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Centre for Economic Policy Research
90–98 Goswell Rd
London EC1V 7RR
Tel: (44 171) 878 2900
Fax: (44 171) 878 2999
Email: cepr@cepr.org

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ABSTRACT

The Markets for Gasoline and Diesel Cars in Europe*

The existing tax policies towards gasoline and diesel cars in the European countries provide a unique opportunity to analyse intertemporal investment aspects in consumer behaviour and quality-based price discrimination aspects in manufacturer pricing behaviour. We develop an econometric framework of demand and pricing for gasoline and diesel cars. Consumers choose a gasoline or a diesel car based on their annual mileage. Manufacturers set gasoline and diesel car prices. Our empirical results show that consumer implicit interest rates are close to capital market rates and considerably lower than the previous estimates obtained in the literature on consumer appliances. Furthermore, the results show that the relative pricing of gasoline and diesel cars is consistent with a monopoly model and inconsistent with competitive models of pricing. On average, about 70% to 85% of the price differentials between gasoline and diesel cars can be explained by mark-up differences. The implied tax incidence is especially based on fuel taxes and less so on annual car taxes.

JEL Classification: D1, D4, L1
Keywords: implicit interest rates, price discrimination, automobile market

Frank Verboven
SESO
Department of Economics
University of Antwerp (UFSIA)
Prinsstraat 13
B–2000 Antwerpen
BELGIUM
Tel: (32 3) 220 4877
Fax: (32 3) 220 4799
Email: frank.verboven@ufsia.ac.be

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NON-TECHNICAL SUMMARY

In most European countries cars are sold under two types of engine: the gasoline and the diesel engine. The diesel engine allows for potentially large savings in annual operating costs since it typically consumes less fuel per mile and requires less expensive fuel due to a favourable tax treatment. At the same time, however, the initial purchase price of a diesel car is generally higher than the price of its gasoline twin brother. These properties raise interesting questions regarding (i) the consumer's intertemporal choice problem whether to buy a gasoline or a diesel car; and (ii) the manufacturer's pricing problem whether to price discriminate between gasoline or diesel purchasers.

This paper considers these questions in two separate parts. In Part I, an econometric model of demand is constructed to analyse the consumer's investment choice problem whether to purchase a gasoline or a diesel car. The outcome of this choice problem depends on the consumer's annual mileage. Using a sample of pairs of automobiles, we infer the consumer's rate of time preference, or implicit interest rate, from the relative popularity of the gasoline and diesel variants, given the observed differences in initial purchase price, fuel costs per mile, and other characteristics. Although Part I focuses on the demand side of the market, the endogeneity of prices is tested and explicitly taken into account in the estimation procedure.

We obtain implicit interest rate estimates that are considerably lower than those of previous studies on consumer durables purchasing decisions. Our estimates roughly vary between 5% and 13%, depending on the adopted specification. This seems slightly above, but does not differ substantially from various measures of the market interest rate. Our estimates are thus consistent with intertemporal choice theory, in contrast with most other empirical evidence on consumer durables purchasing decisions. We attribute our results partly to our improved methodology, which explicitly incorporates consumer-purchasing data in the analysis. Our results may also follow from the unique nature of our data, by which we can focus on the relatively clean gasoline/diesel investment problem and abstract from other complicating decision aspects, such as the problem of how to choose one model out of a variety of differentiated products. Finally, some specific structural features of the automobile market may be responsible for our results, in particular the high liquidity due to a well-established capital market for car financing and the good information available to consumers.

In Part II, an econometric model of pricing is developed and added to the demand model. Various alternative types of conduct are considered and tested. This framework makes it possible to investigate whether the observed price differences between gasoline and diesel cars are due to differences in marginal costs or differences in mark-ups, i.e. price discrimination. Such a price discriminating strategy would be motivated by the heterogeneity in the annual mileage across consumers, which implies differences across consumers in their willingness to pay for gasoline and diesel cars. Although marginal costs are not observed directly, our structural model of pricing is able to identify to which extent price differences between gasoline and diesel cars are cost or mark-up driven.

The empirical results demonstrate that the price differentials are best explained by price discrimination of a monopolistic type. On average, about 70% to 85% of the price premium to be paid for a diesel car can be attributed to price discrimination; the remaining part follows from higher costs due to differences in specifications. These results are interesting in that they empirically demonstrate the feasibility and importance of quality-based price discrimination in the presence of competition.

The results also have important implications for fuel tax and car tax policy. At first sight, the estimates of implicit interest rates close to the capital market rates and the computed partial tax elasticities indicate that a tax policy may be a quite effective instrument in influencing the demand of certain types of engine. Our results demonstrate that it is important to properly take into account manufacturers' pricing responses when evaluating the effects of a change in taxes, however. More specifically, we show that an increase in the diesel fuel tax is only half as effective in lowering diesel car demand, when price discrimination and the implied tax incidence is properly taken into account.

Introduction

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Part I. Consumer implicit interest rates

1 Introduction

The theory of intertemporal choice makes the sharp prediction that people should discount their future gains or losses at the market interest rate i. When faced with this interest rate, consumers should accept any investment opportunity paying more than i and borrow the required amount on the capital market. Similarly, they should reject any investment opportunity paying less than i and lend their available liquidity on the capital market. Growing empirical evidence, however, seems to suggest that this sharp prediction of economic theory is often violated in real world situations. In the context of consumer durables purchasing decisions, people need to trade-o® a larger initial purchase price with future energy savings. Several studies indicate that the consumers' marginal rate of time preference { or their \implicit interest rate" { often well exceeds the market interest rate i. Hausman's (1979) study on air conditioner purchases ¯nds an average implicit interest rate of about 25 percent. This puzzling evidence was con¯rmed and reinforced in subsequent work, with estimates of up to 300 percent, depending on the type of appliance being studied.[1]

Part I of this paper provides estimates of implicit interest rates in automobile purchasing decisions. We focus on the consumer's problem of choosing between two types of engine, the gasoline and the diesel engine. In Europe, almost all cars are sold under both types. The gasoline engine is typically less fuel e±cient and requires more expensive fuel (due to higher taxes) than the diesel engine. At the same time, however, the initial purchase price of a gasoline car is generally lower than the price of its diesel twin brother. The choice between gasoline or diesel cars thus contains an important investment aspect, the outcome of which will depend on the consumer's annual mileage. We construct an econometric model that explicitly takes into account these considerations. Using a sample of pairs of automobiles, we essentially infer implicit interest rates from the relative popularity of the gasoline and diesel variants, given the observed di®erences in initial purchase price, fuel costs per mile, and other characteristics.

We obtain implicit interest rate estimates that are considerably lower than those of previous studies on consumer durables purchasing decisions. Our estimates roughly vary between 5 and 13 percent, depending on the adopted speci¯cation. This seems slightly above, but does not di®er substantially from various measures of the market interest rate. Our estimates are thus consistent with intertemporal choice theory, in contrast with most other empirical evidence on consumer durables

[1] See Lowenstein and Thaler (1989) for a detailed review of this literature.

purchasing decisions. We attribute our results partly to our improved methodology, which explicitly incorporates consumer purchasing data in the analysis. Our results may also follow from the unique nature of our data, by which we can focus on the relatively clean gasoline/diesel investment problem, and abstract from other complicating decision aspects, such as the problem to choose one model out of a variety of di®erentiated products. Finally, some speci¯c structural features of the automobile market may be responsible for our results, in particular the high liquidity due to a well-established capital market for car ¯nancing, and the good information available to consumers.

The next section provides an overview of the market for gasoline and diesel cars in Europe, including some preliminary evidence. Section 3 constructs the model and the econometric speci¯cation. In section 4 the empirical results are presented. Section 5 interprets the evidence in light of previous estimates of implicit interest rates.

2 Gasoline and diesel cars in Europe { a ¯rst look

The vast majority of automobile engines are fuelled with distillates of petroleum { gasoline, diesel or LPG. The ¯rst two variants are the most common in most European countries. In 1994, for example, gasoline cars constituted about 65 percent of total car sales in the European Union; diesel cars amounted to about 30 percent. In a gasoline engine, a mixture of air and fuel is ignited by a spark; in a diesel engine, the mixture explodes spontaneously due to the high pressure. These technical di®erences lie at the basis of the well-known di®erences in performance and comfort. The diesel engine has traditionally produced lower horsepower (at equal displacement), and lower speed and acceleration than the gasoline engine. Furthermore, the diesel engine has a reputation of making more noise and of a less reliable start under cold temperatures. Due to technological improvements (such as the introduction of the turbo and direct injection), these di®erences have diminished during the past years. A diesel engine generally has a greater fuel e±ciency yielding a greater \autonomy" (the number of miles that can be driven with a full). Despite the greater fuel e±ciency, the diesel engine presumably generates more air pollution than the (unleaded) gasoline alternative.[2]

The observable part of these technical di®erences between gasoline and diesel cars can be read in Table 1, which provides summary statistics for the variables included in our data set. We have collected data on sales, list prices, taxes and

[2] As discussed in Michaelis (1995), the diesel engine emits less carbon monoxide than the (unleaded) gasoline engine, roughly the same volatile organic compounds, and more NO_x. In addition, it emits airborne particulates unlike the gasoline engine.

technical characteristics of 41 pairs of automobile makes in three European countries, Belgium, France and Italy, during 1991-1994.[3] The choice of these countries was based on their long tradition with both gasoline and diesel cars, and on data availability; an interesting property is that the three countries experienced quite di®erent tax policies towards both types of cars. Models are the base models from the gasoline and the diesel range. In cases where the base make of a gasoline variant was equipped with a di®erent set of options than the diesel variant (e.g. air conditioner or ABS), we upgraded or downgraded the variants such that they contain the same equipment.[4] The averages in Table 1 illustrate the lower engine power of diesel cars (horsepower, speed, acceleration time) and the higher fuel e±ciency. The higher weight may be partly attributed to a stronger insulation against the diesel noise.

Table 2 summarizes, by country, several essential di®erences between the gasoline and the diesel cars. These ¯gures provide some ¯rst intuition on the investment aspects involved in the gasoline/diesel purchase decision. The ¯rst two parts summarize di®erences in annual operating costs. Annual operating costs consist of both fuel costs (price per liter times liters per mile times annual mileage for the average driver) and annual car taxes. In all three countries there are large savings in annual fuel costs from driving a diesel car.[5] These fuel cost savings vary substantially across countries, due to di®ering national fuel taxation policies; the largest fuel cost savings may be realized in France, amounting to about 510 dollar per year for the average driver. Di®erences in the annual car tax also vary substantially across countries. In France, diesel cars obtain a favorable car tax treatment; in Belgium, a moderate car tax partly o®sets the fuel cost savings from driving a diesel; in Italy, car taxes are so high that they completely outweigh the fuel cost savings, at least for the average driver.

[3] Data on list prices (including value added taxes) and technical characteristics come from the following weekly retail catalogues (August issue) De Autogids (Belgium), l'Automobile Magazine (France), Quattroruote (Italy). Sales data come from publications on new car registrations by the Nationaal Instituut voor Statistiek (Belgium), l'Argus de l'Automobile et Locomotions (France) and A.C.I. (Italy). Average annual gasoline and diesel fuel prices, for all three countries, are taken from l'Argus de l'Automobile et Locomotions. Data on the distribution of mileage, by several principle characteristics, come from the industry associations, A.C.E.A., F.E.B.I.A.C. and from survey data by De Borger (1987) and C.B.S.

[4] Helpful and competent research assistance in this tedious data collection process was provided by Sandy Torrekens. The technical characteristics include weight, displacement, horsepower, ¯scal horsepower, fuel e±ciency, speed and acceleration. Other characteristics such as length or width have not been collected since they are common to the gasoline and the diesel variants of each make. Information on ¯scal horsepower is used to compute the annual car tax for the various cars.

[5] The favorable fuel tax treatment of the diesel engine in most European countries does not have an environmental justi¯cation. Presumably, it is a means of discriminating between automobile and truck drivers, since the latter are equipped standard with a diesel engine.

