Vehicle type choice and differentiated registration taxes

Mabit, Stefan Lindhard

Publication date:
2011

Vehicle type choice and differentiated registration taxes

Stefan L. Mabit

DTU Transport, Technical University of Denmark

Abstract:

Differentiated vehicle taxes are considered as a useful tool for promoting environmental friendly vehicles. Such a tax was introduced in Denmark in 2007. During 2007, the pattern in new vehicle purchases in Denmark changed toward more diesel vehicles and more fuel-efficient vehicles. We analyse to what extent the 2007 vehicle tax reform may explain these changes in purchasing behaviour using a discrete choice model. The model allows us to simulate the effect of price changes that resemble those induced by the tax reform. The analysis shows that the reform only changes purchase patterns slightly. The changes in fuel prices during the year induce a similar minor effect in our simulation. We conclude that while the tax reform appeared in the same year as a large increase in fuel efficiency, it only explains a small part of the shift in fuel efficiency that happened.

Keywords: vehicle type choice, tax reform, discrete choice, fuel price changes

1. Introduction

The fuel efficiency of new cars registered in Denmark during 2007 rose throughout the year and there was an increase in the diesel share from 0.24 before May to 0.40 after May 2007. The average fuel efficiency increased from 15.9 km/l in the first trimester to 17.4 km/l in the remainder of the year. For petrol cars fuel efficiency rose from 15.1 km/l to 15.8 km/l and for diesel cars it rose from 18.5 km/l to 19.8 km/l.

The changes in vehicle purchasing behaviour happened in a year where both the vehicle registration tax was differentiated following a tax reform and fuel prices rose. We hypothesise four reasons for these changes in purchasing behaviour related to fuel economy and fuel type.

1) Seasonal variation
2) Fuel price variation
3) The tax reform
4) Changes in preferences

In 2006 the average fuel efficiency increased from 15.8 km/l to 16.0 km/l and the diesel share increased from 0.20 to 0.23. This pattern is representative of the years prior to 2007. This observation removes seasonal variation as an argument for the changes observed in 2007.

Fuel prices rose through 2007, so this could explain some of the changes in purchasing behaviour. Therefore we control for the expectations about fuel prices at the time of purchase. Our model will then allow us to investigate to what extent fuel price variations affected purchasing behaviour.

In May 2007, the registration tax of a new car was differentiated according to the fuel efficiency of the car. The tax reform changed the new-vehicle price. A petrol car with fuel efficiency above 16 km/l became cheaper while those with fuel efficiency below 16 km/l became more expensive. For diesel cars the threshold was at 18 km/l. Therefore we will analyse the reform using a model that incorporates the consumer sensitivity toward vehicle price.

The changes in purchasing behaviour may be due to changes in preference, e.g. related to fuel economy. While this may be a valid reason for the changes in behaviour we will not be able to include them in the present analysis. If we allowed for changes in preferences this would be able to explain the changed behaviour completely and an analysis of the tax reform would be impossible. Therefore the analysis will be conditional on this aspects.

Finally, changes in technology in the vehicles could also drive a shift in fuel types and fuel economy. But these changes are calculated independently of technological changes in the new vehicles since they are based on vehicle types that are averages across 2007 and 2008 models. So this does not explain the changes.

We develop a discrete choice model to capture vehicle purchasing behaviour. Using our model we analyse the 2007 vehicle tax reform to see to what extent the reform may explain the changes in purchasing behaviour. We use a disaggregate model based on random utility maximisation to describe behaviour. In this way we follow the general framework used in, e.g. Manski and Sherman (1980). Literature reviews of more recent applications of the same methodology may be found in Potoglou and Kanaroglou (2007) and De Jong et al. (2004).

The remainder of the paper is organised as follows. In the next section we discuss the modelling framework used to analyse vehicle type choice. The following section 3 presents the data and the estimation results. Section 4 discusses the effect of the tax reform and the fuel price variation applying the model to several scenarios. The final section 5 presents a conclusion and some future directions of research.

2. Model formulation

The model should be able to capture the effect of the tax reform on the new vehicle market. Some tax reforms may have the intention to make individuals switch away from buying a car or toward buying a new car instead of a used car. Such changes are outside the scope of this paper as they would demand a more general modelling approach. Therefore we make the assumption that the tax reform only alters the distribution of vehicle types chosen but not the underlying population of new-car buyers. Given that the price changes induced by the reform are small compared to the overall vehicle prices in Denmark this seems like a reasonable assumption for the present tax reform, see section 3.1 for a price example. The model presented here models the vehicle choice conditional on the decision to buy a new car. This is similar to the approach used in Manski and Sherman (1980) as well as Train and Winston (2007).

