.

In order to provide a complete picture of the above examination, I would like to add a short note. The analysis above determined only the immediate impact (i.e. at point t) of a misspecification for one of the underlying factors. In practice, however, it is very likely that misspecified or wrongly forecasted factors will not only appear at one single point in time but for numerous occasions or even a specific period. Due to the autoregressive representation of the error terms, one might suppose that such a misspecified influencing factor leaves an impact on the forecasted residual value during the prediction period. Nevertheless, the approach focusing only on the immediate impact is sufficient. This consideration becomes more understandable by looking at the assumption of an autoregressive process of order one for the error term N_t which is exemplified in my study by the Mercedes-Benz C-Class and E-Class. Using its recursive representation, N_t can be expressed as

$$N_t = \phi_1^m N_{t-m} + \sum_{j=0}^{m-1} \phi_1^j \epsilon_{t-j} = \phi_1^m \left(value_{t-m} - \alpha - \sum_{i=1}^{k} \beta_i x_{t-m}^i \right) + \sum_{j=0}^{m-1} \phi_1^j \epsilon_{t-j},$$

by means of some earlier point in time $t - m$ during the prediction period. Thus, a wrong forecast of one of the underlying factors in the out-of-sample period may always be reduced to a representation where $t - m$ is in-sample. Hence, it is adequate to focus solely on the impact of changes at the certain point of interest. A previous misspecification of an underlying factor does not affect the lease rate or the value of the lease contract and does not need to be considered in the risk management of lease contracts.

The numerical examples show that the determination of effects on the lease rate and the value of lease contracts due to changes in influencing factors are applicable to the risk management of lease institutions. The approach of section 4.4.1 provides not only the possibility to forecast residual values but also allows to draw conclusions for the examination of residual value risk. The risk management of lease institutions should consider changes in lease portfolios resulting from changes in the market environment because this might considerably impact their gains and losses.

Furthermore, it is possible to identify a range for the lease rate and the value of a lease contract or respectively a leasing portfolio by using the confidence intervals determined by the applied approach. Moreover, the modelling of residual values by using ARMAX regression models provides the opportunity to run stress tests. By choosing different values for the explanatory variables it is possible to construct and implement various scenarios. It can be derived from those scenarios how residual values evolve in different market environments and, thus, how lease rates and the value of the lease contract may alter. This is the main purpose of the application of stress tests. They are of high importance as leasing institutions in Germany have to accomplish the regulatory requirements of MaRisk[53] which makes these tests compulsory. Those requirements implement the standards of Basel II in German legislation and have been applied to lease providers since 2010.

To conclude, there are various applications in this study to provide answers to the issues of the automobile leasing industry. On the one hand, the prediction of residual values can be used for the valuation of lease contracts. On the other hand, the discussion above mentions only some of the ways in which these results can be applied to improve the risk management of lease institutions. As the numerical example shows, small changes in an underlying factor impact the lease rate and the value of the lease contract. Although these changes may be rather small for a single lease contract, the effects on complete lease portfolios may be substantial.

[53] MaRisk is the abbreviation for "Mindestanforderungen an das Risikomanagement".

4.6 Summary and Future Research

Residual values are of major importance in the valuation of lease contracts as they bear a substantial impact on lease rates. They are, however, not known in advance but are needed at the completion of the contract which is why they have to be forecasted. Thus, the aim of this chapter is to identify a prediction model for residual values of cars.

My analysis is based on cars since automobile leases represent the largest group of equipment leasing in Germany. The duration period covers three years with residual values of a three year old car being predicted for a 36 month period in advance. In order to do so, I have collected a dataset of residual values for the VW Golf, the Mercedes-Benz Class and the Mercedes-Benz E-Class for the period June 1992 until December 2008. I then specify a prediction model based on eleven influences. Those influences can be classified into three main groups presenting the overall economy, the market environment of used and new cars and characteristics of a certain car model. Since the error term includes serial correlation, I use the linear ARMAX regression methodology to model the relationship between residual values and the influencing variables. By using the Akaike Information criteria I identify the best prediction model for an in-sample period from June 1992 to December 2005 and evaluate its performance for an out-of-sample period from January 2006 to December 2008. The prediction of residual values also involves future statements about the independent variables which I forecast by using ARIMA models.

