SPEED AND INCOME WITH ENDOGENOUS SPEED AND DISTANCE

Mogens Fosgerau
Danish Transport Research Institute, Knuth Winterfeldts Allé,
Bygning 116 Vest, 2800 Kgs. Lyngby, Denmark
mf@dtf.dk

Abstract

Considering speed and travel distance as a simultaneous choice, it is shown that speed and distance increase with income due to time and money budget constraints affected by distance and speed. Using a large dataset, an empirical estimate of the income elasticity of speed of 0.044 is found, which translates into average speed differences of more than 4 km/h on motorways between the upper and lower income deciles. The estimates take account of the fact that both speed and distance are endogenous variables. Errors in the equations for speed and distance are highly correlated.

Keywords: Speed; Income; Micro-economics
Topic Area: C2 Safety Analysis and Policy

1. Introduction

The research in this paper was initiated by the recent Danish decision to increase the general speed limit on motorways from 110 km/h to 130 km/h. Some of the political arguments for this decision have concerned the need to legalise the current practice where a large proportion of drivers exceed the speed limit. Thus, in 1998 the average speed for a passenger car on motorways was 119 km/h while the speed limit was still 110 km/h.

Average speeds have been increasing over the years. For all vehicles on motorways in the open country, the average speed has increased from 103 km/h in 1986 to 114 km/h in 1998. This represents somewhat of a puzzle, since there is little apparent relationship with changes in speed limits and enforcement. Finding an explanation for this trend is the general motivation behind this paper and the hypothesis that is being advanced is that income growth is a likely driver behind the growth in speeds. Thus, when it is shown that speed increases with income in a cross-section then it is also likely that the relationship will exist over time.

There are several ways in which income can affect the choice of speed. We assume that car drivers generally want to drive as fast as possible, ceteris paribus. They are, however, constrained by accident risk, fuel costs increasing with speed above a certain level and the risk of receiving a fine. As income grows, fuel costs and fines are less constraining.

There is the further relationship that driving faster can induce discomfort through noise and vibrations. The consumer can compensate by buying a high quality car, which is more comfortable at higher speeds. As income grows, consumers can afford better quality cars. The relationship between income and the quality of the car is very clear and documented, e.g., in Birkeland and Fosgerau (1999). Rienstra and Rietveld (1996) find a significant relationship between i.a. income and the maximum speed of the car, whereby not only the higher income groups have faster cars but also the low-income group.

Fosgerau (2003) investigates the relationship between speed and income first in a micro-economic model and second in an empirical analysis. The model focuses on the trade-off between driving fast and saving time on one side and the risk of receiving a fine on the other side. Distance is taken as exogenously fixed. This is used to show that speed increases with income, decreases with the risk of detection and decreases with the size of the fine. The model furthermore shows when a rational driver will choose to exceed the speed limit. The model is in some ways similar to Gander (1985), who focuses on risk behaviour. The empirical analysis in Fosgerau (2003) confirms the theoretical relationship between speed and income using the same dataset that will be employed here. Models are specified with speed as the dependent variable and income, travel distance and a number of controls as explanatory variables. OLS estimation shows a very significant income elasticity of speed of 0.025, controlling for endogeneity of distance using 2SLS shows a higher and also very significant income elasticity of 0.031. Finally, using OLS on a model with a number of second and higher order interactions including interactions between income and distance, income elasticities are found varying with distance from 0.007 to 0.058 at the longest distances. All these models have in common that distance occurs as an endogenous variable on the right hand side of a single equation and distance is regarded as fixed in the theoretical model.

The purpose of the present paper is to test the relationship between speed and income using a somewhat different approach that more explicitly considers both speed and distance as a simultaneous choice. Thus the theoretical analysis explicitly treats both speed and distance as choice variables. Similarly, the empirical analysis considers the simultaneous choice of speed and distance in two simultaneous equations.

The layout of the paper is as follows. The theoretical analysis is presented in chapter 2, while the empirical analysis is contained in chapter 3. Chapter 4 presents concluding remarks.

