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Conference Paper

Choice Of Travel Cards By Railway Passengers: A Discrete/Continuous Choice Approach

40th Congress of the European Regional Science Association: "European Monetary Union and Regional Policy", August 29 - September 1, 2000, Barcelona, Spain

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: van Vuuren, Daniel; Rietveld, Piet (2000) : Choice Of Travel Cards By Railway Passengers: A Discrete/Continuous Choice Approach, 40th Congress of the European Regional Science Association: "European Monetary Union and Regional Policy", August 29 - September 1, 2000, Barcelona, Spain, European Regional Science Association (ERSA), Louvain-la-Neuve

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Choice of travel cards by railway passengers: A discrete/continuous choice approach

Daniel van Vuuren* Piet Rietveld

Abstract

In this paper we model the demand for train kilometres with a disaggregate structural demand model, thereby recognising the fact that consumers have to make a simultaneous choice for this demand and for the type of ticket with which they want to travel. Our model is in line with microeconomic theory, which implies that the choice of ticket type is closely linked to the indirect utility function. Special attention has been paid to the possibility that individuals do not buy the ticket that would have been most advantageous, given their actual demand for train kilometres. Estimation of the model shows that the demand of off-peak hour travellers in the Netherlands is price elastic at a value of -1.37 and that the average take-up cost of purchasing a reduction card equals 35% of its actual price. This latter result implies that the average traveller behaves *as if* the price of a reduction card were 35% more expensive than it actually is, which not only has considerable implications for the railway company whose aim is to maximise its revenues, but also for the government whose aim is to stimulate the use of public transport.

1 Introduction

Railway companies mostly offer various types of train tickets. Apart from full tariff tickets, travellers are often able to opt for various sorts of tickets which involve a fixed fee in order to ‘participate’ and a marginal price which is lower than the ‘full tariff’ marginal price. This results in a declining price schedule: Travellers with high demand for train

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kilometres face a lower marginal (and average) price than travellers with low demand. The theoretical justifications for such a differentiated price structure have by now become common knowledge among public economists in general and transport economists in particular; see Brown and Sibley (1986) and Carbajo (1988), respectively, for an overview.

This paper aims at developing and estimating a disaggregate model for the demand for train kilometres. This – individual – demand typically depends on price and hence on the choice of train ticket, which implies that the choice of ticket type is a typical explanatory variable for the demand for train kilometres. However, this choice of ticket type is a typical *endogenous variable*, as in turn this variable will depend on the demand for train kilometres. When setting up a demand model it is therefore important to recognise the close relation of the level of the demand for train kilometres on the one hand and the choice of ticket type on the other hand. Simply using the choice of ticket type as an explanatory variable for the demand for train kilometres is inconsistent as this latter variable will surely affect the choice of ticket type too. Conversely, it makes no sense to separately explain the observed choice of ticket type from the observed demand for train kilometres. Using more technical terms, such analyses lead to biased estimates due to neglecting the endogeneity of an explaining variable. It is therefore important to specify a simultaneous model which both explains the demand for train kilometres from the choice of ticket type, in particular from the price of this ticket type, and which explains the choice of ticket type from the demand for train kilometres. Making use of a maximum likelihood procedure this simultaneous model can be consistently estimated. Regarding the model structure, there are many possibilities for such a simultaneous model, but from the point of view of an economist the microeconomic framework is most appealing due to its strong theoretical justifications. This implies that the choice of ticket type is closely linked to the indirect utility function, which can be retrieved from the demand function for train kilometres by making use of Roy's identity.

This approach dates back to Burtless and Hausman (1978)'s seminal paper on the supply of labour by individuals. Since then many empirical studies that involve *nonlinear budget constraints* have been carried out. Amongst others, one can find applications in the fields of *electricity demand* (Dubin and McFadden, 1984; Herriges and King, 1994), and the *demand for housing* (King, 1980; Hausman and Wise, 1980; Hoyt and Rosenthal, 1990). An important distinction between the current work with most of these studies concerns the nature of the discrete choice. In most applications, like e.g. labour supply, the discrete choice is automatically tied to the continuous choice and therefore has an implicit nature. For example, a person who chooses to work H hours a week, will automatically

face the tax rate that goes together with this amount H . In other applications however, such as the demand for telecommunication and travel demand, the discrete choice has an explicit nature. As the choice of the ticket type is *optional*, it is likely that people may in some cases make choices that are *a priori unexpected*. This can be due to optimisation error of the individual, which may for example be caused by bad information. On the other hand it should be realised that the choice of ticket type has to be made in advance – usually on a yearly basis – which may be the cause of risk-averse behaviour of the individual. This hypothesis is confirmed by the data, which suggests that people are conservative with regard to the purchase of a reduction card. This risk aversion, together with the existence of non-monetary application costs such as waiting time and effort to submit an application form, is enough reason to incorporate a threshold parameter into the model which measures to what extent people are reluctant to buy a reduced fare card.

In the context of transport modelling, the present analysis has links with the approach of Abdelwahib and Sargious (1992), who model the demand for freight transport with a joint model for mode choice and shipment size. Studies by de Jong (1990) and Hensher, Milthorpe and Smith (1990), making use of discrete/continuous models for car ownership and car use, are also linked to the approach in this paper. It is remarkable however that in general there has been scarce attention for a discrete/continuous analysis of the demand for transport. Most studies up to present have either made use of discrete choice models, neglecting the continuous choice, or aggregate demand models, often neglecting the endogeneity of certain explanatory variables, such as the price variable. The current study is advantageous over earlier approaches as it provides a theoretically justified framework for the travel behaviour of individuals and it recognises the simultaneous nature of train kilometres and train tickets in a consistent way. More concretely, this study provides estimates of price elasticities for train kilometres during off-peak hours and monetarises the travellers' reluctance to buy reduced fare cards through the inclusion of a “take-up cost” parameter. This study limits itself to the demand for Second Class tickets during off-peak hours, but the model can be readily generalised for the demand during peak hours or even the demand for other transport modes.