I observe very satisfying results for the forecasts of the residual values throughout the prediction period. At the end of the out-of-sample period the predicted residual value differs at most one percent by the originally suggested manufacturer's retail price from the actual value. The prediction errors do not exceed two percent for the VW Golf and the Mercedes-Benz E-Class throughout the whole forecast period. Only the Mercedes-Benz C-Class has a slightly larger prediction error of approximately at most three percent during the out-of-sample period.

Furthermore, I examine how the results can be used for the risk management of lease contracts. Due to the importance of residual values in the valuation of leases, I analyse how fluctuations in the expected market conditions or misspecified residual values affect this valuation. For this purpose, I take a closer look at the kind of changes in either the equilibrium lease rate or the value of a lease contract (which I define as the net advantage to leasing) that may arise from fluctuations in the underlying explanatory factors. By using the empirical results from my analysis I determine the effects of such changes theoretically and apply them onto a numerical example. The used methodology in this study also provides the basis for conducting stress tests in lease institutions. Stress tests are compulsory for lease institutions since leasing providers have to comply with the regulatory standards of Basel II in Germany.

Overall, the study at hand provides very satisfying results regarding the prediction of residual values. The forecast values at maturity of the lease contract are very close to the actual data. Even the prediction errors during the 36 month prediction period are very moderate. Hence, I conclude that the prediction models identified according to the applied methodology give a useful alternative to forecast the residual values of automobiles. Moreover, the implications drawn for the valuation of lease contracts offer important insights for the risk management of lease contracts.

However, there is room for expansion for future research. As I have already mentioned, the ARIMA models used in my study for the determination of the future values for the explanatory variables have limitations. The application of more sophisticated models to predict the values of the influencing variables may improve the prediction results. The addition of other or further influencing variables might also yield more precise forecasted residual values. Moreover, the extension of this approach to more car types, further durations, longer time periods or even other countries may give further evidence of the performance of the used methodology.

Chapter 5

Summary

The work at hand examines the residual value risk in automotive lease contracts. The focus is hereby on the identification of risk factors of residual values and the possibility of their prediction. The aim of this dissertation is to explain residual values of cars by using certain market influences and developing a forecast model for residual values based on these market influences.

In the **first part** of my work, I give an overview of the existing literature. I begin with an examination of the term leasing, which can only be explained according to national legislation, as no uniform definition exists. Then I provide reasons for the existence of leasing by identifying and summarising the arguments found in the related literature. The incentives to lease are manifold. They range from financial considerations like tax- or cost-related arguments to the simple human desire of affording a more expensive and thus prestigious car. Besides the question of why leasing exists at all and why it became such a popular financing form, it is of major importance to assess how lease contracts can be rated in order to use this financing instrument. There are in general two ways to approach this issue. The first methods found in the literature value lease contracts by using discounted cash flows. This approach is rooted in the literature evaluating the lease-or-buy respectively the lease-or-borrow decision. In this context, an intensive discussion arises regarding the question which discount factors are appropriate in the application of this methodology. A large drawback of this approach, however, is linked to its scope of application. The discounted cash flow methodology allows only to value financial leases, an application to operating leases is not feasible. This gap has been closed by the development of the option pricing theory, which provided new opportunities in nearly all research areas of finance. Furthermore, as the name indicates the option pricing approach allows to rate lease contracts containing an option. Many lease contracts offer an option either to the lessee or the lessors whereas a very frequent form is a call option to the lessee inherent in an automotive lease contract. Thus, the development of the option pricing theory allows evaluating lease contracts and their implicit options.