The savings in annual operating costs can be confronted with the extra initial purchase price to be paid for diesel cars. As the third part of Table 2 demonstrates, in all three countries diesel cars are more expensive than gasoline cars.[6] In France, for example, the average driver would need about 5 years before his diesel investment of 2730 dollar is paid back by the savings in annual operating cost. Observe that the extra initial purchase price for diesel cars is much higher in France than in Belgium and in Italy, which indicates that manufacturers take into account the differences in tax treatment in their pricing strategies.

To obtain some further insights in the relationship between the extra initial purchase price for diesel cars and differences in annual operating costs, one may regress the following hedonic equation using our data set of model pairs:

$$\Delta p_j = \beta_0 + \beta_1 \Delta PERF_j - \beta_2 (\mu_j \Delta \pi_j + \Delta \tau_j) + \epsilon_j. \tag{1}$$

This equation regresses the difference in initial purchase price between a diesel and a gasoline variant of make j, Δp_j, on the difference in annual operating costs, controlling for the difference in measured performance $\Delta PERF_j$. The difference in annual operating costs equals the annual car tax difference ($\Delta \tau_j$) plus the difference in fuel costs per mile ($\Delta \pi_j$) times the annual mileage j's average driver (μ_j). The term $\Delta PERF_j$ consists of the variables horsepower, displacement and weight. In a second specification, horsepower and displacement are replaced by speed and acceleration. This regression is essentially the same as in Dreyfus and Viscusi (1995), where the variables are now expressed as differences (between gasoline and diesel) rather than as levels.[7]

Our focus is on the estimate of β_2. One may interpret this coefficient as the consumers' willingness to pay for one extra dollar of savings in operating costs. If consumers capitalize their annual operating costs at an implicit interest rate r, using a time horizon T, then β_2 can be interpreted as what Dreyfus and Viscusi call the "vehicle's discounted life":

$$\beta_2 = 1 + \frac{1}{1+r} + \cdots \left(\frac{1}{1+r} \right)^{T-1} = \frac{1+r}{r} \left[1 - (1+r)^{-T} \right]. \tag{2}$$

Intuitively, if for example a car would be expected to last only one year ($T = 1$),

[6] We also computed price differences after adjusting for differences in observed quality, using hedonic regression techniques. The price difference between a gasoline and a diesel car was regressed on differences in the performance characteristics, horsepower, displacement and weight. The constant of such a regression can be viewed as the quality adjusted price difference, since this is what remains after all differences in characteristics are set equal to zero. The results revealed a similar pattern as in the case of quality unadjusted price differences.

[7] The differencing takes out model-specific effects, which is feasible here since our dataset consists of pairs of automobiles.

then ¯$_2$ = 1, i.e. consumers would be willing to pay one dollar for an extra dollar saved on operating costs. Similarly, if consumers do not discount the future ($r = 0$), then ¯$_2$ = T, i.e. consumers would be willing to pay T dollars for an extra dollar saved on annual operating costs (the undiscounted pay-back time). More generally, from our estimate of ¯$_2$, one can compute the consumer's implicit interest rate r, by assuming a certain value for the time horizon T. As in Dreyfus and Viscusi, we use the median automobile durability (the time at which 50 percent of the automobiles has become obsolete) as a measure of the time horizon. Median durability equals 11 years in Belgium and in France, and 15 years in Italy, compared to 13 years in Dreyfus and Viscusi's study of U.S. automobiles.[8]

The results from an ordinary least squares regression of (1), pooling the data across countries and markets, are presented in Table 3. The regression includes dummy variables for time, market, and country of production location, in addition to the variables discussed above. The R^2 are relatively low in both speci¯cations compared to other hedonic studies. This is because the equation is estimated in differences, which takes away a lot of variation. Nevertheless, most technical characteristics coe±cients have intuitive signs and relatively low standard errors, consistent with other hedonic regressions. In the ¯rst speci¯cation (including horsepower and displacement) the estimate of the \vehicle's discounted life" coe±cient, ¯$_2$, is 4:8; the corresponding estimate of the implicit interest rate r equals 23:5 percent with a standard error of 2:5. This estimate suggests that consumers use a fairly high implicit interest rate when making the gasoline/diesel investment decision. Our second speci¯cation (including speed and acceleration) reinforces this conclusion. The estimate of ¯$_2$ is here 2:8; the corresponding implicit interest rate estimate is 55:7 percent, with a standard error of 16:1. These high estimates seem consistent with the results in most other studies on consumer durable goods purchasing decisions. In particular, one may compare our results with Dreyfus and Viscusi's (1995) hedonic study for the automobile market in the U.S. They report implicit interest rate estimates ranging from 11 to 17 percent. At ¯rst sight, these estimates seem substantially lower than ours. However, one should be very cautious in making a proper comparison. In fact, Dreyfus and Viscusi's \discounted life" coe±cient (our ¯$_2$) is multiplied by another parameter, which they call a \capitalization rate". This is de¯ned as the rate at which the marketplace incorporates life-cycle operating costs (i.e. ¯$_2$(¹$_j$ ¢¼$_j$ + ¢¿$_j$)) into vehicle prices. In our model the capitalization rate parameter is normalized to one,[9] and the implicit interest

[8] Ideally, one should use model-speci¯c data on vehicle durability. However, as in Dreyfus and Viscusi, such detailed data are not at our disposal.

[9] Due to some speci¯c properties in their model Dreyfus and Viscusi separately identify the vehicle's discounted life coe±cient (¯$_2$) and the capitalization rate. One such identifying property

rate can be immediately uncovered from formula (2) for ¯$_2$. To obtain comparable ¯gures for the implicit interest rates in Dreyfus and Viscusi's model, one should ¯rst multiply ¯$_2$ by the capitalization rate, before applying formula (2). Given that they obtain the quite low estimate of 0:35 for the capitalization rate, the comparable implicit interest rates would in fact be much larger than their reported estimates of 11 and 17 percent, possibly well above 30 percent.[10] In sum, our hedonic regression analysis suggests that people behave fairly myopically in the gasoline/diesel investment decision, which seems consistent with previous studies on consumer durables, including Dreyfus and Viscusi's study once their low estimate of the capitalization rate is taken into account.

This analysis, based on the country summary statistics of Table 2 and the hedonic regression of Table 3, did not explicitly take into account consumer behavior, as measured by the relative sales of gasoline and diesel models. The fourth part of Table 2 reports the \dieselization rate", the percentage of diesel cars in the total car sales. Interestingly, the above discussed cross-country di®erences in annual operating costs seem to be re°ected in the countries' dieselization rate. In Belgium and especially in France, where diesel cars may generate large savings in operating costs, the dieselization rate is high. In Italy, where diesel cars do not yield savings in operating costs, at least to the average driver, the dieselization rate only reaches 15 percent. Cross-country di®erences in annual operating costs thus seem responsible for di®erences in dieselization rate, despite our observation made above that car manufacturers may be charging a higher diesel surcharge in those countries with a more favorable tax regime towards diesel cars.

The above discussion provides some ¯rst intuition on how the relationships between prices (possibly adjusted for quality), annual operating costs and sales may say something about the attitude of consumers towards gasoline and diesel cars, and their willingness to pay for investment opportunities. Nevertheless, various issues need to be addressed to provide a more complete analysis. Does the hedonic regression model, which relates prices to operating costs, have a theoretical justi¯cation? How can/should sales data possibly be integrated in an econometric analysis? Can we justify our focus on the \average driver"? Or should we instead take into account the fact that consumers are heterogeneous and incorporate the distribution of annual mileage across consumers? How should we cope with the possibility that prices are determined endogenously by the manufacturers, in response to the same

is the consideration of mortality risk and injury, which involve a di®erent time horizon than car durability; another identifying property is the nonlinearity of the capitalized operating cost variable.

[10] Because Dreyfus and Viscusi allow the operating costs variable to enter nonlinearly, we cannot compute the exact comparable implicit interest rate from the information provided in their paper. The very low capitalization rate of .35 nevertheless suggests they will be quite high.

factors that influence consumer decisions?

3 The econometric model

3.1 Theoretical model

To model the consumer's intertemporal choice problem of paying a higher initial purchase price (the diesel premium) in exchange for future savings in operating costs, we proceed in two steps. First, we formulate a discrete choice model of car purchasing decisions to find the consumers' indirect utility for any car make j coming with an engine variant k. Next, we derive the market share of the gasoline engine variant in the total sales of each make j.

Consider the following discrete choice model of car purchasing decisions. Consumers choose to purchase one particular make j coming with one of the two engine variants k, where $k = G, D$ refers to the gasoline or the diesel engine. The utility derived from purchasing one particular make/engine variant takes the following simple form

$$u_{jk} = z + a_{jk} + \varepsilon_j,$$

where a_{jk} is the mean intrinsic utility from purchasing model j with engine k, common to all consumers; ε_j is an individual-specific random component around that mean; and z is the consumption of goods other than car services. Note that the linear specification is quite standard in the discrete choice literature. Both the mean utility term a_{jk} and the individual-specific term ε_j may depend on observable characteristics such as performance, size and safety. The term ε_j is often modelled as an i.i.d. random variable (as in the popular logit model), implying no correlation of consumer preferences across cars. Advances in the discrete choice literature, most notably by Berry (1994) and Berry, Levinsohn and Pakes (1995), show how to relax this unrealistic assumption and allow consumer preferences to be correlated across cars with similar characteristics. Their specification yields a quite flexible aggregate model of product differentiation, with plausible substitution patterns between cars. As will become clear below, our approach abstracts from aspects of product differentiation between different cars, and does not require any restrictions on the distribution of ε_j.

Consumers have an annual income y to be spent on car services and other goods. Annual expenditures on car services include the following three terms: annualized initial purchase price, annual car taxes and annual fuel expenditures. Consider these three terms in turn. (i) The initial purchase price of a car is p_{jk}. With an expected durability of T years and a rate of time preference, or implicit interest rate, r, the purchase price can be written in annualized terms as ρp_{jk}, where ρ is the annualization coefficient, which is simply the inverse of the discounted life coefficient given by (2),

$$\rho \equiv \frac{r}{1+r}\left[1 - (1+r)^{-T}\right]^{-1}. \tag{3}$$

This is a common approach to annualizing the value of a durable good, for more details see for example Hausman (1979). (ii) In addition to the annualized purchase price ρp_{jk}, the consumers need to pay an annual car tax of τ_{jk}. This tax may differ across makes and variants, and is usually based on the "fiscal horsepower" of a car. The fiscal horsepower is computed from characteristics such as horsepower, displacement and weight according to a formula defined by the government. (iii) Finally, consumers incur annual fuel expenditures. These depend on the fuel price q_k (dollars per gallon of fuel k), the fuel efficiency w_{jk} (gallons per mile), and the annual mileage θ. Annual fuel expenditures per mile are $\pi_{jk} = q_k w_{jk}$. The annual mileage θ is a random variable which may vary from consumer to consumer. For simplicity, assume that annual mileage is not sensitive to fuel prices (inelastic demand), so that a consumer's total annual fuel expenditures equal $\pi_{jk}\theta$.[11]

In sum, when purchasing a particular car j with engine k, total annual expenditures on car services are given by $\rho p_{jk} + \tau_{jk} + \pi_{jk}\theta$. The remaining income $y - \rho p_{jk} - \tau_{jk} - \pi_{jk}\theta$ is left for the consumption on other goods z (at a price normalized to 1). We can then write the indirect utility derived from purchasing a model j with engine k as

$$u_{jk} = y - \rho p_{jk} - \tau_{jk} - \pi_{jk}\theta + a_{jk} + \varepsilon_j. \tag{4}$$

Given this indirect utility function consumers can choose their most preferred model and engine variant. For our purposes it is sufficient to focus on the consumer's choice of engine variant k conditional on purchasing a particular make j. This choice is crucially dependent on the consumer's annual mileage θ. A consumer is indifferent between buying car j with a gasoline engine G and with a diesel engine D if $u_{jG} = u_{jD}$, hence if her annual mileage equals

$$\theta = \theta_j^* \equiv \frac{\Delta a_j - \rho\Delta p_j - \Delta\tau_j}{\Delta\pi_j}, \tag{5}$$

where the Δx_j denotes the difference between a diesel and a gasoline variable, i.e. $\Delta x_j \equiv x_{jD} - x_{jG}$. Notice that the random variable ε_j does not appear in

[11] Previous studies have estimated quite low elasticities of gasoline demand, varying from 0 to around $-.2$. See for example Goldberg (1998) for a discussion. Given that we make use of aggregate demand rather than household level data, a relaxation of the inelastic demand assumption would essentially only affect the specific functional forms in our model. In the empirical results, we report some results with an elastic demand for mileage specification.

this equation. Consumers driving $\theta < \theta_j^*$ prefer the gasoline engine of j; other consumers prefer the diesel engine of j. The market share of the gasoline variant of j in the total sales of j, $s_{G|j}$, is then simply the probability that the gasoline variant is chosen, conditional upon buying j, i.e.

$$s_{G|j} = \Pr(\theta < \theta_j^* \mid j) = F_j(\theta_j^*); \tag{6}$$

where $F_j(\cdot)$ is the conditional cumulative distribution function of θ, i.e. conditional upon choosing j. Note that the empirical distribution of mileage may differ across cars j. For example, it is empirically observed that consumers who decide to purchase larger cars also tend to drive more miles per year. This follows from a correlation between preferences for large cars and mileage.

