Essays on Consumers' Willingness-to-Pay for Energy Efficiency: Empirical Evidence for the German Automobile Market

DOCTORAL THESIS

to acquire the academic degree of
doctor rerum politicarum
(Doctor of Economics and Management Science)

submitted to the

School of Business and Economics of
Humboldt-Universität zu Berlin

by

M.Sc. Vlada Pleshcheva

President of Humboldt-Universität zu Berlin:
Prof. Dr.-Ing. Dr. Sabine Kunst

Dean of the School of Business and Economics:
Prof. Dr. Daniel Klapper

Reviewers:

1. Prof. Dr. Daniel Klapper
2. Prof. Dr. Lutz Hildebrandt
3. Prof. Dr. Amir Heiman

Date of Colloquium: November 16, 2018

Abstract

This thesis empirically examines the consumers' willingness-to-pay (WTP) for improvements in fuel efficiency and explores factors related to differences in the consumers' valuation of these improvements. The empirical investigations in the thesis are based on revealed and stated preference data for the German automobile market, with the focus on passenger cars with gasoline and diesel engines. First, the study explores the effects of fuel prices on the market value of fuel economy. Two types of effects are recovered and compared – one corresponds to changes in the budget for driving a car with better fuel economy and the other reflects changes in capital investments in better car quality. Second, the thesis quantifies the valuation of fuel efficiency at the individual level and relates the recovered heterogeneity in consumers' WTP for a reduction in fuel costs to observed consumer- and purchase-related characteristics. The results indicate that a better financial ability, a higher level of education, and brand loyalty facilitate a better understanding of the benefits of investments in fuel-efficient vehicles. Third, consumers' preferences for identical environmental benefits, whether they are presented in terms of improvements in fuel consumption or CO_2 emissions of cars, are compared. Consumers are found to significantly undervalue the benefits of more fuel-efficient vehicles when presented with information on CO_2. The role of individual characteristics in the consumers' WTP for these environmentally important attributes is additionally studied.

Zusammenfassung

Diese Dissertation quantifiziert die Zahlungsbereitschaft (ZB) der Konsumenten für die Verbesserung des Kraftstoffverbrauchs von Personenkraftwagen (PKW) und untersucht die Faktoren, die sich auf die Unterschiede der Verbraucher bei der Bewertung dieser Verbesserungen auswirken. Die empirische Untersuchung in dieser Arbeit basiert auf offenbarten und geäußerten Präferenzdaten für den deutschen Automobilmarkt, wobei der Schwerpunkt auf PKW mit Otto- und Dieselmotoren liegt. Zuerst werden die Auswirkungen von Kraftstoffpreisen auf den Marktwert der Kraftstoffeffizienz untersucht, wobei zwischen Änderungen im Budget für die Nutzung eines Autos mit niedrigerem Kraftstoffverbrauch und Änderungen im Budget für dessen Kauf unterschieden wird. Anschließend ermittelt diese Dissertation die Bewertung der Kraftstoffeffizienz auf individueller Ebene und setzt die Heterogenität der Verbraucher bezüglich der Zahlungsbereitschaft für eine Senkung der Kraftstoffkosten in Beziehung mit beobachteten verbraucher- und transaktionsspezifischen Merkmalen. Die Ergebnisse zeigen, dass eine bessere Zahlungsfähigkeit, ein höherer Bildungsgrad und eine vorhandene Markenloyalität zu einem besseren Verständnis der Vorteile von Investitionen in ein kraftstoffsparendes Fahrzeug führt. Zuletzt werden die Unterschiede in den Präferenzen der Verbraucher für identische Verbesserungen des Kraftstoffverbrauchs und der CO_2-Emissionen quantifiziert. Die Studie zeigt, dass die Verbraucher eine Verbesserung der Kraftstoffeffizienz signifikant höher bewerten als eine entsprechende Minderung der CO_2-Emissionen. Die Rolle der individuellen Merkmale in der ZB von Verbrauchern für diese umweltrelevanten Autoeigenschaften wird zusätzlich untersucht.

Acknowledgments

This thesis has benefited from contributions by several people. First and foremost I would like to express my deep appreciation and gratitude to Prof. Dr. Daniel Klapper, who has been a thoughtful and supportive supervisor throughout, providing advice, encouragement, and support at critical junctures. I am truly fortunate to have had the opportunity to work with him. I also gratefully acknowledge Prof. Dr. Lutz Hildebrandt, Prof. Dr. Till Dannewald, and Prof. Dr. Heiman for their time, positive attitudes, and valuable feedback on my research.

