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Purchases of cars and CO_2 emissions

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Abstract

A conditional logit model is estimated on Norwegian data for 2010. The data contains all purchases of cars for the period January to July. The estimates imply that taxes on CO_2 emission have a negative impact on the choice of car and the model is used in simulations to demonstrate how purchases of cars can be shifted to types of car with lower emissions. We demonstrate that the total expected emission of CO_2 is reduced when taxes on CO_2 increases.

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1 Introduction

The object of this paper is to investigate the choice of cars under different tax regimes on CO_2 emissions and on other car characteristics. We have had access to all purchases of cars in Norway in the period January-July 2010. We have sorted all the purchases according to the potential emissions of CO_2. These emissions stem from characteristics of the cars as well as from the use of fuel and how much the cars are used. The taxes are in part related to characteristics of the cars and on the use of fuel. We have assumed a standard driving length a year throughout the life of the car.

The reason for doing this study is that the Norwegian government likes to know whether and to what extent the different types of CO_2 emission taxes affect the purchases of cars and if they can use the taxes to reduces substantially the emissions of CO_2.

The paper is organized as follows. In the next Section, the models of the choice of car given the segment, and the choice of segment are explained. The data used in estimations are described in Section 3. The empirical specifications and estimation results are discussed in Section 4. In Section 5 we compare predictions and observed market shares while in Sections 6 we investigate some policy simulations, and changes of purchases of cars in and between car segments. Section 7 concludes. Some detailed tables upon the estimations and simulations are presented in Appendix A and B.

2 The model

We have divided the market into two markets: Big cars and smaller cars.

In the market for big cars we have three different segments of cars: sport cars, terrain cars and multiple cars. In each of these segments there is a varying number of types of cars.

In the market for smaller cars we have two segments: Small cars and medium cars.

In each segment the cars are sorted with respect to potential emission of CO_2 measured in g/km. The range of CO_2 interval is 2 g/km.

2.1 BIG cars

Within each segment the agent is assumed to choose a car that maximizes his or her utility. The choice categories, or alternatives, are the CO_2 intervals. The utility function is assumed to be random and extreme value distributed. The choice probabilities are thus conditional logit probabilities.

We do not observe characteristics of the buyers. The only characteristics that we observe are the characteristics of each car: Technical details like capacity (effect), cylinder volume, weight, fuel type, gear type and fuel consumption per km. Moreover we observe price, including all taxes, and the separate taxes. In Norway there are many taxes on cars. In what follows we have lumped together taxes attached to capacity, cylinder volume and weight and we denote the sum of these taxes simply as “Tax”. In addition there is a tax related to the potential emission of CO_2, which we denote “CO_2 tax”. Both “Tax” and “CO_2 tax” vary across the CO_2 intervals. The reason why “Tax” does this is that CO_2 emissions are related to weight, cylinder volume and capacity. In the deterministic part of the random utility function these two tax variables, relative to the net price (net of taxes), are included. We expect that the higher these tax/price ratios are the less likely it is that cars with high potential emissions of CO_2 will be chosen. In addition we also include “Fuel cost”, which also contain tax on fuels. One component of this tax is a tax on CO_2 emissions. In 2010 it was NOK 0.86 per liter gasoline (NOK 0.58 per liter diesel). We thus expect that the higher the fuel costs is the less likely it is that a car with a high potential emission of CO_2 will be chosen.

Let subscript *i* denote a car of type *i* (that is, CO_2 emission category *i*) and let *s* denote the segment. Let I_s denote the number of types of cars (CO_2 intervals) in segment s.

The conditional logit probabilities, given that segment *s* is chosen, are given by

$$\textbf{(1)}\quad \varphi_{is} = \frac{\exp\left[b_{1s}\dfrac{\text{Tax}_{is}}{\text{Netprice}_{is}} + b_{2s}\dfrac{\text{CO}_2\ \text{Tax}_{is}}{\text{Netprice}_{is}} + b_{3s}\text{Fuelcost}_{is}\right]}{\sum_{j=1}^{I_s}\exp\left[b_{1s}\dfrac{\text{Tax}_{js}}{\text{Netprice}_{js}} + b_{2s}\dfrac{\text{CO}_2\ \text{Tax}_{js}}{\text{Netprice}_{js}} + b_{3s}\text{Fuelcost}_{js}\right]};\quad i=1,2,,,I_s;\ s=1,2,3$$

The agent chooses that segment that gives him (or her) the highest expected consumer surplus. The segment choice probabilities, denoted P_s, is then given by

$$(2)\quad P_s = \frac{\exp(Y_s + \alpha_s Z)}{\sum_{k=1}^{3} \exp(Y_k + \alpha_k Z)}; s = 1,\ldots,3,$$

where

$$(3)\quad Y_s = \ln \sum_{j=1}^{I_s} \exp\left[b_{1s} \frac{Tax_{js}}{Netprice_{js}} + b_{2s} \frac{CO_2\,Tax_{js}}{Netprice_{js}} + b_{3s} Fuelcost_{js} \right]$$

Z is the change in the Oslo stock exchange during the considered period of 2010.

2.2 Small cars

The model is formally the same, with the exception that in this market we have specified two segments: Small cars and compact cars.

3 The data

The data used in this study come from “Opplysningsrådet for veitrafikk AS” (OFVAS), Norway and include CO_2 emissions and different taxes on cars in Norway and consist of a sample of two different markets: Big and small cars.

In the following Table 1 we provide the description of the variables used in the estimation while the summary statistics are provided in Table 2 for big cars and in Table 3 for smaller cars.

Tax is measured in NOK as well as netprice. Thus the Tax/netprice is the ratio of tax to the netprice. The same also is the case for the CO_2Tax/netprice. Note that the Tax could exceed the netprice.

The change in the Oslo stock exchange was 9.05 percentage points during the considered period in 2010.

Table 1. Description of variables.

Variables	Description
Segment	Discrete variable from 1 to 3 for big cars and from 1 to 2 for small cars
category	CO_2 emission (g/km).
pollution	dummy variable equal to 1 if car belongs to a certain CO_2 category, 0 otherwise
tax_netprice	$\frac{(\text{Tax})_{is}}{\text{netprice}_{is}}$
CO_2_netprice	$\frac{CO_2\text{Tax}_{is}}{\text{netprice}_{is}}$
fuelcost	Fuel cost in NOK per km

In the market for big cars (Table 2), the segments are three, and the emissions (see the variable *category*) range from 134 to 388.

Table 2. Descriptive statistics - Market BIG cars

Variable	Obs	Mean	Std. Dev.	Min	Max
category, g/km	599926	197.2722	44.49391	134	388
pollution	599926	0.022893	0.149562	0	1
tax_netprice	599926	1.037293	0.510917	0.442725	3.629107
CO_2_netprice	599926	0.443527	0.373151	0.049116	1.884805
fuelcost	599926	0.919655	0.264962	0.575148	2.124283

In the market small cars (Table 3) the variable *category* ranges from 86 to 208. The negative values of the variable *CO_2_netprice* refer to a case in which drivers have a reimbursement for low emissions.

Table 3. Descriptive statistics - Market SMALL cars

Variable	Obs	Mean	Std. Dev.	Min	Max
category	2252477	149.1919	28.8885	86	208
pollution	2252477	0.0239297	0.1528301	0	1
tax_netprice	2252477	0.6400043	0.2344144	0.2612324	1.960286
CO_2_netprice	2252477	0.1729871	0.1900422	-0.1667797	0.8321599
fuelcost	2252477	0.7219793	0.1828173	0.3734172	1.122366

4 Estimates

In the following Subsections 4.1 we report the results of the maximum likelihood estimation of eq. (1), carried out with maximum likelihood conditional logit, respectively for big cars and for small cars. The coefficients have in general the expected signs and are significant.

4.1 Market BIG

In Table 4 we report the estimation of eq. (1) for segment 1, 2 and 3.