From this rather basic discussion on the topics of lease contracts, I turn to the analysis of the risks in leases. For this purpose, I first describe its structure by using the risk classification of the Basel Committee of Banking Supervision that distinguishes between market, credit, liquidity and operational risk. After discussing each of these types, I focus on the residual value risk that belongs to the category market risk. To begin with I point out its relevance in leases and emphasise the necessity to manage this type of risk. This risk management, however, requires the knowledge of those factors which determine the residual value of cars. For this reason, I summarise the influencing factors available in the literature. Then, I continue by dealing with the prediction models for residual values of cars. The overview reveals that the existing literature regarding these two topics is scarce. As a conclusion there is a lack of research in both areas and a necessity to provide support for the risk management of automotive leases.

Regarding the determinants of residual values, it appears helpful for risk management of lease contracts to focus on market variables rather than a car's features. Whereas features of a car rely heavily on consumer preferences, market factors are superior due to their measurability, observability and availability. Additionally, the analysis of residual values over time and not during the ageing of a particular car promises to give insights to the management of residual value risk. The development of a prediction model and the possibility to validate its performance by using an actual and large dataset extends the literature on predicting residual values to a considerable amount. There are only a few prediction models available and the performance of most of them is not examined due to the lack of data. Hence, the literature overview gives a summary of the basic and actual topics related to automotive leasing and calls for further research regarding the determinants and the prediction of residual values.

The following two parts expand on the two topics posed in the last sections of the literature overview of the previous part: the DETERMINANTS OF RESIDUAL VALUES OF CARS and the PREDICTION OF RESIDUAL VALUES.

The **second part** deals with the analysis of the determinants of residual values. As mentioned in the literature review, promising results are expected when linking the development of residual values over time to the development of the market environment. This approach differs from the widely used hedonic method which mainly relies on features of a car to explain residual values. Thus, I start by describing the influences that characterise the market environment of cars.

Those influences can be classified into three main categories. The first one illustrates the overall economic situation. The financial situation of private consumers is approximated and reflected by using private consumer spending figures whereas the gross domestic product sheds light on the spending behaviour of industrial consumers and the overall economic situation. The unemployment rate is used to illustrate the employment situation and the three month EURIBOR fund indicates the level of financing costs. The variables of the second category describe the situation in the new and used car market. Hereby, the monthly number of cars changing their ownership and the monthly number of first registered cars describe the trading activity as well as the trading volume in these two markets. Additionally, I include the level of petrol prices in order to indicate the costs related to the ownership of a car. The third category specifies a certain car model. I use dummy variables to account for model cycles, model changes and facelifts as well as a modernity factor to describe a car's topicality in the respective market. The empirical analysis is conducted by using an ARMAX regression for each single car of the sample; the explanatory variables are derived from the categories previously mentioned.

The results show that there are no prevailing significant influences throughout the car models. Instead, this observation provides evidence that an individual analysis has to be conducted for each car. The only exception is the modernity factor that is negative significant for a wide majority of the cars of the sample and shows that the longer the car is available in the used car market the lower is its residual value. Further exceptions include the variables indicating a model change or a car's rework. Moreover, it can be generally said that residual values tend to be rather significantly influenced from the situation in the car markets than from the overall economic situation. This supports the assumption that cars are goods that are hard to waive and thus explains why residual values rely less on the overall economic situation. An increasing activity in the car markets, however, leads mostly to rising residual values. Analysing this relation on the level of segments, it can be observed that explanatory variables of the first category are relatively important for the subcompact and compact segment. Thus, an improvement of the consumer's financial situation apparently allows consumers to purchase cars of a higher segment or probably newer cars.

In a last step, I draw conclusions for the risk management of lease firms. On the one hand, it is possible to identify risks in the lease portfolio by using the empirical results which makes lessors aware of certain market situations. On the other hand, I evaluate the impact of fluctuations in one of the underlying variables measured as the variance of the lease rate. For this purpose, I apply the widely accepted theoretical valuation model by McConnell and Schallheim (1983). The empirical results are embedded in this model and allow me to quantify the impact of changes in the variance of an underlying factor on the lease rate. The analysis shows that the lease rate increases in turbulent situations, i.e. if the variance of the factor increases. Furthermore, I observe that this increase in the lease rate is stronger respectively lower the more/less settled the original situation has been, i.e. the lower the original variance of the factor is.