In section 2 the theoretical demand model for the combined demand for train kilometres and train tickets is set out. The data is described in section 3. In this section special attention is paid to the observed combinations of train tickets and train kilometres. Indeed, the data suggest that in general consumers are reluctant to buy a reduction card. The transition from the theoretical economic model in section 2 to an estimable

econometric model is discussed in section 4. In particular three issues are of interest in this step: (i) proper specification of the travellers' reluctance to buy reduced fare cards, (ii) allowance for individually differentiated tastes, and (iii) the stochastic specification of the model. Section 5 reports the estimates, and in particular compares the elasticity estimates to earlier estimates and discusses the implications of a positive take-up cost. Section 6 concludes and suggests several extensions of the approach in this paper.

2 The demand for train tickets and train kilometres: Microeconomic theory

Following elementary microeconomic theory, the demand of an individual for a certain economic good is a function of the price of that good and of the individual's income. A possible specification of such a demand function for the case of train kilometres is the *double-log* specification:

$$\ln k = \alpha \ln y + \beta \ln p + \delta. \quad (1)$$

In this equation the number of train kilometres that is travelled by an individual is denoted by k , income is denoted by y , the price of a train kilometre is denoted by p , and δ is simply a constant. This demand equation fixes a two-good microeconomic framework, consisting of (a) train kilometres and (b) a composite commodity which represents consumption on all other goods. To stay in line with demand theory, and in particular with the homogeneity property of the demand function in income and price, one has to deflate both income and (kilometre) price by the price of this composite commodity. As is usual in cross-section analyses it is assumed that the price of the composite commodity is equal to the 'price' of income, implying a numeraire that equals 1. It is seen that in this specification both the income elasticity of demand and the price elasticity of demand are constant at $\epsilon_y = \alpha$ and $\epsilon_p = \beta$ respectively, which explains why this model is often labelled the *constant elasticity model*. Appearing to be somewhat restrictive at first sight, the constant elasticity model does however not impose any further restrictions on the elasticities as do many other specifications, such as CES, Cobb-Douglas and the linear expenditure system¹.

Consider now the case that consumers can choose between different types of tickets, for example a full tariff ticket and a reduced tariff ticket where the consumers first have to buy a reduction card at fixed cost. This implies that consumers are able to choose their own marginal price of a train ticket. As has been known for a long while, straightforward

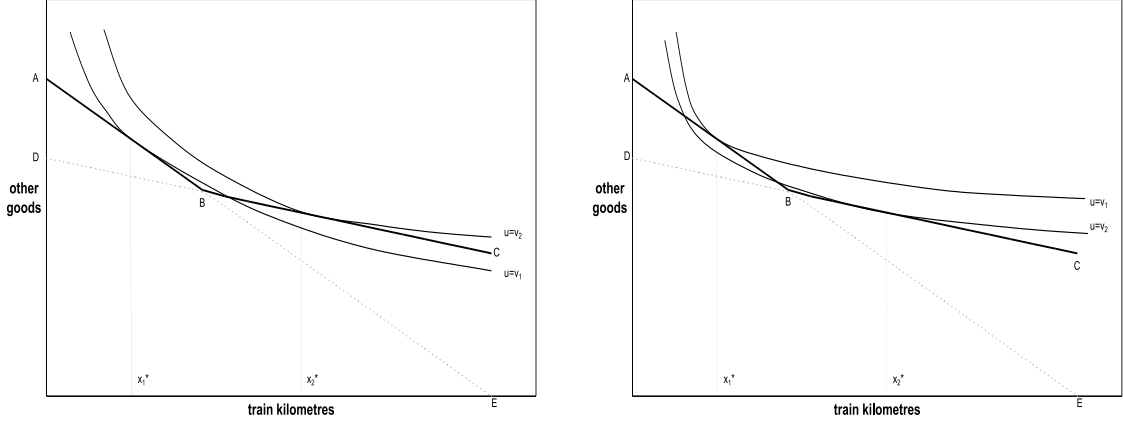
least squares estimation of the model in (1) would yield biased estimates, because the demand for kilometres has a causal influence on the kilometre price². Therefore, it is necessary to add an equation to the model which adequately describes the causality of kilometres on kilometre price. There are several ways to do this, but from an economic point of view it is certainly most appealing to let this additional equation be consistent with microeconomic theory. The proper way of doing so starts by deriving the indirect utility function from the demand equation in (1). This can be achieved by rewriting Roy's identity as a differential equation and making use of the implicit function theorem. Following Burtless and Hausman (1978), this procedure yields the following indirect utility function:

$$v(p, y) = \frac{1}{1 - \alpha} y^{1 - \alpha} - \frac{1}{1 + \beta} p^{1 + \beta} e^{\delta}. \quad (2)$$

Hence it is possible to determine the *conditional demand function* and the *conditional indirect utility function* for each type of train ticket. Suppose that one is able to choose between two ticket types³: Firstly, one may simply travel with the standard *full fare* tickets and pay a marginal price of, say, p_f . The second possibility is to buy a reduced fare card at a fixed price of, say, p_r , and hence pay a marginal price that equals a fraction h of the full tariff price ($0 \leq h < 1$). This gives a budget constraint similar to the one in Figure 1, where the budget frontier ABC is obtained as an optimal combination of the full tariff budget frontier ABE and the reduced tariff budget frontier DBC. Note that the length of AD is exactly the price of a reduction card p_r . To a utility maximising individual the consumption of a package on the curve DBE should be no option, as this is not in accordance with the conventional wisdom that utility is nondecreasing in income. In later sections we will come back to this. Consider now the case that the individual's optimal demand for train kilometres, given that he travels with full tariff tickets, locates on AB, and that his optimal demand for train kilometres, given that he travels at reduced tariff, locates at the segment BC. In the figure these conditional demand functions have been denoted by x_1^* and x_2^* respectively. The accompanying conditional indirect utilities v_1 and v_2 determine the depicted indifference curves " $u = v_1$ " and " $u = v_2$ ". It can now be seen that if