Table 4. Estimate eq. (1) - market BIG

a) segment 1 (sport cars)

Number of obs = 578
LR chi2(3) = 319.25
Prob > chi2 = 0.0000
Pseudo R2 = 0.0790
Log likelihood = -1861.3578

	Coef.	Std. Err.	t-value
tax_netprice	-1.54827	0.224008	-6.91
CO_2_netprice	-2.84268	0.724362	-3.92
fuelcost	-0.39538	0.309166	-1.28

b) segment 2 (terrain cars)

Number of obs = 11958
LR chi2(3) = 3324.49
Prob > chi2 = 0.0000
Pseudo R2 = 0.0361
Log likelihood = -44377.818

	Coef.	Std. Err.	t-value
tax_netprice	-0.27501	0.051281	-5.36
CO_2_netprice	-0.61160	0.073622	-8.31
fuelcost	-1.42977	0.104691	-13.66

c) segment 3 (multiple cars)

Number of obs = 1160

LR chi2(3) = 1522.35

Prob > chi2 = 0.0000

Pseudo R2 = 0.2367

Log likelihood = -2455.0294

pollution	Coef.	Std. Err.	t-value
tax_netprice	-4.08411	0.315366	-12.95
CO_2_netprice	0.09248	1.748783	0.05
fuelcost	-4.13374	1.759931	-2.35

4.2 Market SMALL

In Table 5 we include the maximum likelihood estimation of eq. (1) for segment 1, and 2

Table 5. Estimate eq. (1) - market SMALL

a) segment 1 (small cars)

Number of obs = 11352

LR chi2(3) = 5950.84

Prob > chi2 = 0.0000

Pseudo R2 = 0.0737

Log likelihood = -37384.889

pollution	Coef.	Std. Err.	z
tax_netprice	-9.0333	0.226847	-39.82
CO_2_netprice	-0.84391	0.250610	-3.37
fuelcost	-0.19314	0.188629	-1.02

b) segment 2 (compact cars)

Number of obs = 19998

LR chi2(2) = 12862.16

Prob > chi2 = 0.0000

Pseudo R2 = 0.0764

Log likelihood = -77748.992

pollution	Coef.	Std. Err.	z
CO_2_netprice	-3.05071	0.151038	-20.2
fuelcost	-1.5748	0.144771	-10.88

4.3 Elasticities in each segment and time

In order to evaluate the economic magnitude of the tax effects, we have calculated the direct demand elasticities according to the following equations.

$$(4) \quad E_{j2s} = b_{2s}(1-\varphi_{js})\frac{CO_2Tax_{js}}{Netprice_{js}}$$

$$(5) \quad E_{j3s} = b_{3s}(1-\varphi_{js})\, fuelcost_{js}$$

where:

- E_{j2s} is the elasticity, for category *j* and segment *s*, of the probability φ_{js} with respect to the variable *tax_netprice* $\left(\text{i.e.} \frac{CO_2Tax}{Netprice}\right)$ and b_{2s} is the estimated coefficient of eq. (1);
- E_{j3s} is the elasticity, for category *j*, and segment *s*, of the probability φ_{js} with respect to the variable *fuelcost* (i.e. fuelcost NOK per km), and b_{3s} is the estimated coefficient of eq. (1).

In Table A1 of Appendix A, we include, for market big and for each category *j*, the estimated probabilities (phi_j_1_2010, phi_j_2_2010, phi_j_3_2010) and the elasticities e_j2_1, e_j3_1 for segment 1, e_j2_2, e_j3_2 for segment 2, and e_j2_3, e_j3_3 for segment 3.

The elasticity values have the correct signs and are increasing numerically with category *j*, that is with the emissions of CO_2. Segment 3 (multiple cars) have in general higher elasticities numerically than segment 1 and 2.

In Table A2 we include the corresponding variables for market small. For segment 2 we have only computed e_j3_2 since the variable *tax_netprice* has not been considered in the model.

5 Predictions and observed market shares

Figure 1 and Figure 2 compare observed and predicted market share respectively for the considered segments and for market BIG and market SMALL. We notice that the model predictions capture the overall trend, with the exception of some peaks that are present in the observed market shares.