The prediction of residual values is in the focus of the **third part** which forecasts values for the three cars VW Golf, Mercedes-Benz C-Class and Mercedes-Benz E-Class. The sample is hereby divided into an in-sample period from June 1992 to December 2005 and an out-of-sample period from January 2006 to December 2008. The prediction models are adjusted in-sample and their performance is tested out-of-sample by comparing the prediction results with the actual data. The development of the prediction models involves the influences classified according to the three categories of the previous part. As before, the applied methodology uses an ARMAX regression as forecast model. The figures used to approximate the previously mentioned influences of these three main categories serve again as explanatory variables for the regression equation. Unlike the procedure of the second part though, further variables may be interchangeably applied to approximate the financial situation of consumers (these include the changes of the gross domestic product related to the previous and previous year quarter, the monthly changes of the ZEW and ifo index for the economic climate to reflect the financial situation of industrial consumers and in order to reflect the one of private consumers, figures of the disposable income may be used). Additionally, I account for non-linearity during the model cycle by allowing a squared or cubic term of the modernity factor. In total, I receive 30 different model types whereas the best model in-sample is selected by using the Akaike information criterion.

To forecast the residual values out-of-sample, the explanatory variables must be predicted first for this time period. This issue is solved by using ARIMA models for the prediction of the explanatory variables. Applying those forecasted values to the prediction models of the residual values yields the forecasted residual values. The performance of the models is very satisfying. The predicted values differ at most 3.3% of the original manufacturer's suggested retail price for the Mercedes-Benz C-Class and less than 2% for the other models from the actual data during the complete out-of-sample period. For December 2008, the last value of the out-of-sample period, the deviation from the actual value is approximately 1% for each of the analysed car models. To derive implications for the risk management of lease contracts, the empirical results are again embedded in the theoretical valuation model of McConnell and Schallheim (1983). The focus of this analysis is hereby on a wrong specification or an unexpected development of one of the explanatory variables during the out-of-sample period. I observe that the lease rate or the value of the lease contract is affected by the underlying influence in the opposite direction of its regression coefficient and with a constant proportionality factor. This result is illustrated by using a numerical example.

My thesis contributes to the literature of alternative financing instruments. In contrary to the wide majority of studies in this field of research, which examine the advantages and disadvantages or the reasons for the existence of leasing, I concentrate on the challenges which result from this existence and have to be handled by leasing providers. Therefore, I focus on the risk structure of leasing products – more precisely automotive lease products – and attempt to give support for their risk management. This topic has been hardly covered in the scientific literature. Thus, my thesis provides useful insights in a relatively new and unexplored area of research. I do not claim to provide a complete set of risk factors or to identify *the* model for residual values of cars. But I provide a first step in the analysis of these issues and support the improvement of the understanding of residual value risk as well as the implementation of a suitable risk management. The analysis of additional or other risk factors is thus necessary to deepen these insights. Moreover, further studies should be conducted to deal with the various issues of this research field and to present approaches for their solutions. This leaves a fruitful ground for future research.

Bibliography

Ackerman, S. R. (1973). Used cars as a depreciating asset. *Western Economic Journal*, 11(12):463–474.

Akerlof, G. A. (1970). The market for "lemons": Quality uncertainty and the market mechanism. *The Quarterly Journal of Economics*, 84(3):488–500.

Ang, J. and Peterson, P. P. (1984). The leasing puzzle. *The Journal of Finance*, 39(4):1055–1065.

Basel Committee on Banking Supervision (1988). *International Convergence of Capital Measurement and Capital Standards*. Available at `http://www.bis.org/publ/bcbs04a.pdf`. 02.09.2011.