Dr. Daniel Guhl and M.Sc. Narine Yegoryan have been invaluable colleagues in research and teaching. This thesis has benefited greatly from countless discussions with them and from the thorough feedback on my presentations and drafts. I would also like to thank all fellow doctoral students at the School of Business and Economics for their feedback as well as all student assistants at the Institute for Marketing for their assistance in accomplishing many tasks to advance my work on the thesis. Moreover, all studies presented in this thesis have greatly benefited from comments of participants of various workshops and conferences. I am also grateful to Prof. Dr. Franz Hubert, who supported my application for a grant to come to the Humboldt-Universität zu Berlin to pursue a doctoral degree in the first place.

Lastly, I would like to thank my family and friends for their support. A very special gratitude goes out to Dr. Jan Amaru Palomino Töfflinger and Dr. Felix Strobel, who provided moral support throughout the entire process and helped me to take occasional obstacles with equanimity as well as adequately celebrate any progress of the thesis.

Contents

List of Abbreviations

AIC	Akaike information criterion
ADF	Augmented Dickey Fuller
ANOVA	Analysis of variance
ARIMA	AutoRegressive Integrated Moving Average
CI	Confidence interval
cm	centimeter
CO_2	Carbon dioxide
Cov	Covariance
CPI	Consumer price index
DCM	Discrete choice model
EFO	Environmentally friendly option
EnvC	Environmental costs
EU	European Union
FC	Fuel consumption
FE	Fuel economy
FOC	First order condition
FP	Fuel price
g	Gram
GHG	Greenhouse gases
GEC	"General Environmental Consciousness" (scale)
HP	Horsepower
kg	Kilogram
km	Kilometers
l	Liters
LL	Log-likelihood
MAE	Mean absolute error
MNL	Multinominal logit
MPG	Miles per gallon
MSRP	Manufacturer suggested retail price
MXL	Mixed logit
MSE	Mean squared error
OLS	Ordinary least squares
PVFC	Present-discounted value of fuel costs
RAI	Relative attribute importance
SD	Standard deviation
SE	Standard errors
TC	Total costs
UK	United Kingdom
US	United States
Var	Variance
VW	Volkswagen
WTP	Willingness-to-pay

Chapter 1

Introduction

To reduce environmental pollution and address issues related to climate change due to an increasing level of greenhouse gas (GHG) emissions in the atmosphere, a large number of policies have been developed. Because emissions of carbon dioxide (CO_2), the main GHG that contributes to climate change, and energy consumption are directly linked, improving energy efficiency of energy-using goods has become the primary focus of environmental policies.

Accounting for one third of the final energy consumption, road transport is the second-largest source of GHG in the European Union, whereby passenger vehicles account for 12% of total European Union emissions of CO_2.[1] To promote fuel-efficient and low-carbon vehicles, the European Commission has adopted four policy instruments that include fuel taxation (Directive 2003/96/EC), information provision in the form of car labels (Directive 1999/94/EC), manufacturer-specific standards for new vehicles' fuel economy and CO_2 emissions (Regulation (EC) No 443/2009), and vehicle tax (COM(2012) 756 final).[2] These policies intend to shift choices of economic agents by influencing both the demand and supply side. A fuel tax is equivalent to a carbon tax that prices the negative externality (i.e., a Pigouvian tax) and thus directly influences the car usage as well as the car choices. Information provision in the form of car labels ensures that information on the fuel efficiency and CO_2 emissions of passenger cars is made available to consumers to facilitate informed choices. The specific fuel economy and CO_2 emission targets imposed on car manufacturers for new vehicles restrict the supply of low-efficient products. Lastly, the vehicle tax that is proportional to the car's CO_2 emissions changes the relative prices of products with different fuel efficiency values and thus, aims to influence consumers' decisions towards purchasing more efficient technologies.

[1] https://ec.europa.eu/clima/policies/transport/vehicles/cars_en (accessed: March 08, 2018).
[2] The EU legislation regarding passenger cars can be accessed at https://eur-lex.europa.eu.

The effectiveness of these policies depends on consumers' valuation of improvements in the energy efficiency and CO_2 emissions. Energy efficiency, in general, is defined as energy services provided per unit of energy input (Patterson, 1996). For automobiles, this measure is, for example, presented by fuel economy – distance traveled with a car per unit of fuel consumed (e.g., km/l). A related measure is the fuel consumption (FC) of a vehicle that is reciprocal to fuel economy and is measured in terms of fuel per distance (e.g., l/100 km). Consumers' preferences for these car attributes can be quantified in monetary terms with a measure of willingness-to-pay (WTP) – the maximum amount a consumer is willing to pay for a given quantity of an item (Kalish and Nelson, 1991). In line with the "characteristics" approach, consumers' preferences towards a product are derived from preferences for its attributes and their bundles (Lancaster, 1966). Knowing the consumers' WTP for a specific attribute helps to understand consumers' choices and allows to assess how valuable improvements in the attribute value are to the consumers.