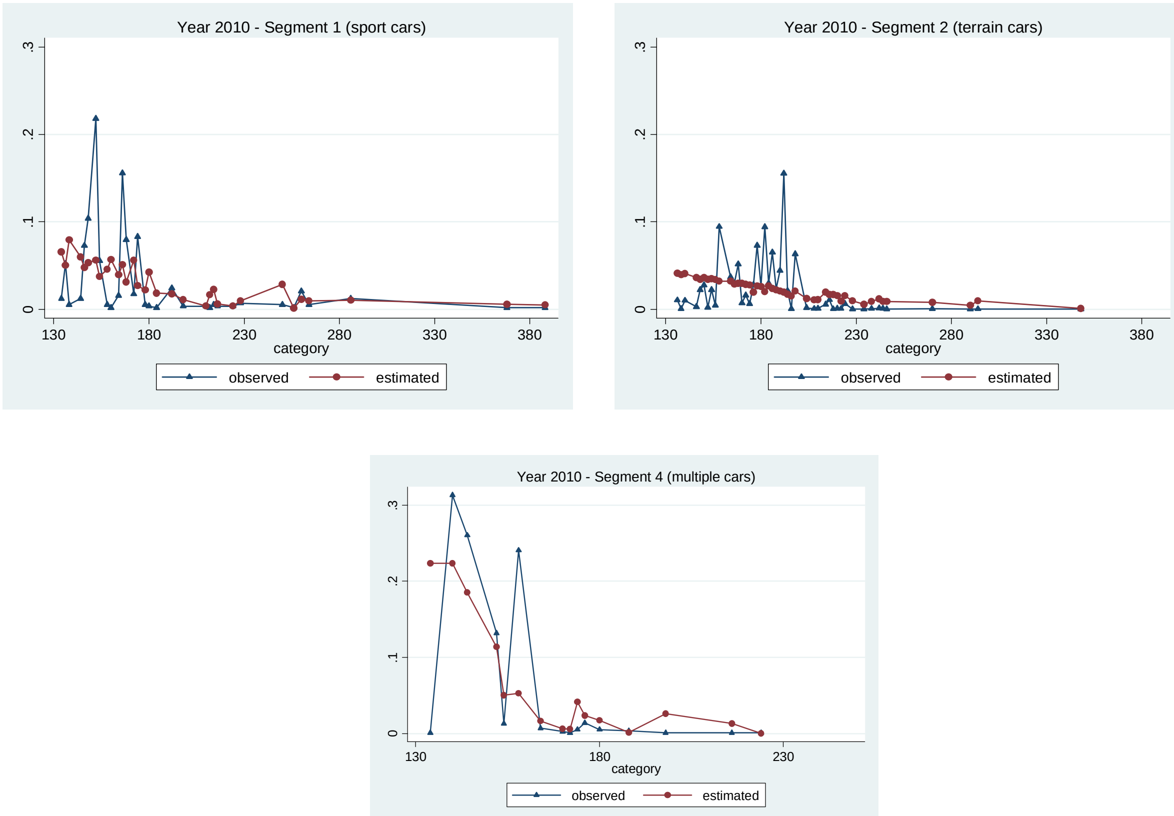


Figure 1. Observed and predicted market share given the segment - Market BIG

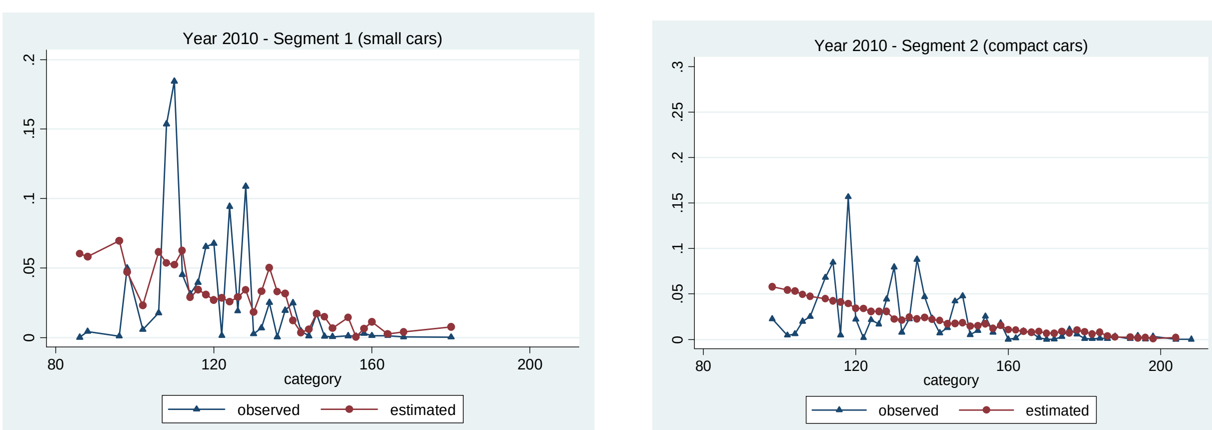


Figure 2. Observed and predicted market share given the segment - Market SMALL

6 Policy simulations, changes in and between car segments

Using the estimates of eq. (1), we did some policy simulations to verify the changes in car choice probabilities in and among segments, both in market BIG and in market SMALL. In particular we want to show the impact on:

i - the probability of the choice of car given the segment (φ_{ist} , Eq.1),

ii - the probability of the choice of segment (P_{st}, Eq.2-4),

iii - the global impact $\sum_{s}\sum_{i=1}^{I_{st}}\varphi_{ist}P_{st}u_{ist}$, where u_{ist} is the average emission of CO_2 in category *i*.

when

a) doubling and tripling CO_2 Tax values
b) increasing *fuelcost* per km by 20,40 and 60 percent

In the following Subsections 6.1, 6.2 and 6.3 we consider points i, ii, and iii for market big. The market small is considered in Subsections 6.4, 6.5, and 6.6.

6.1 Market BIG – changes in probability of the choice of car given the segment

In Tables B1, B2 and B3 of Appendix B, we report the impact of the policy simulations listed at point i, (cases a) and b)) for segment 1 (sport cars), 2 (terrain cars), and 3 (multiple cars), respectively. In general, for segment 1 and 2, we observe that the probabilities for the very low emission categories increase, whereas the probabilities for higher emission categories decrease. This fact may be interpreted as a shift from high emission to low emission categories caused by an increase in tax on CO_2 emissions. This effect is less evident in the case of *fuelcost*. Segment 4 appears more rigid to variations in taxes.

In the following Figure 3 and Figure 4, we report the impacts of the different simulations listed before.

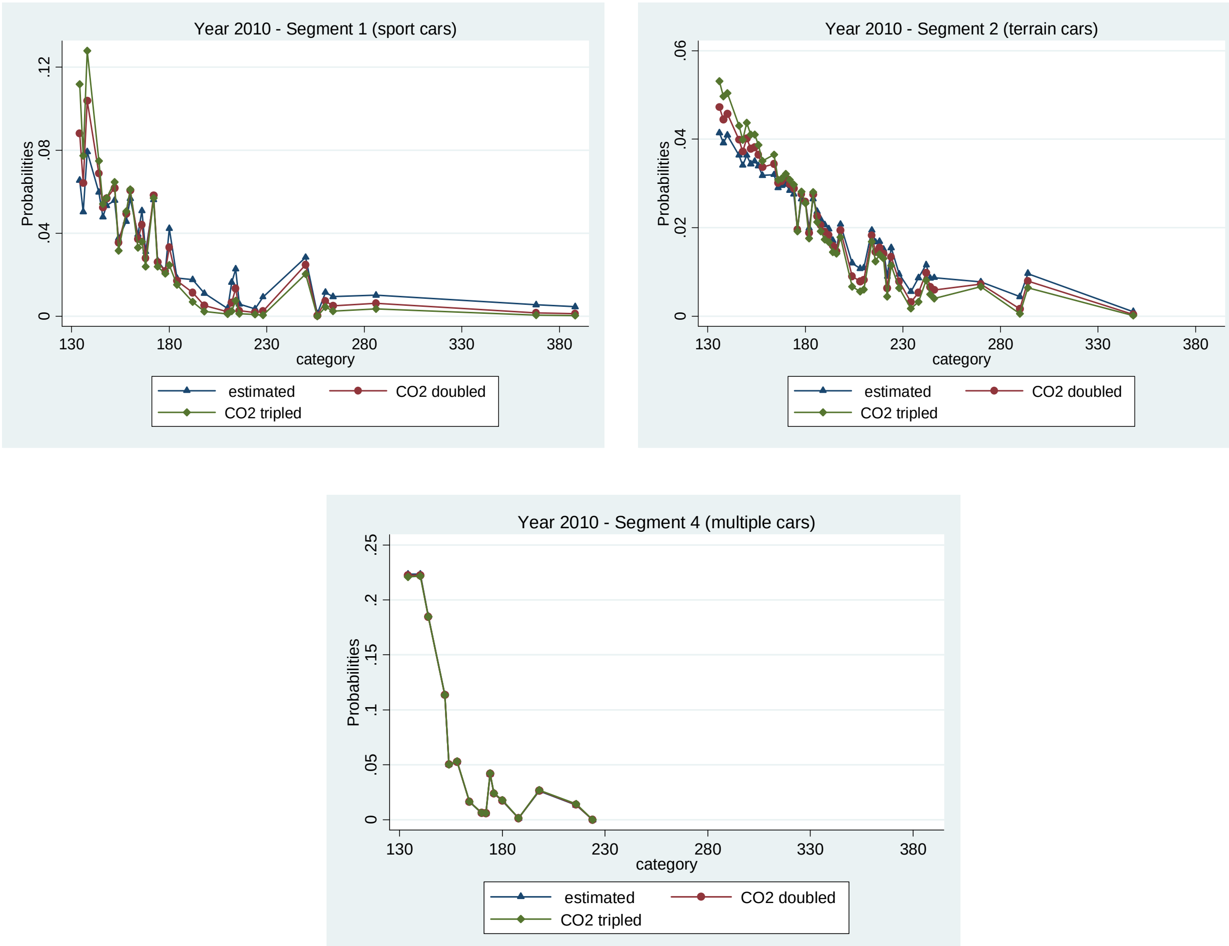
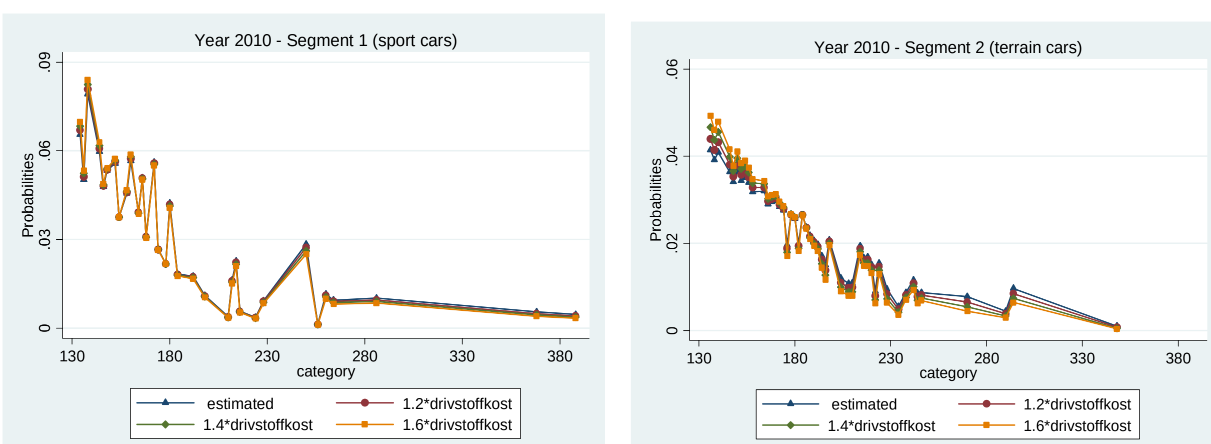