Basel Committee on Banking Supervision (1996). *Amendment to the Capital Accord to Incorporate Market Risks*. Available at `http://www.bis.org/publ/bcbs24.pdf`. 02.09.2011.

Basel Committee on Banking Supervision (2004). *Basel II: International Convergence of Capital Measurement and Capital Standards*. Available at `http://www.bis.org/publ/bcbs107.pdf`. 02.09.2011.

Basel Committee on Banking Supervision (2008). *Principles for Sound Liquidity Risk Management and Supervision.* Available at http://www.bis.org/publ/bcbs144.pdf. 02.09.2011.

Bellalah, M. (2002). Valuing lease contracts under incomplete information: A real-options approach. *The Engineering Economist*, 47(2):194–212.

Betts, S. C. and Taran, Z. (2004). The 'brand halo' effect on durable goods prices: Brand reliability and the used car market. *Academy of Marketing Studies Journal*, 8(1):7–18.

Black, F. and Scholes, M. (1973). The pricing of options and corporate liabilities. *The Journal of Political Economy*, 81(3):637–654.

Bower, R. S. (1973). Issues in lease financing. *Financial Management*, 2(4):25–34.

Bower, R. S., Herringer, F. C., and Williamson, J. P. (1966). Lease evaluation. *The Accounting Review*, 41(2):257–265.

Bundesverband Deutscher Leasing-Unternehmen (2011). *Jahresbericht 2010/2011.* Available at http://www.leasing-verband.de/download/presse/publikationen/pdf/bdl_jahresbericht_2010_11_endgueltig.pdf. 02.09.2011.

Busse, M. R., Knittel, C. R., and Zettelmeyer, F. (2009). *Pain at the Pump: How Gasoline Prices Affect Automobile Purchasing in New and Used Markets.* Working Paper No. 15590, NBER National Bureau of Economic Research. Available at http://www.nber.org/papers/w15590. 02.09.2011.

Cheng, B. and Wu, X. (2006). An modified PLSR method in prediction. *Journal of Data Science*, 4(3):257–274.

Copeland, T. E. and Weston, J. F. (1982). A note on the evaluation of cancellable operating leases. *Financial Management*, 11(2):60–67.

Court, A. T. (1939). Hedonic price indexes with automotive examples. In *The Dynamics of Automobile Demand*, pages 99–117. General Motors Corporation, New York.

Cowling, K. and Cubbin, J. (1972). Hedonic price indexes for United Kingdom cars. *The Economic Journal*, 82(327):963–978.

Cox, J. C., Ross, S. A., and Rubinstein, M. (1979). Option pricing: A simplified approach. *Journal of Financial Economics*, 7(3):229–264.

Der Spiegel (2009). BMW-Händler attackiert Autokonzern. *Der Spiegel*, 10:73.

Desai, P. S. and Purohit, D. (1999). Competition in durable goods markets: The strategic consequences of leasing and selling. *Marketing Science*, 18(1):42–58.

Deutsche Bundesbank (2011). Leasingfinanzierung in Deutschland. *Monatsbericht Juli 2011*, 63(7):39–52.

Dexheimer, V. (2003). *Hedonic Methods of Price Measurement for Used Cars*. Working paper, German Federal Statistical Office. Available at `http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/EN/Content/Statistics/Preise/HedonicUsedCars,property=file.pdf`. 02.09.2011.

Diekmann, C. (2007). *Portfolio Risk in Automotive Finance*. Books on Demand, Norderstedt, 1st edition. Dissertation.

Dudenhöffer, F. and Neuberger, K. (2007). *Die PKW-Restwertentwicklung und die Auswirkung auf die Leasinggesellschaften*. Available at `http://www.uni-due.de/~hk0378/studien/2007/Restwerte-Studie-Juni2007.pdf`. 02.09.2011.

Dunham, W. R. (1997). Are automobile safety regulations worth the price: Evidence from used car markets. *Economic Inquiry*, 35(3):579–589.