Information on the WTP for improvements in fuel efficiency is crucial from both managerial and policy-making perspectives. Valid WTP estimates are essential for development and pricing of profit-maximizing products (Kohli and Mahajan, 1991; Voelckner, 2006; Breidert et al., 2006), as well as for understanding the welfare implications of different energy policies (Newell and Siikamäki, 2014; Allcott and Taubinsky, 2015; Hackbarth and Madlener, 2016; Grigolon et al., 2017). A more efficient product very often implies a trade-off between higher upfront capital costs to acquire it and (potentially) lower future operating costs from its usage. Economic theory suggests that a "rational" consumer should be willing to invest upfront in better energy efficiency as much as it allows the consumer to save on the expected operating costs given expectations of energy prices and the intensity of product usage. If, however, a consumer is willing to pay less (more) than these savings, undervaluation (overvaluation) of energy efficiency occurs. Although extensive financial investments in car purchases should encourage consumers to compare upfront costs and potential savings in future fuel costs, the results of previous empirical studies have been inconclusive regarding the extent to which consumers' car purchase decisions are in line with optimal (cost-minimizing) behavior (see Greene, 2010; Helfand and Wolverton, 2011 for an overview of the studies). The literature provides various explanations attributed to the different valuations of the economic potential of energy efficiency investment at the market and individual levels (e.g., Allcott, 2011; Gillingham and Palmer, 2014; Gerarden et al., 2015; Metcalf and Hassett, 1999; Tietenberg, 2009 to name a few).

The present thesis contributes to this stream of literature by quantifying the consumers' WTP for improvements in fuel efficiency of passenger cars with gasoline and diesel engines at the German automobile market and by exploring factors

related to consumers' differences in the valuation of these improvements. The thesis consists of three self-contained essays presented in the next three chapters. The contributions of the thesis lie in both the conceptual and the methodological domain. On the methodological side, the thesis exploits various data types and statistical techniques to elicit the WTP values for car fuel efficiency. Conceptually, the thesis considers the effects of various determinants, some of which have not yet or only partially been studied in the literature on the consumers' valuation of fuel efficiency. The **first essay** investigates the effects of fuel prices on the market value of fuel economy while distinguishing between changes in the budget for driving a car with better fuel economy and changes in capital investments in better car quality. Revealed preference data, in the form of aggregate market data on vehicle prices and attributes for diesel and gasoline cars, are used to analyze how the differences in attributes of cars are reflected in their prices and to explore co-movements of the vehicle price sensitivity to fuel economy with changes in fuel prices. The investigation in the **second essay** is also based on revealed preference data, but from the observed car purchase transactions at the individual level. This type of data allows to recover the individual valuation of fuel efficiency and to relate the recovered heterogeneity in consumers' WTP for a reduction in fuel costs to observed consumer- and purchase-related characteristics. The **third essay** quantifies the differences in consumers' preferences for identical improvements in FC and CO_2 emissions. Because these two metrics are perfectly correlated, stated preference data from two choice-based conjoint experiments with information either on FC or CO_2 emissions are collected to recover the WTP for FC and CO_2 independently. Using various methodologies and data types for empirical investigations in the thesis, provides an opportunity to gain a more complete understanding of the topic at hand, to use novel sources of identifying variation, and to address several estimation issues discussed in the literature. An overview of advantages and challenges of different preference data and methodologies for eliciting and estimating consumers' WTP is provided, for example, by Voelckner (2006), Miller et al. (2011), and Bateman et al. (2002). The focus and contributions of the essays are next discussed in details.