Figure 3. Choice probability φ_{is} of car by category given the segment: without any increase, doubling, and tripling CO_2Tax (market BIG)



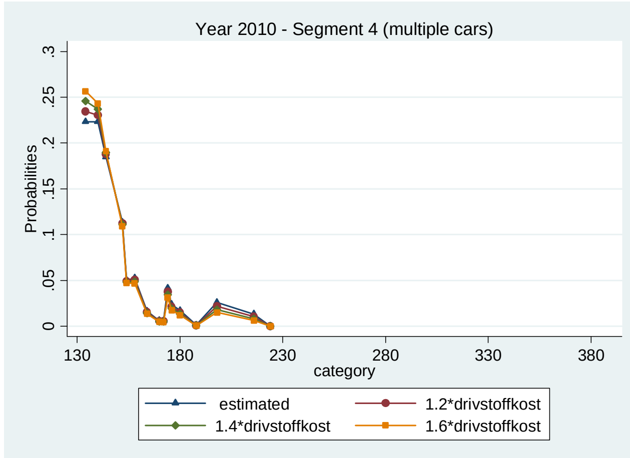


Figure 4. Choice probability φ_{is} of car by category given the segment: without any increase, with the increase of 20, 40 and 60 percent in *fuelcost* (market BIG)

6.2 Market BIG – changes among car segments

To investigate the impact on the choice of segments (point ii above) we calibrate eq. 2 so that the choice probabilities of segments fit the market shares of the segments.

To do that we have to compute the α's so that P_{st} of eq. 2 is equal to the observed market share that is we have to solve the following system of three nonlinear equations:

$$(6) \quad \frac{\text{number of cars in segment s}}{\text{all sold big cars}} = \frac{\exp(Y_s + \alpha_s Z)}{\sum_{k=1}^{3} \exp(Y_k + \alpha_k Z)}; s=1,2,3$$

with α_3=0 and Z = 9.05

The observed market share for sector BIG cars, are the following

segment 1, P_1_2010 = 0.0422
segment 2, P_2_2010 = 0.8731
segment 4, P_3_2010 = 0.0847

Resorting to MATLAB to solve the above system, we find the following α's:

α_1 = -0.5717
α_2 = -0.3243

This means that the stock exchange indicator favors multiple cars relative to sports car and terrain cars.

In Table 6 we include the impact on the choice probability of segment for the different simulation policies (point ii).

We observe that for segment 1 and 2 the probability decrease when doubling CO_2Tax (P_st_d) or tripling CO_2Tax (P_st_t), while for segment 3 there is an increase. We observe a different trend when we increase *fuelcost* by 20, 40 and 60 percent: by increasing *fuelscost* there is an increase in the probability for segments 1 and 2, whereas we predict a decrease for segment 3.

Table 6. Choice probability of segment: without any increase (P_st), doubling CO_2tax (P_st_d), tripling CO_2Tax (P_st_t), increasing fuelcost by 20, 40 and 60 percent (market BIG)

Segment	P_st	P_st_d	P_st_t	P_st +20% fuelcost	P_st +40% fuelcost	P_st +60% fuelcost
1	0.0422	0.0322	0.0255	0.0503	0.0594	0.0696
2	0.8730	0.8666	0.8562	0.8860	0.8931	0.8952
3	0.0848	0.1011	0.1183	0.0637	0.0475	0.0353

6.3 Market BIG – global impact changes

The following Table 7 includes the total impact over segment 1, 2, and 3 of the different simulations (point iii) on total expected emission of CO_2. We always predict a decrease when doubling CO_2tax (S_d), tripling CO_2avgift (S_t), or increasing *fuelcost* by 20 (S_20), 40 (S_40), and 60 percent (S_60).

Table 7. Expected total emission S = $\sum_{s=1,2,4} \sum_{i=1}^{I_{st}} \varphi_{ist} P_{\mathbf{st}} u_{\mathbf{ist}}$ doubling CO_2Tax (S_d), tripling CO_2tax (S_t), increasing fuelcost by 20 (S_20), 40 (S_40), and 60 percent (S_60) - (market BIG)

market_BIG	S	S_d	S_t	S _20 (+20% fuelcost)	S_40 (+40% fuelscost)	S_60 (+60% fuelscostst)
CO_2 g/km	174.9802	171.2378	168.2488	174.0372	173.0199	171.96

6.4 Market SMALL – changes in probability of the choice of car given the segment

In Appendix B, Tables B4, and B5 we report the impact of the policy simulations listed at point i, (cases a) and b)) for segment 1 (small cars) and segment 2 (compact cars), respectively. As for market big cars, we observe that the probabilities, for the very low emission categories, increase when taxes are increased while for higher emission categories the probabilities go down.

Segment 1 appears more rigid to variations in taxes on fuel cost.

In the following Figure 5 and Figure 6, we report the impacts of the different simulations listed before for market big.

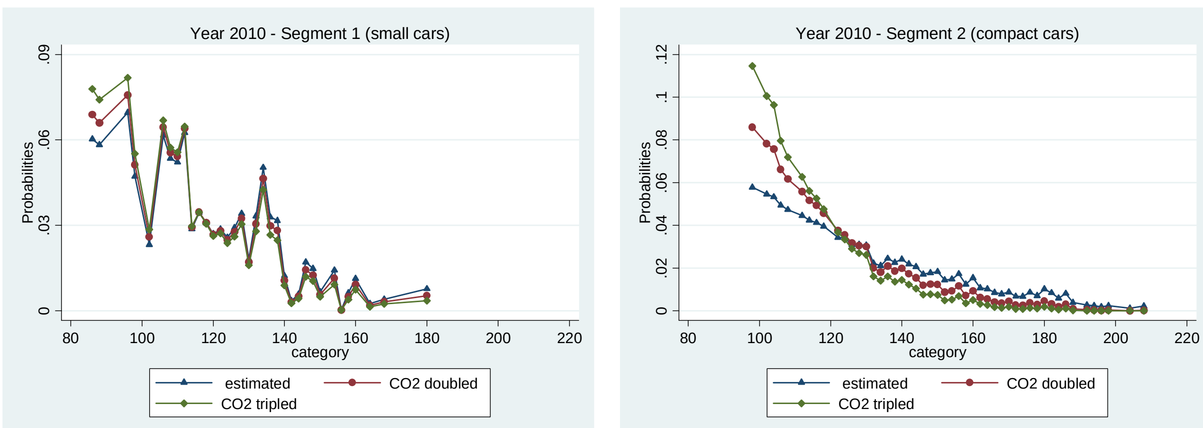


Figure 5. Choice probability φ_{is} of car by category given the segment: without any increase, doubling, and tripling CO_2Tax (market SMALL)