- (i) the conditional indirect utility of travelling at reduced tariff exceeds the conditional indirect utility of travelling at full tariff: $v_2 > v_1$;
- (ii) utility is quasi-concave,

Figure 1: Two ticket types: Budget constraint and preferences



(a) Preference of a reduction card ($v_2 > v_1$)

(b) Preference of full tariff tickets ($v_1 > v_2$)

then the individual will prefer to buy a reduction card and simultaneously *consume* x_2^* kilometres at reduced tariff. The quasi-concavity condition guarantees that the indifference curves do not cross, so that demand at x_2^* is indeed optimal. Figure 1b depicts the case where the individual favours to travel at full tariff, so the inequality in (i) reverses⁴. The case that the conditional demand for a reduced tariff card locates at DB can be ruled out, as the indirect utility that is involved to such demand will always be inferior to the conditional demand for full tariff tickets which locates on AB - provided that the quasi-concavity condition holds⁵.

Returning to the model, the condition in (i) for preferring to travel at reduced tariff instead of full tariff rewrites as

$$v(hp_f, Y - p_r) > v(p_f, Y), \quad (3)$$

where total income is now denoted by Y . Having made the decision with which type of travel card one wants to travel, the net income y equals $Y - p_r$ for reduced tariff travellers and Y for full tariff travellers, respectively. Working out this equation with the expression for the indirect utility function in (2), it transforms into

$$p_r < \gamma Y, \quad (4)$$

where

$$\gamma := 1 - \left\{ 1 - \frac{1 - \alpha}{Y^{1-\alpha}} \cdot \frac{(1 - h^{1+\beta}) p_f^{1+\beta}}{1 + \beta} e^\delta \right\}^{\frac{1}{1-\alpha}}. \quad (5)$$

Thus γ can be interpreted as the (maximum) fraction of income that is available for the purchase of a reduction card. This parameter, which determines one's inclination to buy a reduced fare card, primarily depends on the individual's sensitivity to (changes in) price and income⁶. At first sight this expression may look somewhat cumbersome, but a closer inspection reveals that it can be rewritten as

$$\gamma = 1 - \left\{ 1 - \frac{\Delta v_r}{v(0, Y)} \right\}^{\frac{1}{1-\alpha}}. \quad (6)$$

With income held constant, the increase in utility due to the purchase of a reduction card equals $\Delta v_r := v(hp_f, Y) - v(p_f, Y)$. With Roy's identity it can be seen that this measure of welfare change is nonnegative. This implies that the fraction $\frac{\Delta v_r}{v(0, Y)}$ can be interpreted as the individual's sensitivity to a price reduction of kilometres *relative to* his sensitivity to a (change in) income. As would be expected γ is increasing in this quantity: A relatively high price sensitivity will increase the individual's inclination to buy a reduced fare card.

Finally the quasi-concavity condition in (ii) writes as⁷

$$\beta < -\frac{\alpha p k}{y},$$

where y equals $Y - p_r$ or Y respectively, dependent on whether one owns a reduction card or not, and p equals hp_f and p_f for the same respective cases. In less technical terms this inequality states that the compensated own price-effect of train kilometres should be negative, a well-known result in microeconomic theory.

3 Data

In this paper we make use of a data set from the Netherlands Railways (NS), the so-called 'Basisonderzoek' (BO). This data set was obtained through a survey during the period April 1992 until March 1993. The most important objective of the study was to analyse the profiles of travellers, in particular those of travellers by train. The survey consisted of two parts: At first a random sample from the population of Dutch households was drawn, after which one individual from the household was asked about personal characteristics

Table 1: Budgetary efficiency of travellers (%)

	efficient	inefficient	total
full tariff	31.9	26.6	58.5
reduced tariff	31.9	9.6	41.5
total	63.8	36.2	100.0

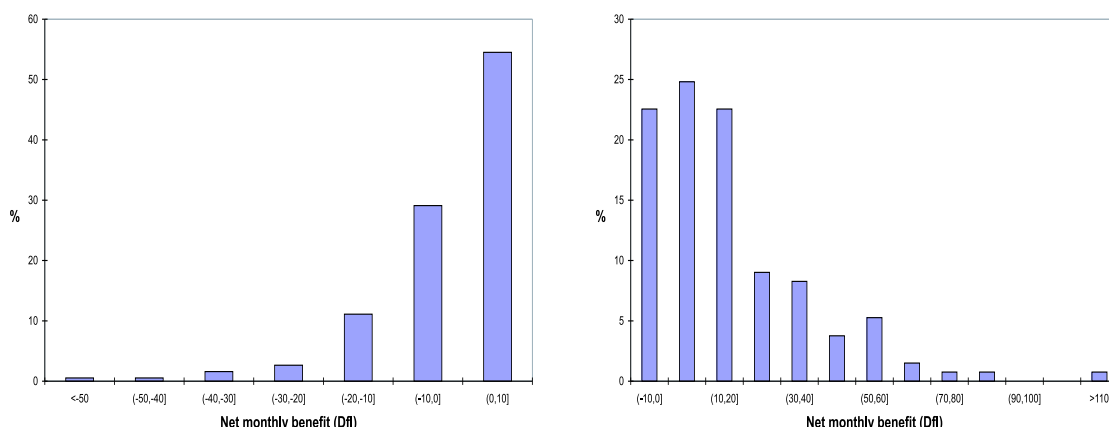
like age, gender and education. Moreover the subjects were asked about their possession of train fare reduction tickets, car possession and other factors of interest for the Netherlands Railways. In the second part every subject was asked to keep a month’s diary of his travel behaviour as far as railway transport was concerned. The subjects in the second data set are a subsample of those in the first, satisfying two selection criteria: (i) the subject indicated that he travelled by train during the past year, and (ii) the subject was willing to keep a travel diary. For the purpose of this paper we have linked both data sets in order to be able to include individual characteristics into the demand equation that was specified in (1).