3.2 Econometric specification

Our interest is in estimating the demand (6). Since the cumulative distribution function $F_j(\cdot)$ is a monotone increasing function, we can invert this equation such that $\theta_j^* = F_j^{-1}(s_{G|j})$. Rearrange using (5) to obtain:

$$F_j^{-1}(s_{G|j})\cdot\pi_j + \Delta\tau_j + \rho\Delta p_j = \Delta a_j; \tag{7}$$

where $F_j^{-1}(\cdot)$ is a monotone function defined as the inverse of $F_j(\cdot)$. To complete the demand specification, we need to specify $F_j^{-1}(\cdot)$ and Δa_j in (7).

First consider $F_j^{-1}(\cdot)$. Econometrically, this function simply transforms the market share data $s_{G|j}$, analogous to for example a logarithmic transformation. Economically, since $F_j^{-1}(\cdot)$ is the inverse of the cumulative distribution function of mileage, one can interpret $F_j^{-1}(s_{G|j})$ as a threshold mileage, i.e. the mileage that is not reached during one year by a given proportion $s_{G|j}$ of consumers purchasing j. In principle, this information can be obtained from consumer survey tables containing, for each model, one column with annual mileage categories and a second column with the proportion of cars corresponding to each mileage category; there is no need for making parametric assumptions on the distribution function of θ. In practice, we do not have such a detailed information at our disposal for the three countries. We therefore specify the cumulative distribution function of θ, and its corresponding inverse, parametrically as a parsimonious function of two parameters, the mean annual mileage μ_j and the standard deviation σ_j, for which we have prior information by several principle characteristics of the models, such as horsepower and weight. Given our parametric approach, it is important to examine the robustness of our results with respect to various alternative distribution functions. We consider three different functional forms: the double exponential (which resembles the bell shape of the normal distribution), a two-parameter exponential (which is a skewed distribution function) and the uniform. All distributions contain two parameters, which are written in such a way that they obtain the interpretation of mean and standard deviation. More specifically, for these three distribution functions the market share equations $s_{G|j} = F_j(\theta_j^*)$ are given by:

$$\text{Double exponential} \quad : \quad s_{G|j} = \exp\left(-\exp\left(-\left[\theta_j^* - \mu_j\right]\frac{\pi}{\sqrt{6}\sigma_j} - \gamma\right)\right) \tag{8}$$

$$\text{Exponential} \quad : \quad s_{G|j} = 1 - \exp\left(-\frac{\theta_j^* - \mu_j + \sigma_j}{\sigma_j}\right)$$

$$\text{Uniform} \quad : \quad s_{G|j} = \frac{\theta_j^* - \mu_j + \sqrt{3}\sigma_j}{2\sqrt{3}\sigma_j}$$

where $\pi \approx 3.14$ and $\gamma \approx .577$ are constants. It is now straightforward to rearrange these market share equations to obtain a parametric solution for $\theta_j^* = F_j^{-1}(s_{G|j})$, which can then be substituted into our main equation (7).

Now consider Δa_j. Recall that Δa_j captures the difference in the mean intrinsic utility from purchasing j with a diesel engine (a_{jD}) or with a gasoline engine (a_{jG}). Note that variables measuring size and safety are common to the gasoline and diesel variants of a j, so that they do not enter Δa_j. Hence only the performance variables, such as horsepower, displacement, speed and acceleration, enter Δa_j. More precisely, we specify Δa_j as follows:

$$\Delta a_j = \alpha_0 + \alpha_1 \Delta PERF_j + \varepsilon_j, \tag{9}$$

where $\Delta PERF_j$ captures differences in observed performance variables, for example differences in horsepower. The constant α_0 can be interpreted as the mean extra utility from a diesel variant, possibly negative. It captures specific diesel features that are not measured by the performance variables in $\Delta PERF_j$, such as discomfort from noise, unreliability and even durability[12]. Finally, the term ε_j is a mean zero i.i.d. error term. It captures diesel features specific to car j that influence utility, but are unobserved by the econometrician. For example, it is possible that a Renault 19 has a diesel engine with above average reliability, whereas Volkswagen Polo has one below average.

To summarize, substituting the expression of Δa_j, (9), in equation (7), we obtain the following equation to be estimated:

$$F_j^{-1}(s_{G|j})\Delta\pi_j + \Delta\tau_j + \rho\Delta p_j = \alpha_0 + \alpha_1 \Delta PERF_j + \varepsilon_j, \tag{10}$$

[12] In principle, differences in durability between gasoline and diesel models should be captured by allowing for differences in time horizon T. In practice, however, this cannot be identified from the constant term α_0.

where $F_j^{-1}(s_{G|j})$ can be computed from the distribution functions given by (8). The parameters to be estimated in this model are α_0, α_1 and ρ. From our estimate of ρ one can compute the implicit interest rate r using (3).

3.3 Identification and estimation

It is useful to compare our econometric model to a hedonic regression, which is the common approach to estimate implicit interest rates from aggregate data, see e.g. Dreyfus and Viscusi (1995). We presented implicit interest rate estimates using such an approach in the previous section, based on specification (1), relating price differences between gasoline and diesel cars to differences in annual operating costs, controlling for differences in characteristics. After dividing the hedonic equation (1) by β_2, and slightly rearranging, one can verify the apparent similarity to the derived structural equation (10). Our parameter ρ is thus comparable to the inverse of β_2 in the hedonic specification. The essential difference between both equations is the replacement of the term $\mu_j \Delta\pi_j$, measuring differences in average annual fuel expenditures, with the term $F_j^{-1}(s_{G|j})\Delta\pi_j$, which can be interpreted as measuring differences in threshold annual fuel expenditures, since the latter is the product of our "threshold mileage term" and fuel costs per mile. Crucially, the threshold fuel expenditure term, $F_j^{-1}(s_{G|j})\Delta\pi_j$, depends on consumer behavior, as reflected by the market share variable $s_{G|j}$, in contrast to the average fuel expenditure term $\mu_j \Delta\pi_j$ from hedonic regressions. Our aggregate specification derived from an individual choice model thus replaces the somewhat arbitrary average fuel expenditure term by a threshold fuel expenditure term, which depends on the market share variable $s_{G|j}$. Put somewhat differently, by moving $\rho\Delta p_j$ to the right-hand side, we may interpret (10) as a demand function, the dependent variable being a simple monotone transformation of the market share variable $s_{G|j}$. As the price surcharge for a diesel variant of j, Δp_j, increases, the demand for the diesel variant of j will fall in favor of the gasoline variant.[13] The larger ρ, the more myopic consumers are, and the more sensitive they are to changes in initial purchase price.

To estimate the parameters in our demand equation (10) consistently, in particular ρ, it is important to recognize that Δp_j is an endogenous variable, determined by the pricing strategy of the car manufacturers. Consequently, Δp_j may be correlated to the error term ε_j, which reflects the unobserved (to the econometrician) diesel features of car j. To understand this correlation intuitively, consider a car model j with a particularly high ε_j, say due to below-average discomfort from diesel noise and above-average diesel reliability. On the one hand, given these features, the manufacturer will find it profitable to charge a relatively high extra price for

[13] To verify this, bear in mind that $\Delta\pi_j < 0$.

this diesel variant, hence the positive correlation between Δp_j and ε_j. On the other hand, one may expect a high market share for such a good diesel variant, despite the relatively high extra price. In sum, when the diesel variant of make j is particularly good (a high ε_j), a large diesel price and a large diesel market share may coincide. Vice versa, a low diesel price and a low diesel market share may occur when ε_j is small (below zero). As a result, a simple ordinary least squares (OLS) estimator will yield inconsistent demand parameter estimates; in particular our main parameter of interest, ρ, will be biased towards zero and may even be negative. To the extent that the manufacturer follows a profit-maximizing rather than a fully random pricing strategy, the price endogeneity problem will be of a real concern and an instrumental variable estimator should be used.

What instruments can be used? In traditional demand estimation problems, one may borrow exogenous variables from the supply side as instruments. In models of product differentiation, the choice of suitable instruments is more difficult. The variables that are commonly assumed exogenous are the non-price characteristics of the goods, such as performance, fuel efficiency or taxes.[14] These variables, however, may influence both the demand and supply (cost). Berry (1994) and Berry, Levinsohn and Pakes (1995) discuss this problem and provide a solution suitable for their application. In our framework, the restrictions that are implicit in specification (10) provide an answer to the choice of instruments. In particular, the variables $\Delta\pi_j$ and $\Delta\tau_j$ do not interact with any parameter to be estimated. We may thus use these variables as instruments for Δp_j. Using $\Delta PERF_j$, $\Delta\pi_j$ and $\Delta\tau_j$, we have one more instrument than the number of parameters to be estimated. Our specific instrumental variable method used to estimate (10), is Hansen's (1982) generalized method of moments (GMM) estimator, with heteroskedasticity-consistent standard errors.

4 The empirical results

The empirical results from estimating model (10), using the data set described in section 2, are presented in Table 4. The estimates are based on the bell-shaped double exponential distribution function for mileage, i.e. the first row in (8). The robustness of the results with respect to the other two distribution functions will be discussed afterwards. We present results from both an ordinary least squares estimator and our instrumental variable (GMM) estimator, which allows the price variable Δp_j to be endogenous.

[14] The usual justification for this assumption is that these characteristics are variables that can only be slowly adjusted, so that they may be viewed as predetermined at the pricing stage.

For all regressions, we need to specify which technical characteristics enter in $\Delta PERF_j$. As discussed in more detail in section 2, we have collected data on the following performance variables, which may differ between the gasoline and diesel variants: horsepower, displacement, weight, speed and acceleration. We experimented with several alternative specifications. Table 4 presents results for two combinations of variables: one specification including horsepower, displacement and weight; and another in which horsepower and displacement are replaced by speed and acceleration. The estimates for our main parameter of interest, ρ, and the corresponding implicit interest rate, r, were robust with respect to various alternative specifications.[15]

We impose some further structure on the error term ε_j through fixed effects. Since our sample covers three markets (Belgium, France and Italy) during the period 1991-1994, we include the appropriate market and time dummies to capture unobserved differences in consumer valuations across markets and time (the reference market is Belgium; the reference period is 1991). Similarly, we include source dummies to capture unobserved differences in valuations across country of origin. Cars may originate from France, Germany, Italy or "other countries" (Japan, Spain or the United Kingdom).

A Hausman-Wu exogeneity test statistic has been computed to compare the OLS and GMM estimates, for both specifications of the characteristics. This chi-squared distributed test-statistic looks at the difference between the least squares and instrumental variables estimates, standardizing by the difference in the covariance matrices of the two sets of estimates. Under the null hypothesis of exogeneity, the least squares estimator would be more efficient. However, as shown by the large test-statistics on the bottom of the OLS columns, we reject the hypothesis of exogeneity. This confirms our intuition of the previous section that price is an endogenous variable, correlated to the error term due to the pricing practices of the manufacturers. We therefore concentrate our discussion on the GMM results. Nevertheless, it will be instructive to return to a comparison between the OLS and GMM results afterwards.