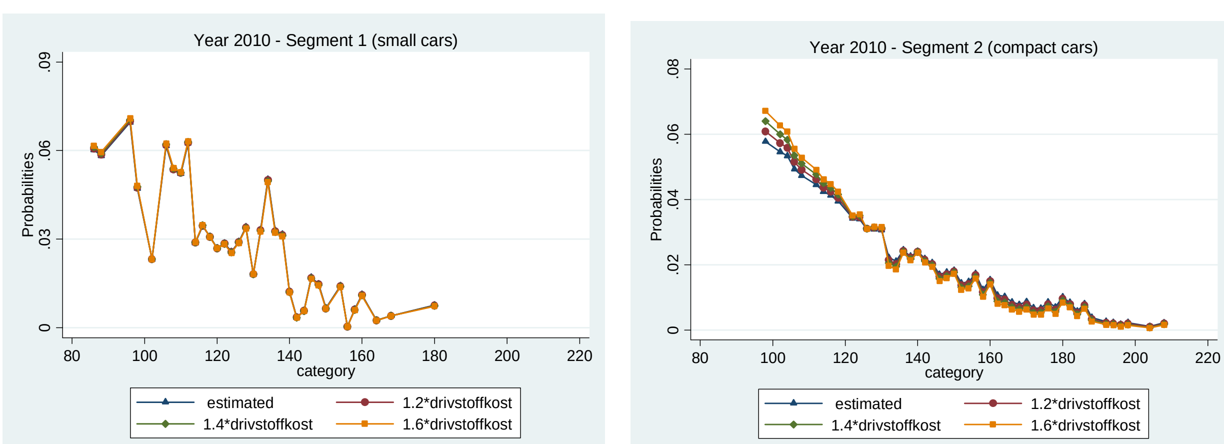


Figure 6. Choice probability φ_{ist} of car by category given the segment: without any increase, with the increase of 20, 40 and 60 percent in fuelcost (market SMALL)

6.5 Market small - changes among car segments

To investigate the impact on the choice of segments we have to compute the α's so that P_s of eq. 2 equals the observed market share, that is we have to solve a nonlinear equations similar to (eq. 6) above, which yields $\alpha_1 = 0.22$. Thus the stock exchange indicator favors small cars relative to compact cars**.**

Table 8 gives the impact on the segment probabilities of different simulation policy alternatives.

We observe that for segment 1 (small cars) the probabilities increase when doubling the CO_2Tax (P_st_d), tripling CO_2tax (P_st_t) or increasing *fuelcost* by 20, 40 and 60 percent. The opposite happens for segment 2 (compact cars) the probabilities decrease. Thus there is a shift from compact cars towards small cars.

Table 8. Choice probability of segment: without any increase (P_st), doubling CO_2Tax (P_st_d), tripling CO_2Tax (P_st_t), increasing fuelcost by 20, 40 and 60 percent (market SMALL)

Segment	P_st	P_st_d	P_st_t	P_st +20% fuelcost	P_st +40% fuelcost	P_st +60% fuelcost
1	0.33900	0.36956	0.37695	0.37670	0.41544	0.45477
2	0.66100	0.63044	0.62305	0.62330	0.58456	0.54523

6.6 Market SMALL – global impact changes

Table 9 reports the results of increasing taxes on the total expected emissions of CO_2 in the market for small cars. We can observe that there is a decrease in the total expected emissions when doubling CO_2Tax (S_d), or tripling CO_2Tax (S_t), and there is a decrease also when increasing *fuelcost* by 20 (S_20), 40 (S_40), and 60 percent (S_60) .

Table 9. **Expected total emission S=** $\sum_{s=1}^{2}\sum_{i=1}^{I_{st}}\varphi_{ist}P_{st}u_{ist}$ **doubling** CO_2**Tax (S_d), tripling** CO_2**Tax (S_t), increasing fuelcost by 20 (S_20), 40 (S_40), and 60 percent (S_60) - (market BIG)**

market_SMALL	S	S_d	S_t	S _20 (+20% fuelcost)	S_40 (+40% fuelcost)	S_60 (+60% fuelcost)
CO_2 g/km	125.249	118.9588	114.9698	124.042	122.9217	121.8902

7 Conclusions

A conditional logit model is estimated on Norwegian data for 2010. The data contains all purchases of cars for the period January to July. The estimates imply that taxes on CO_2 emission have a negative impact on the choice of car and the model is used in simulations to demonstrate how purchases of cars can be shifted to types of car with lower emissions. We demonstrate that the total expected emission of CO_2 is reduced when taxes on CO_2 increases.

Appendix A

Table A1. Category probabilities and elasticities given segment - year 2010- Market BIG

	Segment 1 (sport cars)			Segment2 (terrain cars)			Segment 3 (multiple cars)		
category_j g/km	phi_j_1_2010	Elasticity: e_j2_1	Elasticity: e_j3_1	phi_j_2_2010	Elasticity: e_j2_2	Elasticity: e_j3_2	phi_j_4_2010	Elasticity: e_j2_4	Elasticity: e_j3_4
134	0.065474	-0.071065	-0.212514				0.223340	-0.227629	-1.860300
136	0.050251	-0.099034	-0.220811	0.041432	-0.017492	-0.800022			
138	0.079240	-0.083914	-0.217197	0.039162	-0.019546	-0.819606			
140				0.040913	-0.025935	-0.823998	0.223334	-0.276310	-1.929215
144	0.059716	-0.150645	-0.230921				0.185027	-0.380388	-2.096667
146	0.047782	-0.178553	-0.282401	0.036395	-0.034673	-0.869273			
148	0.053366	-0.193200	-0.294334	0.034116	-0.037549	-0.920698			
150				0.036372	-0.031403	-0.887035			
152	0.055776	-0.171010	-0.271796	0.034395	-0.032814	-0.906632	0.113680	-0.453337	-2.390302
154	0.037579	-0.257903	-0.321487	0.035040	-0.036861	-0.913178	0.050180	-0.592608	-2.595259
156				0.033974	-0.043100	-0.930740			
158	0.045635	-0.185150	-0.281171	0.031809	-0.049932	-0.944709	0.052633	-0.703648	-2.672600
160	0.056674	-0.190036	-0.257739						
164	0.039310	-0.258157	-0.341055	0.032020	-0.042944	-0.974313	0.016322	-0.871090	-2.879755
166	0.050874	-0.299939	-0.333230	0.029031	-0.058829	-0.995089			
168	0.031130	-0.283266	-0.349452	0.029532	-0.060202	-1.006487			
170				0.029812	-0.054868	-1.012150	0.006130	-1.136143	-2.997760
172	0.056097	-0.204775	-0.344010	0.028464	-0.054182	-1.025668	0.005923	-1.181986	-3.033661
174	0.026823	-0.244762	-0.345107	0.027639	-0.055591	-1.042076	0.041609	-0.870316	-2.975770
176				0.019678	-0.077857	-1.329123	0.023724	-0.924805	-3.048623
178	0.021774	-0.232271	-0.324452	0.026525	-0.058958	-1.083223			
180	0.042271	-0.352235	-0.375249	0.025768	-0.073926	-1.078081	0.017221	-1.172840	-3.156116
182				0.019936	-0.099527	-1.241371			
184	0.018401	-0.269055	-0.390975	0.026559	-0.059952	-1.100119			
186				0.023669	-0.095751	-1.114531			
188				0.021828	-0.100985	-1.162294	0.001487	-1.473955	-4.271100
190				0.020677	-0.110978	-1.196500			
192	0.017651	-0.467670	-0.408286	0.019730	-0.108612	-1.228968			
194				0.017128	-0.108823	-1.383191			
196				0.015035	-0.086257	-1.518913			
198	0.011088	-0.632310	-0.425999	0.020806	-0.105839	-1.195642	0.026088	-1.242376	-3.438677
204				0.012036	-0.203216	-1.581111			
208				0.010823	-0.217610	-1.610583			
210	0.003889	-0.545642	-0.452819	0.010969	-0.205149	-1.625829			