Eisfeldt, A. L. and Rampini, A. A. (2009). Leasing, ability to repossess, and debt capacity. *Review of Financial Studies*, 22(4):1621–1657.

Engers, M., Hartmann, M., and Stern, S. (2009). Annual miles drive used car prices. *Journal of Applied Econometrics*, 24(1):1–33.

Farrell, M. J. (1954). The demand for motor-cars in the United States. *Journal of the Royal Statistical Society*, 117(2):171–201.

Feinen, K. (2002). *Das Leasinggeschäft*. Verlag Fritz Knapp GmbH, Frankfurt am Main, 4th edition.

Finucane, T. J. (1988). Some empirical evidence on the use of financial leases. *The Journal of Financial Research*, 11(3):321–333.

Franks, J. R. and Hodges, S. D. (1978). Valuation of financial lease contracts: A note. *The Journal of Finance*, 33(2):657–669.

Geske, R. (1977). The valuation of corporate liabilities as compound options. *Journal of Financial and Quantitative Analysis*, 12(4):541–552.

Geske, R. (1978). The prices of options with stochastic dividend yield. *The Journal of Finance*, 33(2):617–625.

Giacotto, C., Goldberg, G. M., and Hedge, S. P. (2007). The value of embedded real options: Evidence from consumer automobile lease contracts. *The Journal of Finance*, 62(1):411–445.

Goodmann, A. C. (1983). Willingness to pay for car efficiency: A hedonic price approach. *Journal of Transport Economics and Policy*, 17(3):247–266.

Gordon, M. J. (1974). A general solution to the buy or lease decision: A pedagogical note. *The Journal of Finance*, 29(1):245–250.

Gordon, R. J. (1990). New and used automobiles. In *The measurement of durable goods prices*, pages 321–382. University of Chicago Press, Chicago.

Graham, J. R., Lemmon, M. L., and Schallheim, J. S. (1998). Debt, leases, taxes, and the endogeneity of corporate tax status. *The Journal of Finance*, 53(1):131–162.

Grenadier, S. R. (1995). Valuing lease contracts: A real-options approach. *Journal of Financial Economics*, 38(3):297–331.

Grenadier, S. R. (1996). Leasing and credit risk. *Journal of Financial Economics*, 42(3):333–364.

Hartmann, R. S. (1987). Product quality and market efficiency: The effect of product recalls on resale prices and firm valuation. *The Review of Economics and Statistics*, 69(2):367–372.

Helwig, C. (2008). *Portfolioorientierte Quantifizierung des Adressenausfall- und Restwertrisikos im Leasinggeschäft – Modellierung und Anwendung*. Verlag Fritz Knapp GmbH, Frankfurt am Main, 1st edition. Dissertation, Schriftenreihe des Zentrums für Ertragsorientiertes Bankmanagement, Münster; 53.

Hendel, I. and Lizzeri, A. (2002). The role of leasing under adverse selection. *Journal of Political Economy*, 110(1):113–143.

Hochman, S. and Rabinovitch, R. (1984). Financial leasing under inflation. *Financial Management*, 13(1):17–26.

Johnson, J. P. and Waldman, M. (2003). Leasing, lemons, and buybacks. *The RAND Journal of Economics*, 34(2):247–265.

Johnson, R. W. and Lewellen, W. G. (1972). Analysis of the lease-or-buy decision. *The Journal of Finance*, 27(4):815–823.

Jost, A. and Franke, A. (2005). *Residual Value Analysis*. Working paper presented at the 23rd International Conference of the System Dynamics Society in Boston 2005. Available at `http://www.systemdynamics.org/conferences/2005/proceed/papers/JOST158.pdf`. 02.09.2011.

Kahn, J. A. (1986). Gasoline prices and the used automobile market: A rational expectations asset price approach. *The Quarterly Journal of Economics*, 101(2):323–340.