Table 1 reports the frequencies of “efficient” and “inefficient” travellers, where an “efficient traveller” is defined as an individual who buys the right type of train ticket, given his demand for train kilometres. Formally, a traveller who owns a reduction ticket and has reported to travel k kilometres is called efficient if

$$c_f(k) \geq c_r(k), \quad (7)$$

where $c_f(\cdot)$ is the full tariff cost function and $c_r(\cdot)$ is the reduced tariff cost function⁸. A similar definition can be given for “full tariff efficiency”. Table 1 shows that nearly half of the full tariff travellers would gain by buying a reduced fare card. In the case of reduced fare travellers it appears that still about 23% of the travellers travel too little to make the purchase of the reduced fare card a good investment. Note that travellers who are categorised as “inefficient” at this point, are precisely those travellers who locate themselves at a suboptimal part of the budget set, i.e. the inner line DBE. A more detailed picture of the distribution of the net benefits is given in Figures 2. These figures depict an absolute measure of efficiency, which is defined as the difference between the cost of the ticket type that is not chosen and the cost of the chosen ticket type. (For reduction card holders this benefit equals $c_f(k) - c_r(k)$.) On average, one is indifferent between the two types of tickets at a yearly consumption of 1240 train kilometres. The many negative values for full tariff travellers, some with considerable magnitude, as compared to the few

Figure 2: Monthly net benefits compared to the alternative ticket type



(a) Full tariff travelers

(b) Reduced tariff travelers

negative values for reduced tariff travellers, all with low magnitude, suggest that many individuals are reluctant to buy a reduced fare ticket. Note that both the maximum benefit of a full tariff traveller and the maximum loss of a reduced tariff traveller equal the price of a reduced fare card, which can be clearly seen in both histograms. The price of a reduced fare card equalled Dfl 9 per month (Dfl 108 per year) in 1992 and Dfl 8.25 per month (Dfl 99 per year) in 1993.

It should be noted that the current findings bear much resemblance to Moffitt (1983)'s ascertained disutility from participation in a welfare program, and the finding of Koning and Ridder (1997) that there is an 'entry fee effect' for households that might apply for rent assistance. For the current case, several explanations are possible for the discrepancy between what is observed and what might have been expected on grounds of a basic microeconomic specification. The most important explanation is probably that travellers have to make their choice of ticket type in advance, which means that the decision involves a certain risk. In principle, one buys a reduced fare card for the period of one year, so the person who invests Dfl 108 to buy a reduced fare card takes a risk because he is not certain about his future travel behaviour. This theory is in line with the findings of Train, Ben-Akiva and Atherton (1989), who find that consumers who are able to 'self-select' among different telephone tariffs "do not choose tariffs with complete knowledge of their demand, but rather choose tariffs at least partly on the insurance provided by the tariff in the face of uncertain consumption patterns." Other possible explanations are

that travellers are not well informed about the different types of travel cards, and that there exist some application costs for the purchase of a reduction card. As examples of the latter, one may think of waiting time at the ticket-window, and time and effort to make a photo – which is required in the Netherlands – and to fill in an application form.

4 Econometric specification

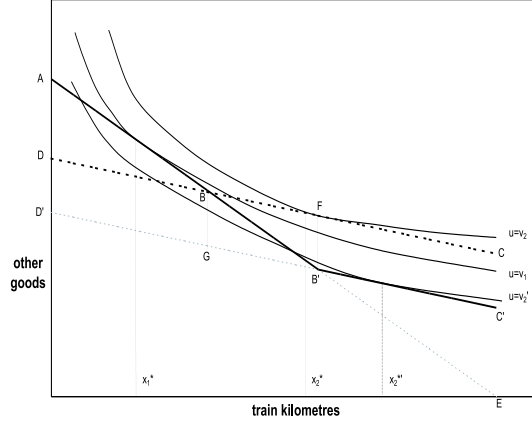
4.1 Inclusion of take-up cost for reduction cards

The previous section has shown that many travellers experience a certain threshold before they buy a reduced fare card. Indeed there are also some reduced tariff travellers who appear to be on the wrong side of their budget constraint, but these are easily outnumbered by the “inefficient” full tariff travellers. In order to take this into account in the economic model of section 2, a fixed *take-up cost* T can be incorporated into the decision process that has been described in (3) and (4). The latter equation then modifies into

$$\begin{aligned} v(hp_f, Y - p_r - T) > v(p_f, Y) &\Leftrightarrow \\ p_r + T < \gamma Y. & \end{aligned} \quad (8)$$

The expression for γ remains unaltered, as in (5). It is seen that if $T > 0$, which is expected on the grounds of section 3, the customer is more reluctant to buy a reduced fare card than would have been expected on grounds of the theory in section 2. In Figure 3 the implications for the microeconomic model are shown: With the introduction of a take-up cost DD' , the budget constraint changes to $AB'C'$, the conditional demand for the reduced fare ticket changes to x_2^{*} , and the indifference curve through this conditional demand is drawn by the line $u = v_2'$. Clearly, this figure shows that the take-up cost of a reduced fare card can make this card less attractive than the option of full tariff tickets. Whereas the original conditional demand x_2^* was superior to the conditional demand for the full tariff option, the existence of take-up costs makes that the full tariff option is superior to the purchase of a reduction card in this example. Thus the optimal demand now equals x_1^* , due to its superiority over the conditional demand with a reduced fare card x_2^{*} . Figure 3 shows that individuals who locate at BB' now locate on their budget frontier, which implies that they are behaving perfectly efficient. The other side of the coin is that the consumers in the segment BF , who are efficient with zero take-up costs, are shifted to the segment GB' in the case of positive take-up costs, implying that they are no longer efficient. A glance at Figure 2 suggests that the number of travellers on BF

Figure 3: Positive take-up cost implies reluctance to buy a reduced fare card



is smaller than on BB' , so that the introduction of positive take-up costs leads to a larger number of efficient travellers.