212	0.016366	-0.719128	-0.451406						
214	0.022780	-0.512739	-0.452693	0.019464	-0.104544	-1.287709			
216	0.005862	-0.641261	-0.464834	0.016794	-0.139784	-1.306744	0.013264	-2.076900	-3.799087
218				0.016914	-0.113902	-1.321222			
220				0.015137	-0.105653	-1.329654			
222				0.009043	-0.230027	-1.729837			
224	0.003630	-0.602839	-0.483133	0.015481	-0.139119	-1.383307	0.000041	-3.924827	-5.069373
228	0.009344	-0.931284	-0.491085	0.009541	-0.161913	-1.767735			
234				0.005577	-0.327370	-1.821515			
238				0.008713	-0.290716	-1.450868			
242				0.011662	-0.151672	-1.473846			
244				0.008648	-0.195557	-1.649602			
246				0.008753	-0.246968	-1.502516			
250	0.028441	-0.302811	-0.527185						
256	0.001357	-0.981172	-0.553411						
260	0.011554	-0.476592	-0.556319						
264	0.009515	-0.568620	-0.566043						
270				0.007836	-0.106600	-2.032256			
278									
286	0.010157	-0.499485	-0.612816						
290				0.004423	-0.516055	-1.777902			
294				0.009686	-0.163215	-1.786737			
348				0.001059	-0.438826	-2.721227			
368	0.005511	-0.860300	-0.835275						
388	0.004685	-0.92232809	-0.83596858						
	Σ phi_j_1_2010			**Σ phi_j_2_2010**			**Σ phi_j_4_2010**		
	1			1			1		

Table A2. Category probabilities and elasticities given segment - year 2010- Market SMALL

	segment 1(small cars)			segment 2 (compact cars)	
category_j g/km	phi_j_1_2010	elasticity e_j2_1	elasticity e_j3_1	phi_j_2_2010	elasticity e_j3_2
86	0.0602265	1.4158354	-0.0677773		
88	0.0582452	1.3347057	-0.0694816		
96	0.0696072	0.9186579	-0.0740422		
98	0.0472327	0.9145822	-0.077782	0.0577716	-0.63050895
102	0.023214	1.2145431	-0.1063859	0.0545724	-0.65182093
104				0.0533347	-0.66547173
106	0.0616126	0.5288865	-0.0832353	0.0493667	-0.68753789
108	0.0534476	0.4680574	-0.0855001	0.0473041	-0.70190873
110	0.0521804	0.446855	-0.0864531		
112	0.0624843	0.2985041	-0.0871633	0.044564	-0.72348615
114	0.0287938	0.2733474	-0.0934869	0.042402	-0.74391057
116	0.0344954	0.1387363	-0.0935839	0.0412518	-0.75380951
118	0.0309082	0.0664543	-0.1166265	0.039502	-0.76884277
120	0.026961	-0.0016762	-0.1099361		
122	0.0286551	-0.1498377	-0.1253085	0.0343087	-0.85189418
124	0.0257229	-0.2857524	-0.1278437	0.0339801	-0.81951427
126	0.0291001	-0.4577084	-0.1243856	0.0309648	-0.89073943
128	0.0341749	-0.4817678	-0.130685	0.0309428	-0.85639773
130	0.01811	-0.5273995	-0.1058151	0.0307333	-0.85169961
132	0.0332686	-0.7912152	-0.135812	0.0222431	-1.0939105
134	0.0502879	-0.7417079	-0.1350327	0.0210934	-1.1076019
136	0.032915	-0.9665344	-0.1400982	0.0245179	-0.95202799
138	0.0316298	-1.1369777	-0.1423091	0.0226199	-0.99003507
140	0.0122873	-1.5270202	-0.1462419	0.024128	-0.92346561
142	0.0035232	-1.3659748	-0.1506782	0.0218783	-0.98768045
144	0.0058396	-1.479407	-0.1513792	0.0206144	-0.99645239
146	0.0170639	-1.7269394	-0.1518158	0.0170877	-1.1142752
148	0.014808	-1.6925668	-0.1541807	0.0177177	-1.0757382
150	0.0066439	-1.5150358	-0.1575591	0.0183349	-0.99999863
152				0.0143954	-1.1533659
154	0.0142605	-2.1988368	-0.1608411	0.0148166	-1.1448947
156	0.0003963	-2.3219714	-0.1648921	0.0173315	-1.0570581

158	0.006251	-2.3502911	-0.1668624	0.0123828	-1.2270779
160	0.0112706	-2.079715	-0.1672803	0.0154546	-1.0647694
162				0.010748	-1.3828096
164	0.0025796	-2.8367992	-0.1732708	0.0102693	-1.3821258
166				0.0085727	-1.4022729
168	0.0040888	-2.5590202	-0.1386984	0.0078648	-1.4408751
170				0.0087644	-1.4528851
172				0.0067659	-1.4729417
174				0.0067039	-1.4636732
176				0.0086056	-1.3236193
178				0.0070755	-1.4868367
180	0.0077144	-4.0097055	-0.1888672	0.0101637	-1.2043028
182				0.008458	-1.2197824
184				0.0058584	-1.4067822
186				0.008102	-1.2489539
188				0.0038685	-1.5385931
192				0.0026452	-1.6510353
194				0.0024074	-1.6715911
196				0.0018232	-1.6954274
198				0.0023186	-1.6189531
204				0.0011597	-1.7654498
208				0.0022099	-1.4028214
	Σ phi_i_I_2010			**Σ phi_i_II_2010**	
	1			1	

APPENDIX B: simulations

Table B1. Segment 1: Choice probability of car by category: without any increase (phi_j_1_2010), doubling CO_2 Tax (phat_doubling), tripling CO_2Tax (phat_triple); increasing fuelcost by 20, 40 and 60% (market BIG - Year 2010)

Segment 1 (sport cars)						
category_j	phi_i_1_2010	phat_doubling CO_2Tax	phat_triple CO_2Tax	phi 1.2 *fuelcost	phi 1.4 *fuelcost	phi 1.6 *fuelcost
134	0.065474	0.088042	0.111660	0.066903	0.068336	0.069772
136	0.050251	0.064158	0.077259	0.051295	0.052340	0.053385
138	0.079240	0.103640	0.127850	0.080832	0.082422	0.084011
144	0.059716	0.068801	0.074763	0.060797	0.061874	0.062944
146	0.047782	0.052361	0.054116	0.048155	0.048510	0.048849
148	0.053366	0.056725	0.056870	0.053627	0.053868	0.054088
152	0.055776	0.061842	0.064672	0.056308	0.056823	0.057319
154	0.037579	0.035524	0.031673	0.037589	0.037584	0.037563
158	0.045635	0.049415	0.050467	0.046008	0.046366	0.046708
160	0.056674	0.060535	0.060984	0.057383	0.058077	0.058756
164	0.039310	0.037110	0.033041	0.039156	0.038987	0.038803
166	0.050874	0.044032	0.035944	0.050714	0.050534	0.050335
168	0.031130	0.028139	0.023990	0.030973	0.030804	0.030624
172	0.056097	0.058238	0.057024	0.055771	0.055425	0.055059
174	0.026823	0.026135	0.024017	0.026720	0.026606	0.026483
178	0.021774	0.021770	0.020529	0.021790	0.021797	0.021796
180	0.042271	0.033269	0.024695	0.041796	0.041310	0.040814
184	0.018401	0.017201	0.015165	0.018171	0.017937	0.017698
192	0.017651	0.011387	0.006929	0.017370	0.017086	0.016801
198	0.011088	0.005300	0.002389	0.010879	0.010669	0.010459
210	0.003889	0.002199	0.001173	0.003797	0.003706	0.003616
212	0.016366	0.006611	0.002518	0.015967	0.015571	0.015178
214	0.022780	0.013441	0.007480	0.022204	0.021635	0.021072
216	0.005862	0.002773	0.001237	0.005709	0.005557	0.005408
224	0.003630	0.001848	0.000887	0.003523	0.003418	0.003315
228	0.009344	0.002571	0.000668	0.009049	0.008759	0.008476
250	0.028441	0.024813	0.020417	0.027286	0.026168	0.025085
256	0.001357	0.000345	0.000083	0.001299	0.001242	0.001188
260	0.011554	0.007371	0.004435	0.011040	0.010545	0.010068

264	0.009515	0.005127	0.002606	0.009076	0.008654	0.008248
286	0.010157	0.006218	0.003590	0.009597	0.009064	0.008557
368	0.005511	0.001741	0.000519	0.004982	0.004502	0.004067
388	0.004685	0.001322	0.000352	0.004235	0.003827	0.003457
	Σ phi_j_1_2010					
	1.00	1.00	1.00	1.00	1.00	1.00