The **first essay** (chapter two) explores the effects of fuel prices on the market value of fuel economy. To recover this value, a hedonic price model is estimated using aggregate market data on vehicle prices and attributes for diesel and gasoline cars of three sequential model years on the German automobile market. The hedonic price model is based on the assumption that the observed price of a good reflects a combination of implicit values for each of its attributes (Rosen, 1974). Econometrically, the implicit values for product attributes are estimated by regressing the product price on its characteristics. The previous literature has

applied the hedonic price regression to study the responsiveness of vehicle prices to fuel prices or fuel economy (Boyd and Mellman, 1980; Goodman, 1983; Atkinson and Halvorsen, 1984; Mulalic and Rouwendal, 2015). The present study advances the prior work by looking at the effects of both these variables and their interaction. In contrast to previous studies, the estimated specification of the hedonic price regression differentiates between the valuation of fuel economy by consumers and their reactions to fluctuations in fuel prices. Thus, two sources of changes in the consumers' WTP for better fuel economy are recovered – changes in the budget for driving a car and changes in the capital investment in better fuel economy. Prior studies could recover only the former source because the marginal benefit of driving a car of a particular fuel economy remained constant, and thus, the increased fuel prices result in a proportional decrease in car usage (e.g., Ohta and Griliches, 1986). The present study shows that, when the marginal benefit of driving a car varies with fuel prices, the total effect of the mentioned two sources of changes in the consumers' WTP for better fuel economy may lead to either a decrease or an increase in the vehicle distance traveled. If the utility from driving a car with better fuel economy exceeds the income effect of higher fuel prices on the driving budget, then the car usage increases. Using the quantified impact of fuel prices on the market value of fuel economy, the implied changes in the kilometers driven with cars and the resulting CO_2 emissions – two crucial outcomes for policy evaluation, are assessed. The analysis recovers values for the considered market outcomes that are in line with the official statistics.

The **second essay** (chapter three) aims at investigating the role of consumer heterogeneity in the valuation of fuel efficiency. It first recovers the individual valuation of expected future fuel costs at the time of a car purchase and then, explores how various consumer- and transaction-specific characteristics relate to the recovered consumers' WTP for a reduction in fuel costs. The empirical investigation in this essay is based on revealed preferences by exploiting household-level survey data on new automobile purchases in Germany over a period of seven years. The richness and structure of the data provide several conceptual and methodological advantages. Conceptually, the analysis in this essay contributes to previous studies by explicitly accounting for the substantial heterogeneity across consumers in their car utilization along with heterogeneity in their tastes for car attributes. The previous literature has stressed the importance of considering the consumer heterogeneity in tastes for products and their attributes (e.g., Kamakura et al., 1996; Allenby and Rossi, 1998; Keane and Wasi, 2013). If consumers are heterogeneous in their tastes and car usage, they may select into different vehicles. A consumer, who expects to drive extensively, may choose either a more fuel efficient vehicle to save money on fuel costs or a larger, more comfortable vehicle to make the long

drives more pleasant (West, 2004). As a result, this self-sorting into vehicles based on individual preferences would confound the estimated WTP values because the price of subsequent car utilization is different. Bento et al. (2012), for example, used a simulation to show that ignoring heterogeneity in consumers' tastes and product usage in empirical analyses can significantly affect the estimated WTP values and result in incorrect implications. Methodologically, the individual tastes for a reduction in fuel costs are estimated by using the hedonic discrete choice model – a method that addresses weaknesses of the discrete choice and hedonic price models while estimating the WTP for car attributes. In contrast to the discrete choice model, the distributions of consumer tastes for product attributes are recovered directly from the data without a need to impose any distributional assumptions. Furthermore, there is no need to make assumptions on the total market size and consumer choice sets. The hedonic price model is extended by allowing for heterogeneity in the values for consumers' WTP for product attributes. Additionally, a highly detailed definition of a car type allows to reduce the possible effect of omitted car attributes on the estimation. A joint distribution of consumer tastes and heterogeneity determinants is recovered by applying a quantile regression, which allows to investigate a disparity in the covariates' effects among different levels of the estimated fuel cost valuation. The estimation results indicate that there is a high degree of undervaluation of potential fuel savings – for a €1 reduction in future fuel costs, the consumers are willing to pay no more than €0.20 on average. Consumers' financial ability, education, and stickiness to a previously bought car make as a strategy to reduce choice complexity are found to be the most important determinants of the consumer heterogeneity in valuation of fuel costs.

The **third essay** (chapter four) investigates whether and how consumers differ in their preferences and WTP for identical improvements in FC versus CO_2 emissions of cars. From a technical perspective, these two metrics are linearly connected by a constant factor and thus are equivalent in describing the environmental impact of vehicles. However, it remains unclear whether consumers value improvements in CO_2 as much as improvements in FC. If consumers' car choices vary across metrics, such a shift in choices may lead to negative financial consequences for consumers and higher environmental costs from car use. Although consumers' preferences for a reduction in FC and CO_2 emissions of cars are extremely important in the context of environmental policies, no prior work has directly compared consumers' preferences for them. Prior research on revealed preferences has not been able to separately identify these effects because the metrics are perfectly correlated, and research on stated preferences has either focused on one of these environmentally important attributes or also considered both measures simultaneously and thus did not disentangle the separate effects of each metric. The present study recovers