In both specifications, the coefficients of the characteristics have the expected sign. Extra weight on diesel models, which according to consumer reports partly follows from a better insulation against diesel noise, is valued positively by consumers. Similarly, in the first specification, horsepower and displacement positively

[15] For example, we considered a specification with the horsepower/weight ratio and displacement as characteristics. We also considered specifications in which horsepower, displacement, weight, speed and acceleration all enter together. Due to (common) multicollinearity the parameters of some of the technical characteristics have the unexpected sign, without affecting the results on the estimate of ρ, our parameter of main interest.

and signi¯cantly a®ect consumer valuations. In the second speci¯cation, maximum speed positively in°uences consumer valuations, whereas acceleration time (time to reach 100 km/hour) has a negative impact. The constant term (units expressed in dollar) is estimated signi¯cantly negative in both speci¯cations. This implies that consumers tend to place a negative value on a diesel variant after controlling for observed di®erences between gasoline and diesel. This may follow from unobserved discomfort from the slower diesel start, noise or lower reliability under cold temperatures. This perceived discomfort seems especially important in France (negative ¯xed e®ect) and less important in Italy (positive ¯xed e®ect). The positive time e®ects (though often insigni¯cant) suggest that the diesel discomfort became less important after 1991, consistent with conventional wisdom (more widespread use of the turbo, and direct injection which essentially eliminates most diesel disadvantages). Country of origin seems to matter only for Italian cars: consumers value the diesel version of an Italian car about 80$ higher than its gasoline twin brother.

We can now come to a discussion of our estimates of ½, from which the implicit interest rate r can be computed. We estimate ½ = 0:146 and ½ = 0:126 for our ¯rst and second speci¯cation, respectively, with corresponding standard errors of 0:019 and 0:018. First of all, notice that these estimates are much larger than the estimates of ½ obtained using ordinary least squares (precisely estimated around 0:02 and 0:01, respectively). This is intuitive. Our Hausman tests rejected the hypothesis of exogenous prices, so that ordinary least squares will be inconsistent. In the previous section, it was argued that the bias of ½ would be downwards under a positive correlation between price and the error term. The \cost" of using instruments is a reduced e±ciency, as evidenced by the larger standard errors for our estimated coe±cients. Nevertheless, our standard errors our still relatively low, indicating that our instruments for the price variable (the fuel and car tax variables) perform well.

The estimates of the implicit interest rate r corresponding to our estimates of ½ can be easily computed, using (3). Table 5 provides these estimates for both speci¯cations of characteristics. As a further check for the robustness of our results, Table 5 also provides estimates of r based on the other distribution functions of mileage referred to in (8), the exponential and uniform.[16] For example, our point estimate of r under the double exponential distribution with the variables horsepower and displacement included, is equal to 11:8 percent with a 95 percentage con¯dence interval of [7:88; 15:80]. More generally speaking, the point estimates for the implicit interest rates range between 5 and 13 percent, depending on the

[16] The estimates of the parameters using the exponentional and uniform distribution do not di®er by much from the estimates of the double exponential presented in Table 4. Since they yield no interesting new insights, they are not reported.

adopted specification. The lowest estimates were obtained under the assumption that annual mileage is distributed exponentially across consumers. Yet given the magnitude of the standard errors, it seems fair to conclude that the implicit interest rate estimates are essentially robust with respect to the choice of functional form for mileage distribution.[17]

Under all specifications for the distribution of mileage, we obtain estimates of r that are substantially below the reported estimates of 23.5 and 55.7 percent in the hedonic regressions. Why is it that we now obtain interest rate estimates that are so much lower than in the hedonic model? To see this, recall that our structural model incorporates the market share variable measuring the relative popularity of the gasoline and diesel variants. This relative popularity varies a lot from model to model (see Table 1). What our estimates tell us, is that this variability can be explained quite well by price and operating cost differences between the diesel and gasoline variants. Other things equal, those diesel cars that offer a better financial deal are also considerably more popular. If consumers did not respond well to such financial deals, a higher estimate of the interest rate would have resulted. Clearly, such consumer responses cannot be captured appropriately in an aggregate model without market share data, as in the hedonic regressions of section 2, or in Dreyfus and Viscusi's (1995) hedonic study. Similarly, Gately's (1980) study of refrigerators does not take into account market share data. He compares three pairs of refrigerators, each pair coming in an energy-efficient and an energy-inefficient variant. Based on a high ratio of energy-savings to initial purchasing premium, he computes extremely high returns from purchasing the energy-efficient variants, for all three types of refrigerators (varying between 45 and 300 percent). His estimates do not, however, take into account a possible strong popularity of the energy-efficient variants. If, in an extreme example, one would observe that the energy-inefficient models have a zero market share, one cannot draw any conclusions about implicit interest rates from the computed returns.

As discussed in the introduction, economic theory predicts that consumers should discount their future gains or losses at the market interest rate i. To which extent do our estimates of the consumers' implicit interest rate r, summarized in Table 5, coincide with the market interest rate i? Of course, there is no single market interest rate, so one should consider some alternative measures. The three-month interbank

[17] Recall that our specification is based on the assumption that consumers have inelastic fuel demand. The exposition and functional forms become very tedious when elastic demand is allowed for. We nevertheless experimented with an elastic demand specification, assuming consumers have a uniform distribution across types. In this example, pinning down the elasticity to -0.2, we obtained an implicit interest rate estimate of 13 percent, compared to the 12 percent estimate for the corresponding inelastic demand case. Details on the derivation of the functional forms and the estimates are available on request.

interest rate roughly varied between 6 and 9 percent in the three countries during our sample period. The long term government bond interest rate (over 5 years) varied between 7:5 and 10 percent. We also obtained information about interest rates in Belgium on installment loans speci¯cally for purchasing cars (value of loan of 400; 000 BF, i.e. about 10; 000$; ¯xed monthly payments during 48 months).[18] The \best-buy" interest rates for these loans varied between 9:03 and 11:71 percent during 1992-1994. These market rates generally fall within the 95 percent con¯-dence intervals for our implicit interest estimates implied by Table 5. Looking at our point estimates in Table 5, it seems safe to conclude that our estimated implicit interest rates only slightly and not signi¯cantly exceed the above measures of the market interest rate. This result is in stark contrast with most previous studies, which report much higher estimates than the market rates, usually well above 20 or even 30 percent.

5 Discussion of the results

We have analyzed the consumer's investment problem to buy a gasoline or a diesel car { a trade-o® between a higher initial purchase price and future annual savings in operating costs. Our empirical results indicate that consumers roughly behave according to the predictions of intertemporal choice theory. Our estimated implicit interest rates vary between 5 and 13 percent, slightly but not substantially above the market interest rate. Our estimates may have implications for the debate in environmental economics about the relative e®ectiveness of fuel tax policies and fuel e±ciency standards. We leave this as an interesting topic for further research. In the remaining part of this section, we concentrate our discussion on an interpretation of our estimates. The puzzle to be explained is not another rejection of traditional economic theory. The question is rather why we obtain implicit interest rate estimates so much lower than other studies on consumer durables purchasing decisions.

In the previous section we compared our results with those of other studies that use aggregate data, e.g. Gately (1979), Dreyfus and Viscusi (1995), and our results of section 2. We pointed out that our lower interest rate estimates may follow from our improved methodology, which explicitly takes into account consumer behavior through market share data in the aggregate model. While this may account for part of the results, it leaves unexplained the high interest rate estimates obtained in household-level consumption studies, which, of course, also explicitly incorporate consumer behavior. Hausman (1979) studied individual purchasing behavior for air-

[18] This historical information was kindly provided by the Belgian consumer organization Test-Aankoop.

conditioners, in which consumers face the choice between various brands which differ in energy-efficiency. He obtains implicit interest rate estimates of on average 25 percent. In a micro-study on space and water heating choice, Dubin and McFadden (1984) obtain an estimate of about 20 percent.

A first explanation for our lower implicit interest rates, close to capital market rates, may be the presence of some specific structural features in the automobile market. Loewenstein and Thaler (1989) report experimental evidence that individual interest rates tend be lower when the time to be waited increases, when the size of the award rises, and when it concerns a loss rather than a gain (debt aversion). However, it seems that cars and other durables goods, such as airconditioners, do not significantly differ in these dimensions. Lower liquidity constraints and better consumer information may be a more plausible explanation for our lower estimates. First, there is a well-established capital market for financing automobile purchases. Automobiles can be financed through specifically designed installment loans or leasing contracts. Car manufacturers generally also offer special financing options. Although it is also possible to finance the purchase of other durable goods on the capital market, this needs to be done through the general-purpose personal loans; these are typically more expensive, by about 3 percent in Belgium during our sample period. Second, consumers receive quite detailed information regarding their "investment opportunities" in the car market. Specialized car magazines regularly publish tables with the cost per mile for very large samples of cars. A Belgian consumer report computed the critical mileages for about one hundred different cars, at which it would become profitable to purchase the diesel version.[19] Furthermore, consumer awareness about fuel costs may be particularly strong, compared to energy costs for household appliances. Consumer incur fuel costs at the gas station several times per month. Electricity and other energy costs for household appliances are incurred much less frequently and, perhaps more importantly, enter a general energy bill.

A final explanation for our low implicit interest rate estimates, compared to other studies, is the simple consumer choice problem we have focused on. Our approach considers the problem of selecting a gasoline or a diesel variant, conditional upon choosing a particular model. This is a relatively clean investment problem, unclouded by product differentiation aspects of choosing one car out of all possible models.[20] The other (household-level) studies on consumer durables infer implicit

[19] Test-Aankoop Magazine nr. 373, January 1995. Incidently, to compute these critical mileages, the study adopted a zero interest rate.

[20] Formally, this is because the model-specific term γ_j in an individual's utility, which captures the individual-specific valuation for car j, is irrelevant when comparing a gasoline and diesel variant of the same model.

interest rates from the more complicated individual choice problem of deciding upon the most preferred brand across a large set of brands. This problem contains a mixture of both intertemporal aspects of investment (future energy savings) and a-temporal aspects of product di®erentiation.

Part II. Manufacturer Price Discrimination

1 Introduction

Price discrimination based on willingness to pay for quality has been studied extensively in the theoretical literature. Mussa and Rosen (1978) show how a monopolist can extract higher pro¯t margins from consumers with a higher willingness to pay for quality by o®ering a wide product line of price-quality combinations. When several ¯rms compete, the feasibility and the nature of quality-based price discrimination is less well understood. It depends on the precise pattern of competitive interaction, and no general results are available.[21] At the same time, e®orts to quantify the empirical importance of price discriminating practices have been limited. The problem is, of course, that observed price di®erentials between high and low quality variants may stem from either cost or markup di®erences.

In the European car market a unique opportunity is available to empirically analyze quality-based price discrimination. In most European countries, cars are sold under two types of engine: the gasoline and the diesel engine. The diesel engine has a higher \quality" in the sense that it consumes less fuel per mile and also requires less expensive fuel due to a favorable tax treatment. Consumers di®er in their willingnes to pay for this quality aspect since they are heterogeneous in their annual mileage. As a result, manufacturers may consider a price discriminating strategy by charging di®erent pro¯t markups on the gasoline and the diesel variants.

Part II of this paper develops an econometric model of pricing to decompose the observed price di®erentials into cost and markup components. The model is estimated under alternative types of conduct. The empirical results demonstrate that the price di®erentials are best explained by price discrimination of a monopolistic type. On average, about 70 to 85 percent of the price premium to be paid for diesel makes can be attributed to price discrimination; the remaining part follows from higher costs due to di®erences in speci¯cations. These results are not just interesting in that they empirically demonstrate the feasibility and importance of quality-based price discrimination in the presence of competition. The results also have important implications for fuel tax and car tax policy. More speci¯cally, the analysis implies that an increase in the diesel fuel tax is only half as e®ective in lowering diesel car demand, when price discrimination and the implied tax incidence is

[21] See, for example, the speci¯c assumptions on brand preferences used in Katz (1984) to model product di®erentiation and competitive interaction. Gilbert and Matutes (1993) use a di®erent model of brand preferences, and ¯nd, surprisingly, that competition eliminates the feasibility of quality-based price discrimination. The theoretical di±culties in analyzing quality-based price discrimination with competing ¯rms are generally present in screening models of second-degree price discrimination.

properly taken into account.