Table B2. Segment 2: Choice probability of car by category: without any increase (phi_j_2_2010), doubling CO_2Tax (phat_doubling), tripling CO_2Tax (phat_triple); increasing fuelcost by 20, 40 and 60% (market BIG - Year 2010)

Segment 2 (terrain cars)						
category_j	**phi_j_2_2010**	phat_doubling CO_2 Tax	phat_triple CO_2 Tax	phi 1.2 *fuelcost	phi 1.4 *fuelcost	phi 1.6 *fuelcost
136	0.041432	0.0472534	0.0530642	0.0440083	0.0466221	0.0492702
138	0.039162	0.0444566	0.0496914	0.041444	0.0437441	0.0460588
140	0.040913	0.0457572	0.050389	0.0432435	0.0455876	0.0479409
146	0.036395	0.0399038	0.0430779	0.03814	0.0398634	0.0415627
148	0.034116	0.0371646	0.0398636	0.0353875	0.0366104	0.0377827
150	0.036372	0.0401801	0.0437048	0.0379751	0.0395453	0.0410794
152	0.034395	0.037879	0.0410743	0.0357795	0.037122	0.0384204
154	0.035040	0.0382283	0.0410661	0.0363957	0.0377053	0.0389663
156	0.033974	0.0365406	0.0386971	0.0351681	0.0363089	0.0373948
158	0.031809	0.0336869	0.0351272	0.0328463	0.0338287	0.034755
164	0.032020	0.0344582	0.0365122	0.0328612	0.0336361	0.034345
166	0.029031	0.0301342	0.0307989	0.0296844	0.0302735	0.0307986
168	0.029532	0.0305563	0.0311301	0.0301232	0.0306456	0.0311007
170	0.029812	0.0312238	0.0322002	0.0303711	0.0308599	0.0312798
172	0.028464	0.0298646	0.0308522	0.0289261	0.0293185	0.0296434
174	0.027639	0.028908	0.0297711	0.0279974	0.0282866	0.0285088
176	0.019678	0.0195885	0.0191995	0.0188327	0.0179762	0.0171167
178	0.026525	0.0275346	0.0281435	0.0266496	0.0267048	0.0266946
180	0.025768	0.025853	0.0255397	0.0259209	0.0260065	0.0260285
182	0.019936	0.0188915	0.0176271	0.0194222	0.0188726	0.0182936
184	0.026559	0.0275072	0.0280515	0.026591	0.0265536	0.0264512
186	0.023669	0.0226036	0.0212545	0.0236435	0.0235564	0.0234121
188	0.021828	0.0206078	0.0191565	0.0216024	0.0213228	0.0209952
190	0.020677	0.019088	0.0173502	0.0203262	0.019929	0.0194916

192	0.019730	0.0183163	0.0167425	0.0192718	0.0187749	0.0182459
194	0.017128	0.0159033	0.0145394	0.0162239	0.0153274	0.014445
196	0.015035	0.0146971	0.0141463	0.0138623	0.0127479	0.0116944
198	0.020806	0.0194322	0.0178699	0.0204563	0.0200594	0.019622
204	0.012036	0.0090475	0.0066967	0.0109686	0.00997	0.0090401
208	0.010823	0.0078812	0.0056508	0.0098086	0.0088661	0.0079945
210	0.010969	0.0082142	0.0060565	0.0099102	0.00893	0.0080269
214	0.019464	0.0182376	0.0168262	0.0187863	0.0180852	0.0173675
216	0.016794	0.0145397	0.0123947	0.0161582	0.0155061	0.0148439
218	0.016914	0.0155258	0.0140329	0.0162252	0.0155241	0.0148169
220	0.015137	0.0141628	0.0130477	0.0145031	0.0138594	0.0132118
222	0.009043	0.00641	0.0044736	0.0080056	0.0070684	0.0062256
224	0.015481	0.0134293	0.0114701	0.0146709	0.0138664	0.013074
228	0.009541	0.0078783	0.0064053	0.0083803	0.0073416	0.0064158
234	0.005577	0.0031856	0.0017915	0.004853	0.0042117	0.0036462
238	0.008713	0.0053905	0.0032838	0.0081604	0.0076232	0.0071038
242	0.011662	0.009846	0.0081853	0.0108622	0.0100911	0.0093519
244	0.008648	0.0066243	0.0049959	0.007782	0.0069841	0.0062526
246	0.008753	0.0059735	0.0040141	0.0081128	0.0075	0.0069165
270	0.007836	0.0073287	0.0067492	0.0065291	0.0054261	0.0044984
290	0.004423	0.001659	0.0006126	0.0038844	0.0034022	0.0029726
294	0.009686	0.0079738	0.0064637	0.0084742	0.007395	0.0064374
348	0.001059	0.0004735	0.0002085	0.0007709	0.0005596	0.0004053
	Σ phi_j_2_2010					
	1.00	1.00	1.00	1.00	1.00	1.00

Table B3. Segment 4: Choice probability of car by category: without any increase (phi_j_4_2010), doubling CO_2Tax (phat_doubling CO_2), tripling CO_2Tax (phat_triple); increasing fuelcost by 20, 40 and 60% (market BIG - Year 2010)

Segment 3(multiple cars)						
category_j	**phi_j_4_2010**	phat_doubling CO_2 Tax	phat_triple CO_2 Tax	phi 1.2 *fuelcost	phi 1.4 *fuelcost	phi 1.6 *fuelcost
134	0.223340	0.2221263	0.2209078	0.2346352	0.2457151	0.2346352
140	0.223334	0.2224357	0.2215297	0.2305026	0.2371422	0.2305026
144	0.185027	0.1847468	0.1844572	0.1876079	0.1896176	0.1876079
152	0.113680	0.1136222	0.1135592	0.1124372	0.1108536	0.1124372
154	0.050180	0.0502821	0.0503823	0.0492802	0.0482425	0.0492802

158	0.052633	0.0528823	0.0531304	0.0507803	0.0488368	0.0507803
164	0.016322	0.0164521	0.0165829	0.0154154	0.0145131	0.0154154
170	0.006130	0.0062153	0.0063013	0.005688	0.0052609	0.005688
172	0.005923	0.0060111	0.0061006	0.0054565	0.0050111	0.0054565
174	0.041609	0.0419628	0.0423178	0.0379285	0.0344635	0.0379285
176	0.023724	0.0239471	0.0241712	0.0215491	0.0195111	0.0215491
180	0.017221	0.0174798	0.0177419	0.0153669	0.0136689	0.0153669
188	0.001487	0.0015187	0.0015513	0.0010719	0.0007703	0.0010719
198	0.026088	0.0265294	0.0269775	0.0218388	0.0182237	0.0218388
216	0.013264	0.013744	0.014241	0.0104164	0.0081543	0.0104164
224	0.000041	0.0000442	0.0000478	0.0000252	0.0000155	0.0000252
	Σ phi_j_4_2010					
	1.00	1.00	1.00	1.00	1.00	1.00