Kraftfahrt-Bundesamt (2009). *Außerbetriebsetzungen im Jahr 2008 nach Alter der Fahrzeuge*. Available at `http://www.kbashop.de/webapp/wcs/stores/servlet/ProductDisplay?catalogId=10051&categoryId=17204&storeId=10001&productId=15355&langId=-3&parent_category_rn=17204&top_category=10010`. 02.09.2011.

Krishnan, V. S. and Moyer, R. C. (1994). Bankruptcy costs and the financial leasing decision. *Financial Management*, 23(2):31–42.

Leaseurope (2011). *Annual Survey 2010*. Available at `http://www.leaseurope.org/uploads/documents/stats/European%20Leasing%20Market%202010.pdf`. 02.09.2011.

Lee, W. Y., Martin, J. D., and Senchack, A. J. (1982). The case for using options to evaluate salvage values in financial leases. *Financial Management*, 11(3):33–41.

Makridakis, S. G., Wheelwright, S. C., and Hyndman, R. J. (1998). *Forecasting: Methods and Applications*. John Wiley & Sons, Inc., New York, NY, 3rd edition.

Mannering, F., Winston, C., and Starkey, W. (2002). An exploratory analysis of automobile leasing by US households. *Journal of Urban Economics*, 52(1):154–176.

Matas, A. and Raymond, J.-L. (2009). Hedonic prices for cars: an application to the Spanish car market, 1981-2005. *Applied Economics*, 41(22):2887–2904.

McConnell, J. J. and Schallheim, J. S. (1983). Valuation of asset leasing contracts. *Journal of Financial Economics*, 12(2):237–261.

Merton, R. C. (1973). An intertemporal capital asset pricing model. *Econometrica*, 41(5):867–887.

Merton, R. C. (1987). A simple model of capital market equilibrium with incomplete information. *The Journal of Finance*, 42(3):483–510.

Miller, M. H. and Upton, C. W. (1976). Leasing, buying and the cost of capital services. *The Journal of Finance*, 31(3):761–786.

Miller, S. E. (1995). Economics of automobile leasing: The call option value. *The Journal of Consumer Affairs*, 29(1):199–218.

Moldenhauer, T. (2006). *Leasing mobiler Anlagegüter – Eine betriebswirtschaftliche Analyse unter besonderer Berücksichtigung steuerlicher Aspekte.* Verlagshaus Monsenstein und Vannerdat OHG, Münster, 1st edition. Dissertation.

Murray, J. and Sarantis, N. (1999). Price-quality relations and hedonic price indexes for cars in the United Kingdom. *International Journal of the Economics of Business*, 6(1):5–27.

Myers, S. C., Dill, D. A., and Bautista, A. J. (1976). Valuation of financial lease contracts. *The Journal of Finance*, 31(3):799–819.

Ohta, M. (1987). Gasoline cost and hedonic price indexes of U.S. used cars for 1970-1983: A note. *Journal of Business & Economic Statistics*, 5(4):521–528.

Ohta, M. and Griliches, Z. (1976). Automobile prices revisited: Extensions of the hedonic hypothesis. In Terleckyj, N. E., editor, *Household Production and Consumption*, pages 325–398. NBER National Bureau of Economic Research, New York.

Ohta, M. and Griliches, Z. (1986). Automobile prices and quality: Did the gasoline price increase change consumer tastes in the U.S.? *Journal of Business & Economic Statistics*, 4(2):187–198.

Peles, Y. C. (1988). On the depreciation of automobiles. *International Journal of Transport Economics*, 15(1):43–54.

Perridon, L., Steiner, M., and Rathgeber, A. (2009). *Finanzwirtschaft der Unternehmung.* Verlag Franz Vahlen, München, 15th edition.

Prado, S. M. (2009). The European used-car market at a glance: Hedonic resale price valuation in automotive leasing industry. *Economics Bulletin*, 29(3):2086–2099.

Purohit, D. (1992). Exploring the relationship between the markets for new and used durable goods: The case of automobiles. *Marketing Science*, 11(2):154–167.

Realdon, M. (2006). Pricing the credit risk of secured debt and financial leasing. *Journal of Business Finance & Accounting*, 33(7 & 8):1298–1320.