As noted above, there exists very little econometric evidence on quality-based price discrimination. To the best of my knowledge, Shepard (1991) is the only exception. Essentially, she exploits a natural experiment in which ¯rms di®er in their ability to price discriminate, but presumably not in their cost of production. Observed di®erences between ¯rms in price di®erentials may then be attributed to markups, i.e. price discrimination.[22] In contrast, I have no direct information on costs at my disposal. Rather, I infer the presence of price discrimination from the structural model of conduct that best ¯ts the data.

There have been only a few empirical papers on tax incidence related to market power. One example is Barnett, Keeler and Hu (1995) on the tobacco industry. Fershtman, Gandal and Markovich (1998) estimate an oligopoly model for the Israeli car market, and then simulate the e®ects of taxes. Their simulation results are quite promising in assisting tax policy analysis. However, they do not empirically establish that ¯rms indeed do take into account taxes in their pricing strategies; this is largely driven the assumptions of their model (i.e. Bertrand behavior). My paper is distinct in that it explicitly tests whether ¯rms take taxes into account by comparing alternative models of pricing behavior.[23] Furthermore, whereas the other papers consider the e®ects of taxes within the same industry, my paper provides strong evidence on tax incidence in a complementary good market, which relates to the presence of quality-based price discrimination.[24] This stresses the empirical relevance in taxation analysis for adopting a \general equilibrium perspective", by properly taking into account what may happen in related sectors.

Research on pricing in the automobile market has received considerable attention in recent years. Most contributions ignore the issue of quality-based price discrimination by limiting attention to base model cars. The focus is instead on the nature of competition between di®erent car models, see the contributions by Bresnahan (1981), Berry, Levinsohn and Pakes (1995), and Goldberg (1995). Regarding the European car market, Verboven (1996) and Goldberg and Verboven (1998) have provided evidence of international price discrimination. This is price

[22] In particular, Shepard (1991) considers price di®erentials between full-service and self-service at gasoline stations. She compares these di®erentials between stations o®ering both types and stations o®ering only one type of service. Assuming that there is no di®erence in the cost of o®ering these services combined rather than separately, one may attribute higher price di®erentials at multi-service stations to price discrimination.

[23] In our application, this approach is feasible since the large variation of taxes across car makes provides us with a natural experiment, in contrast to Fershtman et al. (1998) where taxes are the same percentage for most models (with a di®erence only between cars subject or not subject to customs duties).

[24] See Myles (1987), for a theoretical paper on tax incidence in complementary goods markets.

discrimination of the third degree, and is achieved by manufacturers' strategies to prevent cross-border consumer (or parallel importer) trade. The present paper may be seen as reinforcing the evidence that ¯rms in a seemingly competitive market succeed in price discrimination, also of the second degree type.

The next section describes tax and price policies on gasoline and diesel cars in three European countries: Belgium, France and Italy. Section 3 introduces the econometric model. Note that the demand side of the model is taken from the ¯rst part of this paper, where it was used to estimate the interest rates that are implicit in the consumers' decision to purchase a gasoline or a diesel car. Section 4 presents the empirical results. Section 5 concludes.

2 Tax and price policies on gasoline and diesel cars

The technical di®erences between gasoline and diesel cars, and the implied differences in performance and comfort, have been discussed in detail in Part I, Section 2 of this paper. Recall that Table I summarized some of these di®erences, and also served to introduce the dataset on sales, list prices, taxes and technical characteristics of 41 pairs of automobile models in three European countries (Belgium, France and Italy) during 1991-1994. The choice of these countries was based on their long tradition with both gasoline and diesel cars, and on data availability; an interesting property is that the three countries experienced quite di®erent tax policies towards both types of cars.

It is hard to underestimate the importance of taxes on automobiles in Europe. In France and Belgium, automobile-related tax revenues respectively amounted to about 800 and 1000 dollars per capita in 1997.[25] In other European countries, similar amounts apply. The most important taxes are value added taxes on the purchase of a (new or second-hand) car, annual car taxes, and excise taxes on fuel. Interestingly, the annual car taxes and the fuel taxes have been designed to follow a discriminatory policy towards gasoline and diesel cars. Furthermore, di®erent countries typically adopted di®erent policies. Table 2 illustrates this for the countries of our data set. The ¯rst three rows present the average annual fuel costs, i.e. price per liter times liters per mile times annual mileage for the average driver. These fuel costs consist for about 70% of excise taxes. In all three countries, the average person driving a gasoline car spends about 1100 dollars per year on fuel. About 400 dollars per year can be saved from driving a diesel car; in France, the average savings are even 500 dollars per year. The next three rows on Table 2 present the annual car taxes, which are based on the ¯scal horsepower assigned to a car. In France, the annual car taxes also favor diesel cars. In Belgium and

[25] These numbers are from CCFA and FEBIAC, the French and Belgian automobile associations.

especially in Italy, the annual car taxes on diesel cars are higher than on gasoline cars. In Italy, the higher annual purchase taxes even outweigh the savings in fuel costs from driving a diesel, at least for the average driver.

The policy reasons behind the di®erential tax treatment towards gasoline and diesel cars are not obvious. From an environmental perspective, the favorable diesel tax treatment does not seem justi¯ed. As discussed in Michaelis (1995), the diesel engine emits less carbon monoxide than the (unleaded) gasoline engine, roughly the same volatile organic compounds, and more NO_x. In addition, it emits airborne particulates unlike the gasoline engine. According to the OECD (1993, p. 210), the favorable tax treatment on the diesel fuel \is intended to avoid disabling freight transport, but governments also see some value in the introduction of diesel cars". For example, the OECD attributes the particularly favorable attitude towards diesel cars in France to the strength of French manufacturers in exporting diesel cars and supplying engines to other manufacturers; it also re°ects a more general concern in French energy policy to minimize oil dependence (since diesel cars consume less).

Whatever the motives behind the discriminatory tax policies, the average price data in rows 7-9 of Table 2 suggest that manufacturers have taken them into account in their pricing strategies. In all three countries, diesel cars are more expensive than gasoline cars.[26] The question is, of course, whether these higher prices are caused by higher (marginal) costs or by higher markups. This question will be adressed in the sections below. At this point, observe that the price premium for diesel cars is much higher in France than in Belgium and in Italy. Given the most favorable tax treatment for diesel cars in France, this indicates that price di®erentials between gasoline and diesel cars are at least partly markup driven.

The ¯nal three rows of Table 2 report the \dieselization rate", i.e. the percentage of diesel cars in the total car sales. Generally speaking, the countries' dieselization rates seem to re°ect the local tax policy. In Belgium and especially in France, where diesel cars have a favorable tax treatment, the dieselization rate is high. In Italy, where diesel cars do not yield savings in operating costs, at least to the average driver, the dieselization rate only reaches 15 percent. Tax policies thus seem responsible for di®erences in dieselization rate, despite our observation made above that car manufacturers seem to be charging a higher diesel surcharge in the countries that adopt a more favorable tax regime towards diesel cars.

The above discussion gives some ¯rst intuition on how tax policies may in°uence both manufacturer pricing behavior and consumer demand. This intuition is now formalized in an econometric model to explain price di®erentials, and decompose them into marginal cost and markup di®erences.

[26] This remain true after adjusting for di®erences in observed quality. This was veri¯ed in a hedonic regression from which quality-adjusted price di®erences may be computed.

3 The econometric model

3.1 Consumer Demand

Consumers choose to purchase one particular car make j coming with one of two engine variants k, where $k = G; D$ refers to the gasoline or the diesel engine. Part I, Section 3.1, formulated a discrete choice model of car purchasing decisions. The market share of the gasoline variant in the total sales of each car make, $s_{G|j}$, was derived in (6), where θ_j^* was defined by (5). We refer to that section for further details.

3.2 Pricing

For each make j, firms set the prices of the gasoline and the diesel variants, p_{jG} and p_{jD}, to maximize profits. Assume for simplicity that firms do not take into account the effects of their price decisions on the sales and profits from other makes owned by the firm (single product profit maximization). Denote the (constant) marginal cost of make j with engine k by c_{jk}, and the fixed costs by FC_j. The maximization problem, for each make j, is then:

$$\max_{p_{jG},p_{jD}} (p_{jG} - c_{jG}) s_{jG} M + (p_{jD} - c_{jD}) s_{jD} M - FC_j$$

where s_{jk} is the market share of make j with an engine k, dependent on the prices of all possible makes/variants, and M is the total number of consumers considering to purchase a car. It will be convenient to write s_{jG} as the market share of variant G in the total sales of j, multiplied by the total market share of j, i.e. $s_{jG} = s_{G|j} s_j$. Similarly, $s_{jD} = (1 - s_{G|j}) s_j$. One can then write the first-order conditions with respect to p_{jG} and p_{jD} as:

$$\begin{aligned} (p_{jG} - c_{jG} - p_{jD} + c_{jD}) \frac{\partial s_{G|j}}{\partial p_{jG}} s_j + \lambda_j \frac{\partial s_j}{\partial p_{jG}} + s_{G|j} s_j &= 0 \qquad (11) \\ (p_{jG} - c_{jG} - p_{jD} + c_{jD}) \frac{\partial s_{G|j}}{\partial p_{jD}} s_j + \lambda_j \frac{\partial s_j}{\partial p_{jD}} + (1 - s_{G|j}) s_j &= 0; \end{aligned}$$

where λ_j is defined as:

$$\lambda_j \equiv (p_{jG} - c_{jG}) s_{jG} + (p_{jD} - c_{jD}) s_{jD}.$$

There are as many pairs of first-order conditions as there are car makes. Taken together, these first-order conditions constitute a Nash equilibrium, which we simply assume here to exist.

We seek to obtain an econometric framework for explaining price differentials between gasoline and diesel models; we are not interested in a full solution to the equilibrium. For this reason, we now simplify the above first-order conditions to focus on price differentials. Add up both first-order conditions (11); use (6) to compute that $\partial s_{G|j}/\partial p_{jG} = \rho f_j(\theta_j^*)/\Delta\pi_j = -\partial s_{G|j}/\partial p_{jD}$; and rearrange further to obtain the following expression, which decomposes the price difference between a diesel and gasoline variant $\Delta p_j \equiv p_{jD} - p_{jG}$ into a marginal cost difference $\Delta c_j \equiv c_{jD} - c_{jG}$ and a markup difference:

$$\Delta p_j = \Delta c_j + \frac{\alpha_j - s_{G|j}}{\rho f_j(\theta_j^*)}(-\Delta\pi_j). \tag{12}$$

The term α_j, defined as

$$\alpha_j \equiv \frac{\partial s_j/\partial p_{jG}}{\partial s_j/\partial p_{jG} + \partial s_j/\partial p_{jD}}, \tag{13}$$

measures the effect on make j's total market share when only the price of variant G of j increases, relative to the effect on j's total market share when the prices of both variants of j change. Intuitively, α_j measures the relative importance of p_{jG} versus p_{jD} in influencing the total sales or market share of j. Generally speaking, this term is difficult to compute since it depends on the precise nature of competitive interaction implied by consumer preferences, in particular on the distribution of the individual-specific taste parameter γ_j in (4). I therefore instead compute α_j in a few relatively simple special cases.

First, consider perfect competition. In this case, markups equal zero; any price difference between gasoline and diesel models is purely cost-driven. Next, consider the monopoly case. For example, for each make j one may specify the individual-specific taste parameter γ_j to equal 0 for a fraction μ_j of consumers and -1 for the remaining fraction. Each car make j then has local monopoly power over $\mu_j M$ consumers, who face the problem of choosing a gasoline variant, a diesel variant, or no car at all. In this case, it is easy to verify that $\alpha_j = 1$, yielding an expression for the price difference Δp_j similar to Mussa and Rosen's (1978) monopoly model. Note that it is in fact not necessary to assume "full monopoly pricing". Recall that our equation (12) is only about explaining price differences. Hence, our "monopoly" case only assumes that price differences are set according to a monopoly type models. This does not exclude the possibility that the price levels of, say, base car models are set quite competitively.