As modelling framework we use random utility maximisation (RUM). We assume that each individual, indexed n=1,...,N, for each alternative j has a utility function, U_{nj}, and then chooses the alternative with maximum utility. In our case, the choice set J consists of 424 vehicle alternatives. We assume the utilities

$$U_{nj} = \delta_j + \beta' x_{nj} + \varepsilon_{nj}, \qquad (1)$$

where the δ_j's are the alternative-specific constants, the x_{nj}'s consist of the vehicle attributes and interactions with socio-economic variables, the β's are coefficients, and the ε_{nj}'s are error terms assumed to be distributed as IID standard EV1. This is a linear-in-parameters multinomial logit (MNL) model.

Given the distributional assumptions on the error terms this model may be estimated by maximum likelihood. This is a fairly simple approach but given the dimension of the $\delta = (\delta_j)$ – vector we will only use partial maximum likelihood as suggested in

Berry, Levinsohn, and Pakes (2004) hereafter BLP. Given the assumption about RUM and the utility specification in equation 1, we have

(2) $$P_n(i \mid \delta,\beta) = \exp(\delta_i + \beta' x_{ni}) / \Sigma_j \exp(\delta_j + \beta' x_{nj}).$$

If S_j denotes the market share of alternative j in the population and $\hat{S}_j$ the predicted share by the model, then the procedure works as follows:

1) Estimate the model $P(i \mid \delta, \beta)$ conditional on a δ-vector
2) Calibrate the δ-vector using the corrections $d_j = \ln(S_j)-\ln(\hat{S}_j)$.

Repeat 2) until the corrections are sufficiently small.

Step 1 uses standard maximum likelihood to estimate β. In step 2 we calculate the difference d_j and update the j^{th} element of δ using $\delta_j' = \delta_j + d_j$, where δ_j' is the new alternative-specific constant. Then we calculate the max norm of δ to judge whether to exit the procedure or redo step 2.

3. Data, specification, and estimation results

3.1 Data

We have a sample of 9,533 individuals who registered a new vehicle in 2007. The sample is a random sample (approx. 10 %) from the population of Danish new-car buyers in 2007. We see each individual as having made a choice from a choice set of 424 alternatives, where each alternative is defined by make, model, fuel and car type, e.g. a Ford Mondeo station car using petrol. Each alternative covers a number of subvariants. The vehicle attributes used to describe the alternatives are presented in Table 1.

Variable	Description
Airbag4	Dummy for more than 4 airbags
Auto	Dummy for automatic transmission
Cost	Purchase price plus weighted annual tax in 100,000 DKK
Diesel	Dummy indicating diesel vehicles
Doors4	Dummy for 4 or more doors
HP per kg	ln(Horse power in kWh divided by own weight in tons)
No. of variants	ln(Number of subvariants included in an alternative)
Operation cost	Fuel costs in DKK for driving 100 km
Weight	Total weight in tons
Class3	Dummy for compact/large vehicles
Class4	Dummy for large/executive vehicles
Class7	Dummy for MPVs
Class8	Dummy for SUVs

Table 1: Description of the vehicle attributes.

As noted in Table 1, the cost is found as the sum of the purchase price and the annual cost weighted. The weight for annual cost is 4 as it was found to be the average Danish WTP for annual cost in an SP study, see Mabit and Fosgerau

(2011). The purchase prices used are list prices ultimo 2007. To find the price of a vehicle purchased before May (i.e. before the reform) we apply the price changes due to the reform backwards. Table 2 presents an example of the price changes due to the reform. The reform altered the vehicle registration tax in the following way. Petrol vehicles driving x km/l more than 16 km/l and diesel vehicles driving x km/l more than 18 km/l were rebated 4000x DKK. Petrol vehicles driving x km/l less than 16 km/l and diesel vehicles driving x km/l less than 18 km/l were added 1000x DKK.

Vehicle	Fuel	Fuel economy (km/l)	Price before (DKK)	Price after (DKK)
Audi A6 station car	Petrol	10.4	841,450	847,050
Peugeot 107 hatchback	Diesel	24.4	140,900	115,300

Table 2: Price changes due to the tax reform in two vehicles.

Operation cost is measured as the fuel cost to drive 100 km. For this calculation we use average fuel price across both petrol and diesel. The reasons for using the average across fuel types are discussed in section 3.2. We average the fuel price across the 4 months prior to the purchase, i.e. the fuel price used represents an individual-specific expectation. The horizon of one month was compared to other durations and gave the best results measured on model fit. The average fuel price using this approach had a low in February at 8.6 DKK/l and a high in December at 10.1 DKK/l.