Table B4. Segment 1: Choice probability of car by category: without any increase (phi_j_1_2010), doubling CO_2Tax (phat_doubling), tripling CO_2Tax (phat_triple); increasing fuelcost by 20, 40 and 60% (market SMALL - Year 2010)

segment 1 (small car)						
category_j	**phi_j_1_2010**	phat_doubling CO_2Tax	phat_triple CO_2Tax	phi (1.2*fuelcost)	phi (1.4 *fuelcost)	phi 1.6 *fuelcost
86	0.0602265	0.068815	0.077933		0.061142	0.061602
88	0.0582452	0.065998	0.074122	0.058668	0.059091	0.059516
96	0.0696072	0.075767	0.081745	0.070031	0.070455	0.070879
98	0.0472327	0.051281	0.055185	0.047501	0.047768	0.048036
102	0.023214	0.02588	0.028598	0.023219	0.023223	0.023226
104						
106	0.0616126	0.064462	0.066848	0.061875	0.062136	0.062396
108	0.0534476	0.055559	0.057245	0.053657	0.053866	0.054074
110	0.0521804	0.054126	0.055648	0.052376	0.052571	0.052764
112	0.0624843	0.063893	0.064757	0.062696	0.062907	0.063116
114	0.0287938	0.029342	0.029636	0.028873	0.028951	0.029028
116	0.0344954	0.034702	0.034602	0.034585	0.034674	0.034762
118	0.0309082	0.030876	0.030572	0.030844	0.030779	0.030712
120	0.026961	0.026757	0.02632	0.026945	0.026927	0.026909
122	0.0286551	0.028036	0.027187	0.028546	0.028436	0.028326
124	0.0257229	0.024842	0.023779	0.025614	0.025504	0.025394
126	0.0291001	0.02764	0.026021	0.028994	0.028888	0.028781

128	0.0341749	0.032377	0.030403	0.034002	0.033828	0.033655
130	0.01811	0.017096	0.015996	0.018118	0.018125	0.018132
132	0.0332686	0.030591	0.027881	0.033066	0.032863	0.032661
134	0.0502879	0.046403	0.04244	0.049964	0.049641	0.049319
136	0.032915	0.029759	0.026667	0.032686	0.032457	0.032229
138	0.0316298	0.028134	0.024803	0.031396	0.031164	0.030931
140	0.0122873	0.010556	0.008988	0.012194	0.012101	0.012008
142	0.0035232	0.003077	0.002663	0.003494	0.003465	0.003437
144	0.0058396	0.005044	0.004318	0.00579	0.005741	0.005693
146	0.0170639	0.014373	0.012	0.016913	0.016762	0.016612
148	0.014808	0.012519	0.01049	0.014671	0.014534	0.014398
150	0.0066439	0.005719	0.004879	0.00658	0.006516	0.006452
152						
154	0.0142605	0.011492	0.009179	0.014109	0.01396	0.013811
156	0.0003963	0.000317	0.000251	0.000392	0.000388	0.000383
158	0.006251	0.004975	0.003924	0.006179	0.006107	0.006037
160	0.0112706	0.009191	0.007429	0.011138	0.011006	0.010876
162						
164	0.0025796	0.001963	0.001481	0.002547	0.002515	0.002482
166						
168	0.0040888	0.003192	0.00247	0.004065	0.004041	0.004017
170						
172						
174						
176						
178						
180	0.0077144	0.00525	0.003541	0.007591	0.00747	0.00735
182						
184						
186						
188						
192						
194						
196						
198						
204						
208						
	Σ phi_j_1_2010					
	1	1	1	1	1	1

Table B5. Segment 2: Choice probability of car by category: without any increase (phi_j_2_2010), doubling CO_2Tax (phat_doubling), tripling CO_2Tax (phat_triple); increasing fuelcost by 20, 40 and 60% (market SMALL - Year 2010)

segment 2 (compact car)						
category_j	**phi_j_2_2010**	phat_doubling CO_2Tax	phat_triple CO_2tax	phi (1.2* fuelcost)	phi (1.4 * fuelcost)	phi (1.6 * fuelcost)
86						
88						
96						
98	0.0577716	0.0859666	0.1144966	0.0608735	0.0640063	0.0671648
102	0.0545724	0.0782806	0.1005037	0.0572699	0.0599735	0.0626782
104	0.0533347	0.0757879	0.0963909	0.0558199	0.0582972	0.0607619
106	0.0493667	0.0662604	0.0796014	0.0514579	0.0535241	0.0555611
108	0.0473041	0.0616672	0.0719543	0.0491747	0.0510112	0.0528096
110						
112	0.044564	0.055862	0.0626752	0.0461371	0.0476645	0.0491433
114	0.042402	0.0515752	0.056149	0.0437268	0.0449976	0.0462119
116	0.0412518	0.0492757	0.0526829	0.0424608	0.0436128	0.0447057
118	0.039502	0.0458311	0.0475936	0.0405443	0.041526	0.0424457
120						
122	0.0343087	0.0375156	0.0367169	0.0346433	0.034907	0.0351019
124	0.0339801	0.0355766	0.0333389	0.0345443	0.0350435	0.0354783
126	0.0309648	0.0317123	0.0290692	0.031036	0.0310415	0.0309844
128	0.0309428	0.0305639	0.0270212	0.0312346	0.0314624	0.0316281
130	0.0307333	0.0300001	0.0262109	0.0310545	0.0313125	0.0315091
132	0.0222431	0.0199786	0.0160613	0.0214218	0.0205872	0.0197452
134	0.0210934	0.0181957	0.0140487	0.0202631	0.0194243	0.0185827
136	0.0245179	0.0210429	0.0161649	0.0242969	0.0240269	0.023712
138	0.0226199	0.018586	0.0136687	0.0222508	0.0218413	0.0213962
140	0.024128	0.0197834	0.0145187	0.0240528	0.023927	0.0237539
142	0.0218783	0.0173322	0.0122896	0.021535	0.0211521	0.0207342
144	0.0206144	0.0155056	0.0104389	0.0202598	0.0198692	0.0194469
146	0.0170877	0.0119671	0.0075014	0.0164079	0.0157219	0.0150341
148	0.0177177	0.0123798	0.0077423	0.0171444	0.0165545	0.0159528
150	0.0183349	0.0122813	0.0073631	0.018015	0.0176632	0.0172835
152	0.0143954	0.0088095	0.0048253	0.013722	0.0130525	0.0123906
154	0.0148166	0.0092573	0.0051768	0.0141464	0.013478	0.0128152
156	0.0173315	0.011618	0.0069706	0.016836	0.0163201	0.0157881
158	0.0123828	0.0070068	0.0035487	0.0116342	0.0109078	0.0102061

160	0.0154546	0.0092915	0.0049998	0.0149954	0.0145191	0.0140296
162	0.010748	0.0061661	0.0031662	0.0097893	0.0088972	0.0080702
164	0.0102693	0.0056215	0.0027542	0.0093559	0.0085056	0.0077171
166	0.0085727	0.0039883	0.0016607	0.0077822	0.0070496	0.0063731
168	0.0078648	0.0034865	0.0013833	0.0070857	0.0063702	0.0057154
170	0.0087644	0.0043883	0.0019666	0.007875	0.0070608	0.0063181
172	0.0067659	0.0026606	0.0009364	0.0060583	0.0054133	0.0048271
174	0.0067039	0.0025876	0.000894	0.0060142	0.005384	0.0048101
176	0.0086056	0.0037126	0.0014336	0.007937	0.0073048	0.0067094
178	0.0070755	0.0029521	0.0011024	0.0063173	0.0056284	0.0050045
180	0.0101637	0.0046003	0.0018637	0.0095987	0.0090459	0.0085078
182	0.008458	0.0032291	0.0011034	0.0079662	0.0074871	0.0070227
184	0.0058584	0.0018638	0.0005307	0.0053175	0.0048163	0.0043535
186	0.008102	0.0030501	0.0010277	0.0075868	0.0070894	0.0066112
188	0.0038685	0.000925	0.000198	0.0034215	0.0030198	0.0026599
192	0.0026452	0.0004832	0.000079	0.0022883	0.0019753	0.0017017
194	0.0024074	0.0004084	0.000062	0.0020741	0.0017833	0.0015301
196	0.0018232	0.0002397	0.0000282	0.0015636	0.0013382	0.0011429
198	0.0023186	0.0003593	0.0000498	0.0020189	0.0017543	0.0015212
204	0.0011597	0.0001039	8.33E-06	0.000981	0.0008281	0.0006976
208	0.0022099	0.0002628	0.000028	0.0020095	0.0018234	0.0016512
	Σ phi_j_2_2010					
	1	1	1	1	1	1