the distributions of the WTP for FC and CO_2 independently based on consumer choices from optimally designed choice experiments and by applying a mixed (random coefficient) logit model. The estimation accounts for consumers' unobserved heterogeneity in tastes for car attributes in addition to the observed heterogeneity in the respondents' socio-demographic characteristics, car use experience, and environmental attitudes and knowledge. Additionally, the differences in the WTP values are explored for diesel and gasoline vehicles. For a rational agent, the presentation of both FC and CO_2 to assess personal fuel costs and the environmental impact of a car option is redundant because each metric presents a "translation" of the same underlying information (Ungemach et al., 2017). However, this study demonstrates that consumers value improvements in FC significantly more highly than the corresponding reduction in CO_2 emissions. Moreover, this discrepancy between the metrics varies with the unit in which the amount of CO_2 emissions is presented. For example, consumers are found to be willing to pay, on average, for only 55% of the fuel savings and environmental benefits from better FC and CO_2 emissions when presented with CO_2 information in kg/km (instead of g/km). The paper's findings suggest that individuals fail to recognize how transport-related CO_2 emissions translate into 'private' costs and ultimately incur higher financial costs than under their optimal choices and cause greater environmental costs for society. These biases persist even when the environmentally friendly product is cost-minimizing.

Table 1.1 provides an overview of the three essays summarizing their key findings, the data studied, and the applied statistical methods. In summary, the present thesis represents a substantive empirical analysis that describes and explains consumer behavior concerning a topic of interest to readers in the areas of microeconomics, economic policy, and marketing. The insights from these essays are useful for policymakers and car manufacturers to understand how persons value improvements in fuel efficiency – an environmentally important car attribute, how to design targeted policies to motivate consumers' choices toward cars with better fuel economy, and how to communicate the environmental benefits of car offers to achieve the pre-specified goals.

Table 1.1: Overview of the essays

	Essay 1 (Chapter 2)	**Essay 2 (Chapter 3)**	**Essay 3 (Chapter 4)**
Title	The Moderating Effect of Fuel Prices on the Market Value of Fuel Economy, Driving Intensity, and CO_2 Emissions	On Factors of Consumer Heterogeneity in the (Mis)valuation of Future Energy Costs: Evidence from the German Automobile Market	Metric and Scale Effects in Willingness to Pay for Environmental Benefits
Contributions	• explicit quantification of the effects of FP on WTP for FE for diesel and gasoline vehicles	• recovering the consumers' WTP for a reduction in fuel costs at the individual level	• quantification of the differences in consumers' preferences for identical improvements in FC and CO_2 (metric effect)
	• identification of two sources of changes in the WTP for FE: (1) changes in the budget for driving a car; (2) changes in capital investments in better FE	• accounting for consumer heterogeneity in car utilization	• exploration of the effects of three scales for CO_2 emissions (0.100 kg/km vs. 100 g/km vs. 10,000 g/100 km) on consumers' preferences and choices (scale effect)
	• allowing marginal benefits of driving a car with a particular FE to vary with FP (prev.: fixed)	• exploration of the determinants of consumer heterogeneity in the WTP	• test for differences in the metric and scale effects by vehicle engine type (diesel vs. gasoline)
Key findings	• significant differences in the market values of FE between diesel and gasoline vehicles and their responsiveness to changes in FP	• consumers undervalue the potential fuel savings from better FE to a high degree	• consumers value improvements in FC significantly more highly than the corresponding reduction in CO_2 emissions
	• utility from driving with better FE exceeds the income effect of higher FP on driving intensity	• significant differences in the individual valuation of reduced fuel costs for diesel and gasoline vehicles of various car classes	• WTP for a reduction in CO_2 is increasing with an expansion of the scale of the numeric information
		• consumers' financial ability, education, and brand loyalty facilitate a better understanding of the benefits of investments in fuel-efficient vehicles	• effects of the framing of information on consumers' preferences are similar for both engine types
Data	observational data (market level)	observational data (consumer level)	choice experiments (within- and between-subject variations)
Type of preferences	revealed	revealed	stated
Statistical methods	multivariate regression (hedonic price model); T-test; ANOVA	nonparametric kernel regression; quantile regression; clustering of variables; T-test; ANOVA	discrete choice models (MNL, MXL); bootstrap method; confirmatory factor analysis; logistic regression; generalized least squares regression; T-test; ANOVA; χ^2-based contingency analysis