Reis, H. J. and Santos Silva, J. M. C. (2006). Hedonic prices indexes for new passenger cars in Portugal (1997-2001). *Economic Modelling*, 23(6):890–908.

Rode, D. C., Fischbeck, P. S., and Dean, S. R. (2002). Residual risk and the valuation of leases under uncertainty and limited information. *Journal of Structured Finance*, 7(4):37–49.

Rubinstein, M. (1976). The valuation of uncertain income streams and the pricing of options. *Bell Journal of Economics*, 7:407–425.

Schall, L. D. (1974). The lease-or-buy and asset acquisition decisions. *The Journal of Finance*, 29(4):1203–1214.

Shanker, L. (1997). Tax effects and the leasing decisions of Canadian corporations. *Canadian Journal of Administrative Sciences*, 14(2):195–205.

Sharpe, S. A. and Nguyen, H. H. (1995). Capital market imperfections and the incentive to lease. *Journal of Financial Economics*, 39(2-3):271–294.

Smith, C. W. (1979). Applications of option pricing analysis. In Bicksler, J. L., editor, *Handbook of Financial Economics*, pages 79–120. North-Holland Publishing Company, Amsterdam.

Smith, C. W. and Wakeman, L. M. (1985). Determinants of corporate leasing policy. *The Journal of Finance*, 40(3):895–908.

Smith, L. D. and Jin, B. (2007). Modeling exposure to losses on automobile leases. *Review of Quantitative Finance and Accounting*, 29(3):241–266.

Spittler, H.-J. (2002). *Leasing für die Praxis*. Fachverlag Deutscher Wirtschaftsdienst GmbH & Co. KG, Köln, 6th edition.

Städtler, A. (1997). Leasing in Deutschland: Weiterhin eine gefragte Dienstleistung. *Ifo-Schnelldienst*, 50(01–02):6–14.

Städtler, A. (2001). Leasing erzielt hohe Marktanteilsgewinne – In Westdeutschland überspringt die Leasingquote die 20%-Marke. *Ifo-Schnelldienst*, 54(24):43–51.

Storchmann, K. (2004). On the depreciation of automobiles: An international comparison. *Transportation*, 31(4):371–408.

Trigeorgis, L. (1996). Evaluating leases with complex operating options. *European Journal of Operational Research*, 91(2):315–329.

van Dalen, J. and Bode, B. (2004). Quality-corrected price indices: the case of the Dutch new passenger car market 1990-1999. *Applied Economics*, 36(11):1169–1197.

Waldman, M. (1997). Eliminating the market for secondhand goods: An alternative explanation for leasing. *Journal of Law and Economics*, 40(1):61–92.

Wassermann, H. (2009). 2221 Leasing-Gesellschaften in Deutschland–Ruhe vor dem Sturm? *Finanzierung, Leasing, Factoring*, 6:260–265.

White, J. B. (1996). Estimating the call option values embedded in closed-end automobile leases. *Journal of Consumer Marketing*, 13(3):19–26.

Wu, J.-D., Hsu, C.-C., and Chen, H.-C. (2009). An expert system of price forecasting for used cars using adaptive neuro-fuzzy inference. *Expert Systems with Applications*, 36(4):7809–7817.

Wykoff, F. C. (1970). Capital depreciation in the postwar period: Automobiles. *The Review of Economics and Statistics*, 52(2):168–172.

Eidesstattliche Erklärung

Gemäß §8 Abs. 2 Nr.4 der Promotionsordnung zum Dr. oec. der Universität Hohenheim.

Hiermit versichere ich, dass die vorliegende Arbeit von mir selbstständig angefertigt worden ist und nur die angegebenen Quellen und Hilfsmittel verwendet wurden. Ferner versichere ich, dass ich wörtlich oder inhaltlich übernommene Stellen als solche gekennzeichnet habe.

Stuttgart, den 04.November 2011

Katharina Nau