Finally note that this new feature of the model does not impose any new restrictions. If the original model without take-up costs is valid, this will simply follow from the estimations by not being able to reject the null hypothesis that “take-up cost equals zero”. If this null hypothesis is rejected, however, there will be proof that there is a take-up cost involved for people who consider to buy a reduced fare card.

4.2 Individual tastes

In the model that has been described in section 2 it was assumed that the parameters α , β and δ are fixed. It is likely however that different individuals will have different tastes, and therefore different parameter values. In general two ways exist to allow such variation in taste: Firstly, one can make one or more of the parameters depend on individual characteristics which are likely to influence the individuals' taste, and secondly, one may specify a stochastic distribution for one or more of the parameters in order to account for unobserved taste variation. This latter extension is discussed in the next subsection. In this paper it is assumed that *nonstochastic preference heterogeneity* can be captured in the constant term δ_i for individual i as follows:

$$\delta_i = S_i' \delta \tag{9}$$

where S_i is a vector with individual characteristics. As possible elements of S_i one may think of age, car possession and other factors of interest. Note that, to allow for a constant term which is not individual-specific, the first element of S_i equals 1 for all individuals.

4.3 Stochastic specification

The crucial step in going from a theoretical economic model towards an empirical model is the stochastic specification. Hausman (1985) gives an excellent overview of the various sources of randomness in simultaneous discrete/continuous choice models and suggests various specifications to incorporate these sources into an econometric model. The two most interesting phenomena that are to be modelled as stochastic error terms are *preference heterogeneity* and *optimisation error*. As has been mentioned in the previous subsection, apart from observed characteristics that may have influence on one's taste, it is likely that there is some *unobserved* heterogeneity in the preferences of travellers. The general way to specify an error term that takes account of this is to let one parameter vary according to a stochastic specification. The parameters of this stochastic specification are then to be estimated alongside the other parameters of the model. Optimisation error occurs because consumers do not always have the opportunity to purchase the desired amount of train kilometres. For example, someone may fall ill, which makes that he is not able to buy his optimal consumption package. An additional source of optimisation error is caused by the fact that travellers are able to choose their own type of train ticket. As has already been argued, this can be partly modelled with an additional (deterministic) constant, which is a part of what was termed 'take-up cost' in subsection 4.1. On the other hand it is likely that there are some unobserved factors which may cause someone to choose an "inefficient" combination of ticket type and train kilometres. These can then be modelled by a stochastic error term. Thirdly there is *specification error*, which is caused by the modeller's inability to specify a perfect econometric model. The usual way to incorporate such an error term is by introducing an additive error term in the demand function. This error term does however not appear in the indirect utility function, as its mere existence is caused by the modeller and the traveller does not have anything to do with it while making his optimal choice of a ticket type. The last form of randomness that is mentioned by Hausman is *measurement error*, which is caused by bad measurement of the data. In the present context, the translation from yearly data to monthly data constitutes an important part of this measurement error. Travel data are on a monthly basis, while the decision to purchase a reduction card or not is in principle taken on a yearly basis. The general problem of measurement error is however a whole issue on itself in the econometric literature, and will therefore not be considered in detail in this paper. A useful summary can be found in Greene (1993).

One can imagine that with all these sources of stochasticity it is possible to construct

a wide variety of econometric specifications that go together with (1). In this paper the following two-error model will be estimated:

$$\begin{aligned} \ln k &= \alpha \ln y + \beta \ln p + \delta + \varepsilon, & \varepsilon &\sim N(0, \sigma^2) \\ v(p, y) &= \frac{1}{1-\alpha} y^{1-\alpha} - \frac{1}{1+\beta} p^{1+\beta} e^{\delta+\nu}, & \nu &\sim N(0, \tau^2). \end{aligned} \quad (10)$$

It is seen that this specification contains two error terms, i.e. ε and ν , which are assumed to be independently distributed. The error term ε takes account of both specification error and optimisation error as far as an exact attainment of the optimal consumption package is concerned. The optimisation error which takes account of possibly inefficient combinations of ticket type and kilometres, is included in ν . The current stochastic specification does not include a separate error term to incorporate stochastic preference heterogeneity, but this is a choice one has to make as it would not be possible to identify a third additional error term.

The likelihood of owning a reduced fare card and travelling k kilometres now equals

$$\ell(k, r) = p(k|r) \cdot P(r),$$

where

$$\begin{aligned} p(k|r) &= \frac{1}{\sigma} \phi \left(\frac{\ln k - \alpha \ln(Y - p_r) - \beta \ln(hp_f) - \delta}{\sigma} \right), \\ P(r) &= 1 - \Phi \left(\frac{G - \delta}{\tau} \right). \end{aligned} \quad (11)$$

The density function $p(k|r)$ gives the probability density for travelling k kilometres, given that one owns a reduced fare pass. Furthermore, the probability that one owns a reduced fare pass is equal to $P(r)$. Subscripts for individuals ' i ' are suppressed for the moment. Together with the inclusion of taste heterogeneity in (9), the right hand sides would modify by adding subscripts i to k , Y , δ and G . The function $G_i \equiv G(Y_i, p_r, h, p_f)$ simply follows by rewriting (8) in terms of δ_i , such that

$$p_r + T < \gamma_i Y_i \Leftrightarrow \delta_i > G_i \quad (12)$$

This follows from a straightforward, but tedious, exercise of algebra, of which the result can be found in Appendix A. (The functional form of γ in terms of δ , amongst others, has been given in (5).) It should be noted that other stochastic specifications, such as e.g. in Moffitt (1986), lead to the same type of likelihood. The structure consists of a density

function which is multiplied by a probability of probit type, which refers to the observed choice of ticket type. The density relates to a transformation of the observed demand for train kilometres. Similarly, the likelihood of travelling k kilometres with full tariff tickets is expressed in terms of the conditional density function of travelling k kilometres and the probability of not owning a reduced fare pass:

$$\ell(k, f) = p(k|f) \cdot (1 - P(r)),$$

where

$$p(k|f) = \frac{1}{\sigma} \phi \left(\frac{\ln k - \alpha \ln Y - \beta \ln p_f - \delta}{\sigma} \right).$$