To describe the vehicle purchasers we include relevant socio-economic variables in the model. These are presented in Table 3.

Variable	Description
Female	Dummy for female individuals
Unemployed	Dummy for unemployed individuals
Single	Dummy for individuals who are only adult in household
Child	Dummy for individuals living together with children
Income	After tax monthly household income
Age	Age of individual
Distance	Dummy for one-way commute distance above 25 km
Copenhagen	Dummy for individuals living in Copenhagen

Table 3: Characteristics of car buyers

3.2 Estimation results

We estimated the model using partial maximum likelihood estimation together with the calibration procedures described in section 2. The estimation was done using a specific program written in Ox, see Doornik (2001). The estimation results are presented in Table 4. The final log-likelihood was LL = -51507.8 which gives $\bar{\rho}^2 = 1 - \frac{LL-K}{LL_0} = 0.11$.

Coefficient	Estimate	T value
Airbag4	0.12	4.2
Auto	-0.75	-3.4
Diesel	-0.65	-9.2
Doors4	0.07	1.3
HP per kg	0.27	2.5
No. of variants	0.43	34.2
Weight	1.07	7.7
Class3	0.56	13.4
Class4	1.06	10.6
Class7	0.24	6.0
Class8	0.94	12.9
Operation cost	-0.05	-18.2
Cost	-0.59	-21.1
Cost*Female	-0.52	-22.6
Cost*Unemployed	-0.04	-1.3
Cost*Single	0.34	7.0
Cost*Child	-0.06	-2.0
Cost*Income	0.73	34.3
Weight*Single	-1.74	-9.2
Weight*Child	0.68	4.9
HP per kg * Age	-0.01	-1.5
Diesel * Age	-0.02	-9.8
Diesel * Female	-0.25	-4.8
Diesel * Unemployed	-0.34	-4.6
Diesel * Distance	0.56	10.0
Diesel * Copenhagen	-0.84	-13.0

Table 4: Estimation results for the MNL model.

The estimation results show that all the parameters are significant at the 95% level. Below we discuss the parameters related to the most important attributes.

The base for the cost parameter is an employed male in a two-adult household without children with average income, i.e. 34,000 DKK. For this group we see that the cost parameter is negative as expected. We see that it is even more negative for females, unemployed individuals, and households with children. For single-adult households it is less negative. The cost parameter also shows the expected pattern with respect to income, i.e. individuals with higher income are less sensitive towards cost. These effects all seems reasonable and in line with results found in the literature. The combined effect of the heterogeneity in the cost parameter means that some individuals have a positive coefficient. This is of course not reasonable since an individual should not have positive marginal utility of cost. It happens because we capture only the 1. order effects of the socio-economic interactions with cost. In our sample it is a problem for less than 2 %. Therefore we keep the model in spite of this minor theoretical inconsistency.

Related to the parameter on fuel costs, we tested splitting the fuel price on average petrol and diesel prices. This test lead to a poorer model fit. Because diesel is cheaper in Denmark the model with two fuel prices implies that an individual should value the unit cost per 100 km less for diesel vehicles. The result indicates the opposite, i.e. that individuals buying a diesel vehicle value operation costs higher. To capture this we would have to estimate separate coefficients on operating cost for petrol and diesel alternatives. But such a model would not make sense for a single individual as the individual's marginal utility of operation cost should not depend on fuel type. Hence we stay with the simpler version of the model with only one coefficient.

The diesel parameter shows a dislike of diesel vehicles everything else equal. This is a common finding in Danish vehicle type models reflecting the fact that the diesel share traditionally has been very low in spite of the lower operation cost of diesel vehicles. A possible explanation for this is that diesel vehicles have a past reputation of being more pollutant. The socio-economic interactions with diesel have the expected signs. Females are known to be more concerned with pollution while the other interactions reflect that diesel vehicle are less attractive to individuals with no or short commuting while attractive to those with a long commute.

The parameter related to the number of subvariants is positive as it should be and very significant, see Ben-Akiva and Lerman (1985) for further discussion concerning aggregation of alternatives. This shows the importance of a supply aspect not often included in vehicle type modelling.

There are two performance attributes HP per kg and Weight. Both of these have the expected positive sign. The first is related to the acceleration of the vehicle while the second is related to safety, size, and luggage space. Given these relations the socio-economic interactions have reasonable signs.

Finally, we have a group of dummies with reasonable signs. The base for car classes are subcompact vehicles and smaller.