Finally, consider a case of "duopoly" competition. Assume that each car make j faces a single relevant competitor k. In the empirical specification, we will assume that this competitor is the "average" competitor in its class. Also, as for example in Anderson et al.'s (1992, p. 34) linear probability model, assume that the random variable $\gamma_k - \gamma_j$ has a uniform distribution on $(-L_j, L_j)$. Intuitively, some consumers have a strong taste and others have a strong distaste for j relative to k. It is shown in the Appendix that under these assumptions $\alpha_j = F(\theta_j^*)$, i.e. the proportion of consumers with an annual mileage less than θ_j^*, unconditional on purchasing model j. To illustrate this, consider firms with identical characteristics in a symmetric equilibrium (assuming it exists). In this case, the conditional and unconditional distributions coincide, $F(\theta_j^*) = F_j(\theta_j^*) = s_{Gjj}$, so that the markup difference in (12) equals zero, as in the case of perfect competition. This is similar to the result obtained by Gilbert and Matutes (1993), in a slightly different symmetric model of brand differentiation.

To summarize, in the empirical analysis we consider the following three alternative equations to explain price differentials between gasoline and diesel cars:

$$
\begin{aligned}
\text{perfect competition} &: \quad \Delta p_j = \Delta c_j \\
\text{“duopoly”} &: \quad \Delta p_j = \Delta c_j + \frac{F(\theta_j^*) - F_j(\theta_j^*)}{\rho f_j(\theta_j^*)}(-\Delta \pi_j) \qquad (14) \\
\text{monopoly} &: \quad \Delta p_j = \Delta c_j + \frac{1 - F_j(\theta_j^*)}{\rho f_j(\theta_j^*)}(-\Delta \pi_j).
\end{aligned}
$$

3.3 Econometric specification

We want to estimate the demand equation (6), jointly with the pricing equation (12), specified by (14) under the alternative assumptions about conduct.

The econometric specification for the demand equation was considered in Part I, Section 3.2 of this paper. It resulted in the transformed market share equation (10). We refer to that section for further details. Since the empirical results in Part I were robust with respect to the three alternative distribution functions for mileage, attention is limited here to a transformed market share equation with an intuitively appealing, bell-shaped double exponential distribution function.

Now consider the pricing equation (12). The term $f_j(\theta_j^*)$ can be easily computed using (8). Finally, we specify Δc_j as follows:

$$\Delta c_j = \gamma_0 + \gamma_1 \Delta PERF_j + \eta_j; \qquad (15)$$

which is analogous to the specification of Δa_j. Intuitively, the same characteristics that influence the differences in the mean consumer utility from buying a diesel rather than a gasoline car, may also influence differences in marginal costs.

To summarize, repeating the transformed market share equation (10) derived in Part I, and substituting the expression for Δc_j, (15), in (12), we obtain the following two equations to be estimated:

$$
\begin{aligned}
F_j^{-1}(s_{Gjj})\Delta \pi_j + \Delta \tau_j + \rho \Delta p_j &= \alpha_0 + \alpha_1 \Delta PERF_j + \varepsilon_j \qquad (16) \\
\Delta p_j - \frac{\alpha_j - s_{Gjj}}{\rho f_j(\theta_j^*)}(-\Delta \pi_j) &= \gamma_0 + \gamma_1 \Delta PERF_j + \eta_j;
\end{aligned}
$$

where $F_j^{-1}(s_{Gjj})$ and $f_j(\theta_j^*)$ can be computed from the double exponential distribution function given by (8), and where α_j takes the value of s_{Gjj}, $F(\theta_j^*)$ and 1 in the cases of perfect competition, duopoly or monopoly, respectively.

3.4 Identification and estimation

The econometric model (16) is a system of two equations, in which s_{Gjj} and Δp_j are endogenous variables, simultaneously determined by consumer demand and manufacturer pricing. As a result, one may expect these variables to be correlated to the error terms ε_j and η_j, which capture unobserved diesel features of model j, influencing utility and marginal cost. Consequently, instrumental variables should be used to obtain consistent estimates.

Furthermore, the parameter ρ appears in both equations, and it seems plausible that the error terms ε_j and η_j are correlated. Therefore, to obtain efficient estimates it is important to estimate the demand and pricing equations jointly. More specifically, we adopt Hansen's (1982) generalized method of moments (GMM) for estimating a simultaneous system of nonlinear equations with possibly correlated error terms.

It remains to specify the set of instruments, which constitute the orthogonality conditions of the GMM estimator. Intuitively, the instruments should be exogenous variables, uncorrelated to the error terms. Our main identification assumption is that the nonprice characteristics of the cars, such as performance, fuel efficiency or taxes, qualify as such variables. This is a common assumption made in the empirical literature on oligopoly models with product differentiation. The usual justification for this assumption is that these are variables that can only be slowly adjusted, so that they may be viewed as predetermined at the pricing stage. The typical difficulty in adopting this approach is that these variables may enter both the demand and supply (cost) side, so that there may not be a sufficient number of instruments for the number of parameters to be estimated. Berry (1994) and Berry, Levinsohn and Pakes (1995) discuss this problem and propose to use (functions of) the characteristics of the competitors as additional instruments. In our application, the restrictions that are implicit in specification (16) provide another answer to the suitable choice of instruments. In particular, the variables $\Delta\pi_j$ and $\Delta\tau_j$ do not interact with any parameter to be estimated. We may thus use these variables as instruments for Δp_j. The economic intuition behind this is that fuel costs and taxes are monetary variables that influence the consumers' budget constraint, and indirect utility, in the same manner as prices, for which they instrument. In sum, using $\Delta PERF_j$, $\Delta\pi_j$ and $\Delta\tau_j$, we have one more instrument than the number of parameters to be estimated.

4 The empirical results

4.1 The estimates

As described in more detail in Part I, Section 2, our data set contains sales, list prices and technical characteristics of 41 pairs of automobile models in three European countries, Belgium, France and Italy, during 1991-1994. To estimate model (16), under the three alternative assumptions of conduct, we need to specify which technical characteristics enter in ¢PERF$_j$. We have data on the following performance variables, which may di®er between the gasoline and diesel variants: horsepower, displacement, weight, speed and acceleration. We experimented with several alternative speci¯cations. The empirical results in Tables 6 to 9 are based on a speci¯cation including the variables horsepower, displacement, and weight. The results, in particular the decomposition of price di®erentials into cost and markup di®erences, and the implications for tax incidence, were robust when other characteristics were included. For example, we considered a speci¯cation with the horsepower/weight ratio and displacement as characteristics. We also considered a speci¯cation in which horsepower, displacement, weight, speed and acceleration all enter together.

We impose some further structure on the error terms "$_j$ and ´$_j$ through ¯xed e®ects. We include market dummies for France and Italy to capture possible differences in tastes and costs, relative to the reference country Belgium. We cannot rule out a priori the presence of taste di®erences for gasoline versus diesel cars across markets. Signi¯cant cost di®erences across markets, in contrast, seem rather unlikely. For example, there is no reason to expect a systematically higher cost of selling a diesel car in France than in Belgium or in Italy. Insigni¯cant estimates for the market dummies on the cost side may thus be expected if the econometric model is well speci¯ed. We also include source dummies for French, German or Italian cars to capture taste and cost di®erences across source countries. The reference is \other countries", i.e. Japan, Spain or the United Kingdom.

Using this speci¯cation, the econometric model (16) has been estimated under the three alternative assumptions of conduct: the competitive model, the monopoly model, and duopoly model. The ¯rst question that arises is which of the three models ¯ts the data best. The ¯rst part of Table 6 shows the value of the objective function for the three estimated models. These ¯gures are a ¯rst indication that the monopoly model ¯ts the data better than the two other models of pricing. To statistically distinguish between the alternative models, I have computed nonnested hypothesis test statistics. More speci¯cally, I adopt the instrumental variable version of the P-test procedure proposed by McKinnon, White and Davidson (1983) in the context of instrumental variables. The P-test statistic compares pairs of models and has a t-distribution. Intuitively, if the null hypothesis is true, then its residuals should be uncorrelated with the difference between the fitted values of the null hypothesis and the alternative hypothesis. The three columns in the second part of Table 6 represent the null-hypotheses being tested; the rows represent the alternative hypotheses.

The first column tests the validity of the monopoly model against the duopoly and perfect competition alternatives. The t-statistics are well below the critical value (at a 95% confidence) of 1.96. The data thus tell us that the monopoly model cannot be rejected in favor of either the duopoly of perfect competition model. Furthermore, the second and the third column show that both the duopoly model and the perfect competition model are rejected in favor of the alternative hypotheses.

To gain some further intuition on these results, I have also run three models that artificially nest the three pairs of pricing models. This nesting was obtained by introducing a "conduct" parameter θ through which the markup terms enter as a linear combination. For example, to nest the competition and the monopoly model, I estimated

$$\Delta p_j = \Delta c_j + \theta \frac{1 - F_j(\theta_j^*)}{\rho f_j(\theta_j^*)}(-\Delta \pi_j)$$

jointly with the demand equation. The results from this excercise reveal an interesting pattern, as shown by the third part in Table 6. In case the monopoly model was nested with either the duopoly or the competition model, the estimate of θ is about 0.90, with a standard error of about 0.12. This indicates that pricing is much closer to (and insignificantly different from) monopoly pricing than duopoly or competition pricing. In case the duopoly and competition models were nested, the estimate of θ is 6.9 (and a corresponding standard error of 1.8), which significantly overshoots unity. Intuitively, both the competition and duopoly models fall short in explaining pricing differentials between diesel and gasoline cars.[27] The monopoly model, in contrast, seems to fit the data quite well.

We now turn to a discussion of the parameter estimates. Table 7 presents the estimates for the three alternative models of pricing. We focus on the estimates of the monopoly pricing model, since this was shown to fit the data best. Nevertheless, it will be instructive to compare the estimates to those of the other two (rejected) models. Most parameter estimates of the monopoly pricing model are intuitive. The parameters of the technical characteristics have the expected positive sign and are precisely estimated, for both the demand and the cost side. The coefficient

[27] This explains why the P-tests both rejected the duopoly model in favor of the competitive model, and vice versa. Yet note that the duopoly model seems to fit the data somewhat better than the perfect competition model.

on the price variable is intuitive. In Part I of this paper, it was shown that this coe±cient implies consumer implicit interest rates that are roughly equal to the capital market rates. Most source country coe±cients are insigni¯cant. The only exception is the demand coe±cient for Italian cars.

The constant terms and market ¯xed e®ects in the demand equation are all signi¯cant. Intuitively, Belgian consumers value a diesel cars about 280 dollar less than a gasoline car, after controlling for observed di®erences in characteristics. This may be due to, for example, discomfort from noice or unreliability. This negative valuation is signi¯cantly stronger in France; in Italy, consumers seem to care less about these diesel discomfort per se. The constant term in the cost equation indicates that the diesel on average has a lower marginal cost, after controlling for di®erences in characteristics. These marginal cost di®erences do not di®er across countries, as indicated by the insigni¯cant market ¯xed e®ects.

It is interesting to make a few comparisons with the parameter estimates obtained in the two alternative models of pricing. First, observe that various technical characteristics have unexpected signs or are imprecisely estimated in the alternative (rejected) models. Similarly, the annualization coe±cient ½ becomes quite high in the model of perfect competition; it di®ers signi¯cantly from the estimate that was obtained when the demand side was estimated separately (Table 4). Most interestingly, consider the market ¯xed e®ects in the cost equations. In both the duopoly and competition model, the market e®ect for France is now signi¯cantly positive and large, whereas the market e®ect for Italy is signi¯cantly negative and small, especially compared to the constant term. This follows from the fact that perfect competition model yields zero markup di®erences, and the duopoly model, as we will see, relatively small di®erences. For this reason, price di®erences between gasoline and diesel cars that vary systematically across countries, must (counterintuitvely) be attributed to cost rather than to markup di®erences in these conduct models. Put di®erently, the fact that the market ¯xed e®ects are only insigni¯cant in the monopoly case may be interpreted as further evidence in favor of the monopoly model, if one accepts that di®erences in marginal costs across countries should not di®er signi¯cantly across countries (after controlling for observed characteristics).