Hence, summing over individuals i , the log-likelihood for the whole data set becomes

$$\ln \ell = \sum_{i: \text{"full tariff"}} \ln \ell_i(k, f) + \sum_{i: \text{"reduced tariff"}} \ln \ell_i(k, r).$$

5 Estimation

5.1 Design

The estimations focus on persons that did actually have to make a choice between different types of tickets. This means that groups which get their travel cards for free have been excluded. In the Netherlands this mainly concerns students, people from the army and railway personnel (around 12% of the sample). Only Second Class passengers (about 90% of the sample) have been selected in the final data set.

The fixed cost of a reduced fare card (p_r) equalled Dfl 9 in 1992 and Dfl 8.25 in 1993 (on a monthly basis). In the estimations the full tariff kilometre price has been fixed at the sample average kilometre price of Dfl 0.22. In the Netherlands, the level of the marginal tariff per kilometre depends on the length of a trip. It starts with a rather high value of around Dfl 0.30 for short trips and slightly decreases to around Dfl 0.10 for longer trips. For very long trips, the marginal price is even equal to zero. In general, one would be able to make use of two different values for the price of a train kilometre: Firstly, the average *individual* kilometre price (\bar{p}_i) may be used in the microeconomic model, and secondly, the average kilometre price of the whole population (\bar{p}) can be used. Thus, the first method allows for individually differentiated prices, while the second makes use of a ‘uniform’ price. An advantage of the first method is that this ‘measurement’ of price will be more precise at the individual level. However, it should be noted that \bar{p}_i is in general

not equal to the marginal price of a train kilometre, which is of course the price that one is interested in⁹. In that respect it remains uncertain a priori, which method is better. The main reason that in this paper \bar{p} has been used instead of \bar{p}_i , is that the latter method constitutes a potential source for endogeneity bias. In this sense, \bar{p} seems to be the best available instrument for the marginal price of each individual, as (a) it safeguards the estimates from endogeneity bias while \bar{p}_i does not and (b) it is not necessarily less precise than the \bar{p}_i method because both methods involve average prices, while eventually it is the marginal price that one is interested in.

As the original data set did not contain information on the respondents' income, their income has been replaced by a proxy variable which has been constructed according to the model in Appendix B. Although this inclusion of "predicted income" into the model may probably bring about some measurement error, it is to be preferred over negligence of this essential explanatory variable¹⁰. Note that under the assumption of independence between the error term of the income regression in Appendix B and the error term in the demand equation (10), this procedure is essentially equivalent to the use of instrumental variables.

The vector S_i in (9), which allows for taste heterogeneity of individuals, contains variables on age, car availability, household size and a dummy which indicates whether the individual is a housewife or not. The exact expression for δ is as follows:

$$\delta = \delta_0 + \delta_1 \text{AGE1} + \delta_2 \text{AGE2} + \delta_3 \text{CAR1} + \delta_4 \text{CAR2} + \delta_5 \text{HHSIZE} + \delta_6 \text{HWIFE}.$$

In this specification "AGE1" and "AGE2" are dummies indicating whether the individual is younger than 30 years of age, or at least 50 years of age, respectively. The dummy variables "CAR1" and "CAR2" signify "can always make use of a car" and "can often make use of a car" respectively.

5.2 Results

Table 2 contains the results of the maximum likelihood estimation procedure that has been outlined in section 4. Apart from the dummy variable for housewives, all parameter estimates turn out to be significant at a 5% confidence level. Moreover, all the estimates have the sign that is consistent with prior expectations and with microeconomic theory. The results indicate that the demand for train kilometres is fairly inelastic with respect to income. With values of -1.24 and -1.37 the demand for train kilometres turns out to be price elastic. The model with take-up costs turns out to be superior to the model without

these costs, as can be read from the likelihood scores and the low standard error of the take-up cost parameter. Moreover, the number of inefficient travellers (in the sense of (7)) turned out to decrease by 7.3% with the introduction of this threshold parameter.

It can be read from the table that the estimate of the price elasticity in the model without take-up costs is lower (in absolute sense) than the price elasticity in the model with take-up costs. Thus negligence of the take-up cost effect leads to under-estimation of the price sensitivity of travellers. In other words, in the model without take-up costs the perceived reluctance of travellers to buy a reduced fare card is solely explained from their relative insensitivity for price differences, which clearly leads to under-estimation of the price elasticity. The model with take-up cost explains the reluctance to buy a reduced fare card not only from relative price insensitivity, but also from other factors which have been mentioned earlier in section 3. Hence the first conclusion is that, given the high significance of the take-up parameter, reluctance to buy a reduced fare card can not only be attributed to relative price insensitivity of a group of individuals. Motives such as risk aversion and bad information induce a threshold effect which is independent of ‘marginal price effects’. Comparing the absolute value of this threshold effect, Dfl 36.73 on a yearly basis¹¹, with the price of a reduction card, Dfl 108 in 1992 and Dfl 99 in 1993, it is seen that the average take-up cost equals 35% of the actual price of a reduction card. The second conclusion is that the estimate for the price elasticity equals -1.37 and thus that the off-peak demand for train kilometres is quite sensitive with regard to price.

The estimation implies that people who are younger than 30 years of age (-7.2%), people with high (-15.4%) or medium (-7.8%) car availability and housewives (-1.8%) have less demand for train kilometres than others. On the other hand people who are older than 50 years of age on average demand 13.3% more train kilometres than others. The negative effect of the household size variable is most probably due to the fact that families with children prefer to travel by car, as the additional costs are zero in this case.