4. Illustration

To investigate the extent to which the tax reform may explain the behavioural changes in vehicle purchases in 2007 we simulate how the model would predict the average fuel economy and diesel share for purchases before the tax reform and for purchases after the reform both with and without the reform. The results are shown in Table 5.

	Jan-Apr	May - December	
With expected fuel price	No reform	No reform	Tax reform
Average fuel economy (km/l)	16.69	16.91	17.11
Diesel share (frequency)	0.331	0.348	0.358

With constant fuel price			
Average fuel economy (km/l)	16.78	16.87	17.07
Diesel share (frequency)	0.339	0.343	0.355

Table 5: Average fuel economy and fuel type with and without the tax reform.

To find the numbers reported, we calculate the market shares of each alternative for each scenario using the model reported in section 3.2. Given these market shares we find the diesel share directly by adding market shares for petrol and diesel alternatives respectively. To find the average fuel economy we calculate the average using the market share in the three scenarios as weights.

The difference between the first two columns, Jan-Apr and May-December with "No reform", is that we use the respective parts of the sample to simulate the average statistics. The difference between the simulations using the "Tax reform" and "No reform" for purchases following May 2007 is that we apply either the price with the effects of the tax reform or without, respectively.

The upper half of Table 5 reports the statistics using the expected fuel price, i.e. the prices applied in the modelling. These results show that our model would only predict an increase in the diesel share from 0.331 to 0.358 and that the reform does only account for little of this increase as the share is predicted to be 0.348 without the reform. Likewise the results for average fuel economy show that this would increase from 16.69 to 17.11 km/l and that average fuel economy without the reform would have increased to 16.91.

The lower half of Table 5 reports the statistics using the annual average of the fuel price, for all individuals. This is done to illustrate how much of the changes in the upper half that are due to rising fuel prices. The results show that there is still a small increase in average fuel economy and the diesel share in the two "No reform" scenarios but most of it disappears when we remove the effect of rising fuel prices. These changes come from minor differences in the population purchasing before and after the tax reform. This could arise because some individuals postponed or hurried their purchase due to the reform. While this switches a few individuals between the before and after tax reform period, it does not violate our general assumption that the reform changes the population of new-car buyers. The results are similar for the diesel share. This shows that much of the differences in the results without a reform are due to increasing fuel prices.

5. Conclusion and future research

In this paper we analyse to what extent the 2007 vehicle tax reform explain the changes in vehicle purchasing behaviour. We develop a discrete choice model to capture vehicle purchasing behaviour and using our model we analyse the tax reform. The analysis shows that the reform only changes purchase patterns slightly. The changes in fuel prices during the year induced a similar minor effect. Overall neither the tax reform nor fuel price changes induce the effects observed in the data.

This indicates that changes in preference may be the major factor behind the shift in fuel economy and fuel type.

An approach to improve the modelling would be to include information related to second choices as introduced by BLP. Another factor that could improve the modelling of vehicle choice could be to incorporate some concept of brand loyalty as discussed in Train and Winston (2007).

While both of these extensions could improve the modelling approach applied in the paper they may not change the conclusions concerning the effects of the tax reform much. BLP observe that the MNL model captures the same average effects as found in their more advanced model.

Another direction of research could be to include some indicators of preference changes, e.g. a measure of the public debate about the environment.

Acknowledgement

This paper is based on a research funded by The Danish Strategic Research Council. The author would like to thank Katrine Hjort for her valuable comments on an earlier version of the paper.

References

Ben-Akiva, M. and Lerman, S. (1985) *Discrete Choice Analysis*, MIT Press.

Berry, S., Levinsohn, J., and Pakes, A. (2004) Differentiated Products Demand Systems from a Combination of Micro and Macro Data: The New Car Market, Journal of Political Economy 112 (1) 68-105.

De Jong, G., Fox, J., Pieters, M., Daly, A.J., and Smith, R. (2004) A comparison of car ownership models, Transport Reviews.

Doornik, J. (2001) Ox: An Object-oriented Matrix Language. London, Timberlake Consultants Press.

Mabit, S.L and Fosgerau, M (2011) Demand for alternative-fuel vehicles when registration taxes are high, Transportation Research Part D 16 225-231.

Manski, C. F. and Sherman, L. (1980) An empirical analysis of household choice among motor vehicles, Transportation Research A 14 349-366.

Potoglou, D. and Kanaroglou, P. S. (2008) Disaggregate demand analyses for conventional and alternative fuelled automobiles: A review, International Journal of Sustainable Transport 2 (4).

Train, K. and Winston, C. (2007) Vehicle choice behavior and the declining market share of U.S. automakers, International Economic Review 48(4) 1469-1496.