4.2 Explaining price di®erentials

Table 8 uses the results from the estimates in Table 7 to decompose the observed price di®erences between gasoline and diesel cars into cost and markup di®erences. In particular, for each make j, I computed the fraction of the price di®erence that is explained by a di®erence in markup, using the results from the preferred monopoly model. The ¯rst two columns of Table 8 presents the average fraction across makes and the standard deviation over the sample. Since markups are a function of the parameter estimates, the fractions are themselves estimates. To have an idea of the precision of this estimate, the third and fourth column show the estimated fraction for a representive make (i.e. with average characteristics) and its corresponding standard error. To compute the standard error, note that the estimated fraction is a nonlinear function of random variables (the parameters). An approximation is obtained by ¯rst linearizing this function around the parameter estimates, and then applying the standard formula for computing the standard error of linear transformations of random variables.

The ¯rst part of Table 8 considers all car makes in the sample. On average, the monopoly model attributes about 81 percent of price di®erences to markup di®erences. The standard deviation is relatively large, 41 percent, which shows that for speci¯c cars the estimated fraction may be much lower or higher. The fraction for a representative make (with average characteristics) is estimated fairly precisely at 56 percent. It is useful to compare these results with the { rejected { duopoly and competition models. In the competition model, of course, all price di®erences are cost-driven, so that the fraction is zero. In the duopoly model, it turns out that the markups also do not explain any of the observed price di®erences. On average, the explained fraction is slightly negative, 6 percent with a standard deviation of 20 percent. The relatively large standard deviation shows that both positive and negative extra markups for diesel cars are common, as predicted by the duopoly model.

The second part of Table 8 splits up the samples by country. This yields some interesting further insights. Markup di®erences especially contribute to price differences in France, and less so in Belgium and in Italy. This is consistent with the estimates in Table 7, which showed that cost di®erences between diesel and gasoline cars do not di®er signi¯cantly across markets. Since there exist large di®erences in the diesel price premium to be paid across countries, with the highest diesel premium in France (Table 2), it is natural that these follow from markup di®erences when cost di®erences are insigni¯cant.

The reason why markup di®erences between gasoline and diesel cars are di®erent across the three countries is related to the quite di®erent tax conditions that apply in these countries, as discussed in more detail in Section 2 based on Table 2. France is the country with the most favorable treatment of diesel cars, both in terms of fuel taxes and annual car taxes. As a result, manufacturers have the greatest incentive to charge high markups on diesel cars in France.

4.3 Implications for tax incidence

Further intuition on how consumers and manufacturers behave in response to taxes is obtained from computing various elasticities of demand with respect to tax changes. We are interested in the effects of both changes in fuel taxes and changes in annual car taxes on the market share of gasoline cars in the total sales of a make j. There are several ways to present these elasticities. For example, one may look at the separate effects of increasing the annual car tax for gasoline and for diesel cars. To summarize this information, we decided to "average" these effects, and focus on the effects of increasing the fuel and car tax differentials. More specifically, we compute the effect on the market share of gasoline cars in the total sales of make j, when the gasoline car tax is increased by 0.5 percent and the diesel car tax is reduced by 0.5 percent; and similarly for the gasoline and diesel fuel taxes. The computed elasticities per make j are:

$$
\begin{aligned}
\varepsilon_j^F &= \frac{1}{2}\frac{ds_{G|j}}{dq_G}\frac{q_G}{s_{G|j}} - \frac{1}{2}\frac{ds_{G|j}}{dq_D}\frac{q_D}{s_{G|j}} \\
\varepsilon_j^C &= \frac{1}{2}\frac{ds_{G|j}}{d\tau_{jG}}\frac{\tau_{jG}}{s_{G|j}} - \frac{1}{2}\frac{ds_{G|j}}{d\tau_{jD}}\frac{\tau_{jD}}{s_{G|j}}.
\end{aligned}
$$

Intuitively, ε_j^F reads as the elasticity of car j's gasoline demand with respect to the fuel tax differential; ε_j^C is the elasticity with respect to the car tax differential.

We computed both partial and full tax elasticities. The partial tax elasticities are those one traditionally obtains from estimating demand equations, i.e. they account for the effects of taxes on demand, holding all other things constant. The full tax elasticities take into account the variables that may simultaneously change in response to the tax change. In our framework, the manufacturers' price strategies may change in response to taxes. As shown, the data favored a specification in which manufacturers set price differentials according to the monopoly model. In other words, the full tax elasticities take into account the possibility of tax incidence. Our estimates in favor of the monopoly model and the implied markup fractions suggest that the presence of tax incidence is important in our application. However, it is not yet clear to which extent tax incidence is more (or less) important for fuel taxes or for car taxes.

Before presenting the estimates, a caveat is in order. Recall that the empirical model assumed that consumers have an inelastic demand for mileage. If an elastic demand would be assumed, our estimated elasticities may change. In this sense, our elasticities are "partial", i.e. they do not take into account changes in driving habits. Nevertheless, given the small estimates for the demand for mileage (conditional upon car purchase) that have been commonly obtained in the literature (ranging between 0 and 0.2), our results would essentially remain robust.

Table 9 presents the estimates. We focus the presentation on the estimated elasticity of a representative car (with average characteristics). The results for other makes are similar. The standard error is computed numerically using the same procedure described above. First, consider the estimated elasticities ignoring tax incidence. Looking at a representative car for the three countries, it can be seen that increasing the fuel tax di®erential has a much larger e®ect on demand than increasing the car tax di®erential (elasticity of -2.63 compared to -.56). The intuition for this is that the annual car taxes are much lower in absolute value than the annual fuel costs, so a percentage increase in car taxes has a smaller e®ect on the consumer's budget constraint than a percentage increase in fuel costs. Notice that Italy has very low fuel and car tax elasticities for its representative car, compared to the other two countries. This follow from the high market share of gasoline cars, caused by the disfavorable diesel tax treatment.

Now consider the estimated elasticities when tax incidence is taken into account. This shows a quite di®erent picture. The car tax and especially the fuel tax elasticity are now much lower than when tax incidence is ignored. Intuitively, manufacturers absorb an important part of an increase in the tax di®erential by lowering their price di®erential. The drop in the elasticities is thus consistent with our earlier ¯nding that markups explain an important part of the price di®erences between gasoline and diesel cars. An interesting new ¯nding also emerges from our estimates: the fuel tax elasticities drop by more than the car tax elasticities when tax incidence is taken into account. This shows that most of the tax incidence is based on the fuel taxes and less so on the car taxes. This is intuitive. Generally speaking, price discrimination exploits the heterogeneity of consumers in their willingness to pay for quality. In the present context, this price discrimination is driven by fuel taxes through which manufactures can discriminate between consumers with di®erent annual mileages. Notice that the drop in tax elasticities is most pronounced for France, the country where price discrimination is most pronounced due to the favorable tax treatment.

These results have implications for tax policy. Note that the U.S. and Europe have followed a quite approach. The U.S. have put most emphasis on direct regulation of the car purchasing decision, e.g. through fuel e±ciency standards (CAFE standard), purchasing mandates for °eet owners, and mandated changes in auto and fuel availability. In Europe, car and fuel taxes have been used more commonly as an instrument to direct the demand towards a speci¯c type of cars. The di®erential gasoline and diesel tax policy is not the only example of this approach. Another example is the substantial tax discrimination between leaded and unleaded gasoline cars to promote the purchase of unleaded cars. In the near future, the introduction of electrical cars may again raise the tax question. At ¯rst sight, the high estimates of the partial elasticities indicate that a tax policy can be a quite e®ective policy instrument. A similar ¯nding was obtained by Borenstein (1993) for U.S. data on leaded and unleaded gasoline cars. However, our results on full elasticities demonstrate that it is important to properly take into account manufacturers' pricing responses when evaluating the e®ects of a change in taxes on demand. In the case of fuel taxes, properly accounting for tax incidence reduces the estimated demand e®ects by more than 50 percent.

5 Conclusion

The existing tax policies towards gasoline and diesel cars in European countries provide a unique opportunity to analyze quality-based price discrimination and the implied tax incidence. We have developed an econometric framework of demand and pricing for gasoline and diesel cars. Consumers make a decision to buy a gasoline or a diesel car based on their annual mileage. Manufacturers set gasoline and diesel car prices with the possible aim of discriminating between consumers with a high willingnes to pay for savings in mileage costs, and those with a low willingness to pay. Our emprical results show that the relative pricing of gasoline and diesel cars is consistent with a monopoly model and inconsistent with competitive models of pricing. On average, about 70 to 85 percent of the price di®erentials between gasoline and diesel cars can be explained by markup di®erences. The implied tax incidence is especially based on fuel taxes and less so on annual car taxes. The results have important implications for measuring the e®ects of increases in the tax di®erentials between gasoline and diesel cars. Accounting for tax incidence, the estimated e®ectiveness of an increase in the fuel tax di®erence drops considerably.

References

Anderson, Simon, Andr¶e de Palma and Jacques-Francois Thisse, 1992, Discrete Choice Theory of Product Di®erentiation, MIT Press, 423 pp.

Barnett, Paul G., Theodore E. Keeler and Teh Wei Hu, 1995, Oligopoly Structure and the Incidence of Cigarette Excise Taxes, Journal of Public Economics, 57(3), pages 457-70.

Berry, Steve, 1994, Estimating discrete-choice models of product di®erentiation, RAND Journal of Economics, 25, 242-262.

Berry, Steve, James Levinsohn and Ariel Pakes, 1995, Automobile Prices in Market Equilibrium, Econometrica, 841-890.

Borenstein, Severin, 1993, Price Incentives for Fuel Switching: Did Price Di®erences Slow the Phase-Out of Leaded Gasoline?, University of California at Davis Working Paper, 93-8, 19p.

Bresnahan, Timothy, 1981, Departures from Marginal-Cost Pricing in the American Automobile Industry: Estimates for 1977-1978, Journal of Econometrics, 17, 201-27.

De Borger, Lieven, 1987, Modelvorming van Personenvervoer, Ministerie van Economische Zaken.

Dreyfus, Mark K. and W. Kip Viscusi, 1995, Rates of time preference and consumer valuations of automobile safety and fuel e±ciency, Journal of Law and Economics, 38, 79-105.

Dubbin, Je®rey A. and Daniel L. McFadden, 1984, An econometric analysis of residential electric appliance holdings and consumption, Econometrica, 52, 345-362.

Fershtman, Chaim, Neil Gandal and Sarit Markovich, 1998, Estimating the E®ect of Tax Reform in Di®erentiated Product Oligopolisitic Markets, mimeo, Tel Aviv University.

Gately, Dermot, 1980, Individual discount rates and the purchase and utilization of energy-using durables: comment, Bell Journal of Economics, 11, 373-374.

Gilbert, Richard, and Carmen Matutes, 1993, Product Line Rivalry with Brand Di®erentiation, Journal of Industrial Economics, 41, 223-40.

Goldberg, Pinelopi Koujianou, 1995, Product Di®erentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry, Econometrica, 63, 891-951.

Goldberg, Pinelopi Koujianou, 1998, The E®ects of the Corporate Average Fuel E±ciency standards in the U.S., Journal of Industrial Economics, 1, 1-33.

Goldberg, Pinelopi Koujianou and Frank Verboven, 1998, The Evolution of Price Dispersion in the European car market, NBER and CEPR working papers.

Hansen, Lars-Peter, 1982, Large Sample Properties of Generalized Method of Moments Estimators, Econometrica, 50, 1029-54.

Hausman, Jerry, 1979, Individual discount rates and the purchase and utilization of energy-using durables, Bell Journal of Economics, 33-52.

Katz, Michael, 1984, Firm-Speci¯c Di®erentiation and Competition among Multiproduct Firms, Journal of Business, 57, S149-S166.

Loewenstein, George and Richard Thaler, 1989, Anomalies { Intertemporal choice, Journal of Economic Perspectives, 3, 181-193.

MacKinnon, James, Halbert WHite and Russell Davidson, 1983, Tests for Model Speci¯cation in the Presence of Alternative Hypotheses: Some Further Results, Journal of Econometrics, 21, 53-70.

Michaelis, Laurie, 1995, The Aabatement of Air Pollution from Motor Vehicles: the Role of Alternative Fuels, Journal of Transport Economics and Policy, 29, 71-84.

Myles, Gareth D, Tax Design in the Presence of Imperfect Competition: An Example, 1987, Journal of Public Economics, 34(3), 367-78.