As has been mentioned at the end of section 2, the reported estimates should satisfy the *Slutsky condition* in order to constitute a valid microeconomic model. Fortunately, the restriction was satisfied for *all* respondents for all different estimations.

5.3 Interpretation of the estimated price elasticity

As has been shown in section 3 the current study is based on a cross-section data set. This means that exactly one observation is available for each individual that has participated in the underlying survey. The static nature of this data set implies that the

Table 2: Model estimates, n=6579

log-likelihood		-14004		-13807	
σ		1.0463		1.0283	
τ		0.6966		0.4608	
Parameters		Estimates	Std.err.	Estimates	Std.err.
δ :	constant	1.6619	0.2221	1.8981	0.1751
	age < 30	-0.0879	0.0216	-0.0743	0.0166
	age \geq 50	0.1630	0.0231	0.1252	0.0179
	car available (always)	-0.2170	0.0216	-0.1675	0.0171
	car available (often)	-0.0993	0.0272	-0.0808	0.0208
	household size	-0.0766	0.0077	-0.0600	0.0062
	housewife	-0.0343	0.0230	-0.0183	0.0173
	ln income	0.1445	0.0285	0.0988	0.0211
	ln price	-1.2386	0.0501	-1.3732	0.0514
	take-up cost	-	-	3.0606	0.1790

current microeconomic analysis aims to describe an equilibrium status, and thus that the reported price elasticities should be interpreted as *long run* estimates of the *average* price sensitivity of travellers by train. It is likely that short-run effects of price changes are smaller in magnitude, in particular because reduced fare card holders have committed themselves to a certain way of travelling during a given period. In other words, substitution effects for reduction card holders will often be ‘lagged’ until the expiration date of the reduction card.

In the past, several attempts have been made to estimate price elasticities for the demand for transport by train. Oum, Waters II and Yong (1992) give an overview of price elasticities for various means of transport, mainly based on studies from the 1980s. There appears to be quite some dispersion between estimates, but this can for a large part be attributed to the type of data that has been used (cross-section, panel, aggregate time series) as well as to the market segment (business, leisure, etc.) for which the elasticity has been estimated. As has been mentioned by Oum (1989) comparison of different estimates is often difficult, especially when the models to be compared are not nested in a more general model. Nevertheless, if the data source and the model assumptions are well taken into account, comparison of different elasticity estimates can be fruitful.

Based on an aggregate time series data set, Oum (1992) reports a price elasticity of -1.16 for the Netherlands (1990). This study does however not distinguish between peak and off-peak hour demand, nor between First and Second Class travellers. Given the widely adopted notion that peak hour demand is less elastic than the off-peak demand for train kilometres, the off-peak price elasticity of -1.37 that has been estimated in this paper perfectly fits into this figure.

5.4 Welfare implications of a positive take-up cost

Clearly, this study shows that the purchase of a reduced fare card involves a large take-up cost. We briefly discuss the welfare implications of this.

As far as lack of information is the cause of the existence of take-up costs, there may be room for a Pareto improvement by providing better information to travellers. In any case this will make all travellers at least as good off as they were. Better information means that individuals have a better perception of their budget constraints, which *de facto* implies a raise in income. In Figure 3 this translates into a raise of the segment B'C', and thus will always yield at least as good a consumption package as the traveller already had. For the railway company, the effect of such an information measure is ambiguous. Better information not only affects people who were already locating *at* their budget constraint, but may as well induce “irrational” travellers to improve their utility by moving towards a consumption package for which their budget constraint is binding. For instance, the railway company often can make an extra profit out of people who travel at full tariff while they would have been better off if they travelled at the reduced tariff (i.e. users on B'E in Figure 3). Better information will surely make the number of these unwise travellers drop. The conclusion is that there exist both negative and positive effects on the profits of the railway company, and that the overall effect remains unclear *a priori*. Thus the overall welfare effect remains undetermined, and will in general depend on the extent to which better information is provided. The inability to foresee ones future behaviour has essentially the same welfare implications as the just named information factor. The only difference is that one's ability to foresee his future behaviour cannot easily be ameliorated, and thus that the practical realisation of a possible welfare improvement is difficult for this case.

Secondly, the existence of take-up costs is an important factor in the eventual design of a modified tariff structure. Whereas standard welfare analysis provides clear-cut results on how to increase total welfare or even on how to obtain a Pareto-improvement (see Brown

and Sibley (1986)), the present case does – in general – not allow for an application of these results. This implies that each proposed modification of the tariff structure has to be carefully examined, thereby taking into account the take-up costs that are involved. See Train et al. (1989) for a more elaborate discussion.

6 Conclusion and discussion

In this paper a model for the demand for train kilometres has been proposed and estimated. The kind of approach that was used has been utilised previously in other areas of interest, such as labour supply and electricity demand, but has hardly received attention in the area of travel demand. As there appear to be many people who demand a combination of ticket type and train kilometres that seems not optimal, this study has paid special attention to this issue by introducing a “take-up cost” parameter into the model.

The current estimates show that the price elasticity equals -1.37 and that the income elasticity is fairly small at about 0.1. Inclusion of a take-up cost in the model clearly shows that on average individuals are more reluctant to buy a reduced fare pass than would otherwise have been expected. To be precise, the average take-up cost equals Dfl 36.72 on a yearly basis which equals 35% of the price of a reduction card. There are several possible explanations for this large take-up cost. Firstly, people who want to buy a reduction card have to take action to purchase it. Such action may include waiting time, filling in forms, etc. Another possibility is that people are not well aware of their opportunities. In other words, they lack information about the different types of train tickets. A final explanation is that people who consider buying a reduction card have to make the decision in advance. People who are uncertain about their future travel behaviour may therefore choose to ‘wait and see’ instead of taking the preventive action of buying a reduced fare card.