Mussa, Michael and Sherwin Rosen, 1978, Monopoly and product quality, Journal of Economic Theory, 18, 301-317.

Myles, Gareth, 1987, Tax Design in the Presence of Imperfect Competition: An Example, Journal of Public Economics, 34, 367-78.

OECD, International Energy Agency, 1993, Cars and Climate Change, 236 p.

Shepard, Andrea, 1991, Price Discrimination and Retail Ccon¯guration, Journal of Political Economy, 99, 30-53.

Rosen, Sherwin, 1974, Hedonic prices and implicit markets: product di®erentiation in pure competition, Journal of Political Economy, 82, 34-55.

Verboven, Frank, 1996, International Price Discrimination in the European Car Market, RAND Journal of Economics, 27, 240-68.

Tables

Table1. Summary statistics (406 observations)

	gasoline cars		diesel cars	
	Mean	Std Dev	Mean	Std Dev
horsepower (kW)	65.88	20.94	59.08	17.29
displacement (cc)	1605	323	1963	342
weight (kg)	1061	203	1143	206
speed (km/hour)	177.7	17.9	169.6	16.4
acceleration (sec. to 100 km/hour)	13.24	2.44	15.21	2.50
fuel e±ciency (liter per 100 km)	7.56	1.05	6.05	.76
French origin	0.160	0.367	{	{
German origin[¤]	0.431	0.496	{	{
Italian origin	0.305	0.461	{	{
initial purchase price (in $)	18093	7061	20417	8063
fuel price (in $ per liter)	.931	.109	.712	.086
annual car tax (in $)	173.7	78.7	285.9	236.5
sales	19033	35885	9399	14689

[¤] Includes G.M. (Opel) and Ford cars produced in Germany.

Table 2. Prices and taxes by country

	gasoline cars	diesel cars	di®erence
Average annual fuel costs, including fuel taxes[¤]			
Belgium	1130	739	-391
France	1188	679	-509
Italy	1090	670	-420
Average annual car taxes			
Belgium	218	284	66
France	126	86	-40
Italy	182	675	493
Average initial purchase price			
Belgium	17455	19585	2130
France	18216	20950	2734
Italy	19072	20973	1901
Dieselization rate			
Belgium			0.442
France			0.537
Italy			0.152

[¤]Annual fuel costs are computed for the average driver by model.

Table 3. Estimates of hedonic model (1)

	OLS estimates	
constant	-227.6	210.0
	(71.2)	(158.1)
time92	-6.1	6.6
	(39.4)	(74.1)
time93	-94.9	-136.9
	(40.2)	(77.5)
time94	-100.3	-128.4
	(44.5)	(85.1)
French market	-98.0	-27.4
	(34.8)	(70.5)
Italian market	335.0	299.4
	(41.0)	(78.3)
French origin	-27.2	-102.0
	(59.3)	(109.5)
German origin	87.3	185.2
	(56.0)	(108.5)
Italian origin	56.6	39.0
	(55.2)	(101.3)
horsepower	5.10	
	(1.90)	
displacement	.741	
	(.081)	
weight	1.417	4.401
	(.456)	(1.000)
speed		23.66
		(6.21)
acceleration		-18.31
		(25.25)
operating costs (¯$_2$)	4.795	2.779
	(.511)	(.495)
R^2	.366	.247

Standard errors are in parentheses. Coe±cients (and standard errors) other than the price coe±cient are divided by ¯$_2$, see discussion later in text.

Table 4. Estimates of demand model (10)

	GMM estimates		OLS estimates	
constant	-306.4	-188.6	-359.5	-338.9
	(52.0)	(43.3)	(34.0)	(35.9)
time92	57.1	53.8	51.7	59.1
	(31.7)	(25.2)	(18.9)	(19.7)
time93	33.2	36.3	66.6	75.5
	(29.5)	(23.8)	(19.0)	(19.8)
time94	39.1	50.9	86.6	102.9
	(30.7)	(24.2)	(21.0)	(22.0)
French market	-54.4	-70.3	-149.7	-160.8
	(22.8)	(18.9)	(15.6)	(16.3)
Italian market	105.1	133.8	-164.9	171.8
	(36.9)	(30.2)	(19.4)	(20.2)
French origin	49.8	-4.2	6.6	-16.2
	(27.7)	(23.8)	(28.1)	(29.1)
German origin	42.1	-10.8	-67.0	-61.8
	(27.6)	(26.0)	(24.8)	(25.6)
Italian origin	79.1	33.8	-4.5	-8.0
	(26.5)	(22.6)	(25.5)	(26.2)
horsepower	3.02		3.22	
	(1.43)		(.91)	
displacement	.409		.264	
	(071)		(.034)	
weight	.943	1.465	-.189	.296
	(.336)	(.294)	(.207)	(.206)
speed		12.75		11.62
		(1.84)		(1.60)
acceleration		-24.75		-38.75
		(8.00)		(6.60)
½	.146	.126	.020	.011
	(.019)	(.018)	(.005)	(.005)
Hausman-Wu exogeneity test			52.6	48.3

Standard errors are in parentheses.

Table 5. Estimates of implicit interest rates r (in percent), alternative distributions

characteristics include:	double exponential (bell-shaped)	exponential (skewed)	uniform
horsepower and displacement	11.84 (2.02)	10.53 (1.67)	12.24 (2.23)
speed and acceleration	8.61 (1.32)	4.99 (0.67)	13.18 (2.64)

Table 6. Comparison of the alternative models of pricing

value of the objective function			
	monopoly	duopoly	competition
	.0518	.1396	.1813
McKinnon-White-Davidson P-tests			
	null hypothesis		
alternative hypothesis	monopoly	duopoly	competition
monopoly	{	5.737	6.672
duopoly	.290	{	6.426
competition	.328	-3.267	{
\conduct" parameters			
	M{D	M{C	D{C
estimate	.903	.915	6.934
standard error	.135	.118	1.762

Standard errors are in parentheses.

Table 7. Estimates of model (16) under alternative assumptions pricing

	monopoly	duopoly	perfect competition
	demand parameters		
constant	-277.5	-264.0	-165.8
	(47.3)	(41.4)	(72.9)
French market	-57.4	-39.7	19.7
	(23.1)	(19.8)	(35.2)
Italian market	108.4	87.8	11.6
	(35.9)	(31.2)	(52.7)
French origin	50.5	48.7	89.9
	(28.5)	(26.0)	(43.0)
German origin	45.8	43.4	96.0
	(28.2)	(26.1)	(41.1)
Italian origin	78.5	91.8	144.7
	(26.8)	(24.3)	(39.4)
horsepower	3.03	3.57	3.40
	(1.47)	(1.31)	(2.22)
displacement	.418	.416	.507
	(071)	(.062)	(.112)
weight	.876	1.290	2.201
	(.335)	(.292)	(.468)
½	.144	.169	.298
	(.017)	(.015)	(.013)

(Table 7 continued on next page.)

Table 7. (Continued)

	monopoly	duopoly	perfect competition
	cost parameters		
constant	-1104.4	761.3	702.6
	(377.2)	(342.3)	(315.7)
French market	-64.3	439.3	533.3
	(175.8)	(156.8)	(155.8)
Italian market	-368.4	-420.5	-956.8
	(206.4)	(213.6)	(204.4)
French origin	-561.8	53.8	317.9
	(316.4)	(248.8)	(200.8)
German origin	277.3	305.4	406.9
	(192.7)	(228.9)	(189.9)
Italian origin	202.4	272.3	419.3
	(201.2)	(227.0)	(185.4)
horsepower	33.18	6.29	-1.61
	(9.2)	(8.27)	(8.75)
displacement	2.32	.879	.535
	(.48)	(.449)	(.461)
weight	9.98	7.98	7.74
	(2.56)	(2.59)	(2.21)

Standard errors are in parentheses.

Table 8. Fraction of price di®erences explained by markups

	Mean	Std Dev	Representative Model	
			estimate	st. error
all countries	.807	.407	.560	.077
Belgium	.737	.397	.512	.085
France	.881	.384	.788	.093
Italy	.782	.446	.480	.077

Table 9. Elasticities of demand with respect to taxes

	Fuel taxes		Car taxes	
	estimate¤	st. err.	estimate¤	st. err.
	Ignoring tax incidence			
all countries	-2.631	(.175)	-.560	(.057)
Belgium	-2.963	(.209)	-.693	(.074)
France	-3.771	(.199)	-.531	(.056)
Italy	-.409	(.035)	-.093	(.010)
	Accounting for tax incidence			
all countries	-1.201	(.002)	-.444	(.033)
Belgium	-1.390	(.004)	-.555	(.044)
France	-.308	(.019)	-.272	(.005)
Italy	-.327	(.025)	-.092	(.009)

¤ The elasticity estimates are for a representative model.

Appendix

This Appendix computes α_j (given by (13)) for a case of duopoly competition. First, we determine the total market share of j, i.e. $s_j = s_{Gj} + s_{Dj}$. Next, we derive the market share derivatives $\partial s_j / \partial p_{jG}$ and $\partial s_j / \partial p_{jD}$ that may be substituted into α_j. To illustrate, consider the case in which $\theta_j^* \le \theta_k^*$. The alternative case can be considered using a similar approach. The total market share for the gasoline and diesel variants of j is given by:

$$\begin{aligned} s_j &= \int_{\underline{\theta}}^{\theta_j^*} \Pr(u_{jG}(\theta) \ge u_{kG}(\theta)) f(\theta) d\theta \\ &+ \int_{\theta_j^*}^{\theta_k^*} \Pr(u_{jD}(\theta) \ge u_{kG}(\theta)) f(\theta) d\theta \\ &+ \int_{\theta_k^*}^{\bar{\theta}} \Pr(u_{jD}(\theta) \ge u_{kD}(\theta)) f(\theta) d\theta . \end{aligned}$$

The derivative of s_j with respect to p_{jG} is given by

$$\begin{aligned} \frac{\partial s_j}{\partial p_{jG}} &= \Pr(u_{jG}(\theta_j^*) \ge u_{kG}(\theta_j^*)) f(\theta_j^*) \frac{\rho}{\cdot \pi_j} - \Pr(u_{jD}(\theta_j^*) \ge u_{kG}(\theta_j^*)) f(\theta_j^*) \frac{\rho}{\cdot \pi_j} \\ &+ \int_{\underline{\theta}}^{\theta_j^*} \frac{\partial \Pr(u_{jG}(\theta) \ge u_{kG}(\theta))}{\partial p_{jG}} f(\theta) d\theta . \end{aligned}$$

The first two terms cancel, since at θ_j^*, $u_{jG}(\theta_j^*) = u_{jD}(\theta_j^*)$ by the definition of θ_j^*. So it remains to compute the third term. Assume that the random variable $\varepsilon_k - \varepsilon_j$ has a uniform distribution on $(-L_j; L_j)$, as in Anderson et al.'s linear probability model. In this case we have:

$$\begin{aligned} \Pr(u_{jG}(\theta) &\ge u_{kG}(\theta)) \\ &= \Pr(\varepsilon_k - \varepsilon_j \le a_{jG} - a_{kG} - (\tau_{jG} - \tau_{kG}) - \theta(\pi_{jG} - \pi_{kG}) - \rho(p_{jG} - p_{kG})) \\ &= \frac{1}{2} + \frac{a_{jG} - a_{kG} - (\tau_{jG} - \tau_{kG}) - \theta(\pi_{jG} - \pi_{kG}) - \rho(p_{jG} - p_{kG})}{2L_j} . \end{aligned}$$

One can then compute that

$$\frac{\partial \Pr(u_{jG}(\theta) \ge u_{kG}(\theta)) f(\theta)}{\partial p_{jG}} = -\frac{\rho}{2L_j};$$

from which it follows that

$$\frac{\partial s_j}{\partial p_{jG}} = \int_{\underline{\theta}}^{\theta_j^*} \left(-\frac{\rho}{2L_j} \right) f(\theta) d\theta = -\frac{\rho}{2L_j} F(\theta_j^*).$$

Similarly one can compute that

$$\frac{\partial s_j}{\partial p_{jD}} = -\frac{\rho}{2L_j} \left(1 - F(\theta_j^*) \right);$$

so that $\alpha_j = F(\theta_j^*)$, as was claimed in the text.