To conclude this paper some possible extensions of the model are mentioned, which may be used in future analyses. Firstly, as has been mentioned in section 4.3, it is possible to construct a wide variety of econometric specifications that have the economic model of section 2 as a baseline. Two specifications that are worth mentioning are (a) inclusion of a ‘structural’ error term, and (b) a random coefficients specification. The first variant, which has been used in most applied work up to present, does not include an independent additional error term in the indirect utility specification, but instead replaces the intercept by a stochastic error term. Thus, both the demand equation and the indirect

utility function contain a same factor, which can be identified as *stochastic preference heterogeneity*. The second extension, which amongst others has been used by Burtless and Hausman (1978), allows a stochastic specification of the elasticities. This extension would be of particular interest, because the optimal pricing policy of a natural monopolist typically hinges on the fact that consumers have different price elasticities. (See Varian (1989), in particular the section on “Second-degree price discrimination”, for an excellent account.) Identification of the *spread* of price elasticities would then allow for constructing the optimal tariff design, which is of course very interesting for both the railway company and the government.

Secondly, as it is likely that there is individual variation in take-up costs, an appealing extension of the current model would be to let the take-up cost parameter vary with each individual. This variation can be achieved through the inclusion of individual-specific parameters in the take-up cost specification, analogous to the specification in (9), or by making the take-up cost parameter stochastic, or even both.

Finally, an interesting extension of this study would be to let the current demand model be part of a larger demand system. Such a more complete model could e.g. include the demand for train kilometres during peak hours. An interesting feature of such, more integrated, models would be the determination of substitution effects with other types of demands. Substitution effects may exist between First Class/Second Class demand, the mentioned peak hour/off-peak hour demand and possibly also with other means of transport. The inclusion of zero-observations is also an interesting extension, as the behaviour of non-travellers may be quite relevant for both policy makers and the Netherlands Railways (NS).

Acknowledgements

The authors are indebted to Jan Rouwendal, Erik Verhoef, Aico van Vuuren, Jerry Hausman and others for help and useful comments. The provision of data by the Netherlands Railways (NS), in particular Harry van Ooststroom, is gratefully acknowledged.

Notes

¹See Hausman (1980) for a discussion.

²See Train (1986) for an intuitively appealing illustration of such endogeneity bias. Mannering (1986) shows, through an empirical comparison of (biased) least squares estimates with unbiased counterparts, that the inconsistent estimation of transport demand models indeed causes a substantial bias in estimates for price and income elasticities.

³The following can straightforwardly be generalised to the case where more ticket types are involved. See Pudney (1989) for more details.

⁴Note that it is theoretically possible that one is indifferent between the two ticket types. In this case the relevant indifference curves coincide and go through both conditional demands x_1^* and x_2^* . In the empirical context this is usually neglected, as with the introduction of stochastic error terms into the model, the probability of being indifferent between the two ticket types equals zero and is therefore not relevant anymore.

⁵As has been mentioned above, no consumer should be inclined to have demand on DBE. Hence, if x_2^* locates on DB, this implies that x_1^* must be at AB.

⁶In later sections we will include a ‘taste’ variable, but for now we assume that taste is fixed with the parameters α, β and δ .

⁷See Burtless and Hausman (1978) for details. Note that in the present two-good case, satisfaction of this inequality automatically dissolves the *integrability problem*, which demands symmetry and negative semidefiniteness of the Slutsky matrix.

⁸Note that in the model of section 2 this inequality is equivalent with (4).

⁹To see this, consider the nonlinear budget constraint $p(k) + H = y$, with the differentiable kilometre expense function $p(\cdot)$. The Lagrange function equals $\mathcal{L} = u(k, H) - \lambda(p(k) + H - y)$, and hence the first order condition for utility maximisation is: $\frac{u_k}{u_H} = p'(k)$. Thus, it is this marginal price $p'(k)$ that we are interested in, and not the average price $\frac{p(k)}{k}$.

¹⁰See e.g. Greene (1993).

¹¹Results in Table 2 are on a *monthly* basis.

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Appendix A. Ticket choice

In this appendix we give a functional form for G , such that the equivalence in (12) holds for all parameter values and all price and income levels:

$$G(Y, p_r, h, p_f) := (1 - \alpha) \ln Y - (1 + \beta) \ln p_f - \ln |1 - \alpha| + \ln |1 + \beta| + \ln \left| 1 - \left(1 - \frac{p_r}{Y} - \frac{T}{Y} \right)^{1-\alpha} \right| - \ln |1 - h^{1+\beta}|.$$

This equation is derived by rearranging (4), taking logs and rearranging once more. The absolute signs appear in order to allow for possibly income- and/or price elastic demand, i.e. $\alpha > 1$ and/or $\beta < -1$ respectively.

Appendix B. The income equation

Making use of the 'OSA-arbeidsaanbodpanel 1985-1988' the following income equation has been estimated:

$$\begin{array}{rccccr} \ln \text{INCOME} & = & 5.72 & + & 0.542 \ln \text{EDU} & + & 0.231 \ln \text{AGE} & - & 0.633I \{ \text{FEM} \} \\ & & (0.172) & & (0.0401) & & (0.0399) & & (0.0256) \end{array}$$

$$R^2 = 0.325$$

In this model the logarithm of income has been specified as a linear function of (the logarithmic transformations of) education ('EDU'), age ('AGE') and gender ('FEM'). This last variable equals 1 if the individual is a female, and 0 otherwise. Income is defined as the net personal monthly income. Standard errors are denoted in parentheses below the corresponding estimates. All parameters turn out to be highly significant at the 5% and 1% level. It is seen that 'gender' explains a large share of the variation in individual income: on the average the model predicts that women earn 47% less than the average male person. Of course 'discrimination' is not the only explanation for this gap, as in the Netherlands labour participation of women is lower and many women that do work have part time jobs. More sophisticated specifications have not been taken into consideration since an important side constraint is that the explanatory variables to be included have to be present in both the OSA and the NS data sets.