2. Theoretical analysis

We begin by analysing the simultaneous choice of travel distance and speed in a microeconomic model. Consider an individual with potential income wL, where w is the after tax wage rate and L is total time endowment. This income can be spent on consumption X, time for travel T, distance dependent costs αD, and speed dependent costs βSD, where S is speed. Altogether we have the budget restriction

$$X=wL-wT-\alpha D-\beta SD$$

The individual receives utility from consumption and from travel distance, U=U(X,D). The inclusion of distance within the utility function is not intended to say that distance as such yields utility but rather that accessibility does. Longer travel distances means more destinations can be reached.

One of the variables D, S and T is redundant since D=ST. We replace D by ST in the utility function such that $U(X(S,T),D(S,T))=U(wL-wT-\alpha ST-\beta S^2T, ST)$. For simplicity we take U to be Cobb-Douglas with parameter γ and derive the first order conditions for maximum by differentiation with respect to S and T.

$$S: \gamma\alpha D+2\gamma\beta SD=(1-\gamma)X$$
$$T: \gamma wD/S+\gamma\alpha D+\gamma\beta SD=(1-\gamma)X$$

This generally shows that speed depends on distance and that distance depends on the choice of speed. However, since both speed and distance are simultaneous choices made by the same individual, these cannot be regarded as structural equations. It is possible to solve these equations for speed and distance. Solving the two equations together yields

$$S = \sqrt{\frac{w}{\beta}} \text{ and } D = \frac{(1-\gamma)wL}{\alpha + 2\sqrt{w\beta}}.$$

It is observed that both speed and distance depends positively on income. In practice these relationships are complicated by the fact that trips of different lengths do not use the same roads. Short trips are likely to use local roads with low speed limits, whereas long trips might use motorways with high speed limits. Furthermore, there is a start up time associated with each trip. Thus, speed depends on distance not only through the mechanism of individual utility optimisation.

3. Empirical analysis

3.1. Data

For the empirical test of the relationship between speed and income we utilise the Danish National Travel Survey, which is a continuous telephone interview survey of about 15-17,000 respondents annually (Danmarks TransportForskning, 2003). We select the same sample as in Fosgerau (2003). There are a total of 86,491 observations of car driver trips from the period 1996-2001, where both trip ends are outside the relatively congested capital region around Copenhagen. Discarding observations where income is not recorded leaves 76,001 observations. We further discard 15,846 observations of trips below 2 kilometres, as the time involved in starting the car and getting onto the larger roads is likely to dominate results. We discard 225 observations of trips above 200 kilometres, as the recorded average speed seems to decline at longer distances. This is thought to reflect coffee breaks and the like included with the reported time of trips. Finally, we discard 1,541 observations with average speed less than 20 km/h. After discarding observations in this way, we are left with 58,389 observations for analysis.

The main variables are speed, income and distance. The respondents have stated the time and distance for each trip from which we compute the average speed of the trip. Distance is measured in kilometres and speed is measured in kilometres per hour. Income is the pre-tax income of the driver, deflated to year 2000 prices and measured in 1000 Danish Kroner (DKK).[1] The sample mean income is 243,000 DKK.

Table 1 presents the basic relationship in the data between speed, income and distance. The sample has been split by income into three equal groups (breakpoints at 193,000 and 270,000 DKK). We further split the sample into five distance bands. The table presents the average speed and the number of observations in each group.

A number of points are noted from table 1. First note that both speed and distance increases with income as predicted by the theoretical analysis. Note also that average speed increases with distance. This may be because people with a preference for driving longer also like to drive faster. Another likely explanation is that trips take place on different types of roads with different speed limits and traffic characteristics. Short trips are likely to have a higher proportion on local urban roads with low speed limits. Also, some time is fixed regardless of the length of the trip such as getting from the front door to the car.

There are a number of potential confounding factors, as the table does not control for age, sex and other variables, which may influence speed and travel distances. Therefore, we perform regressions of speed and distance on income and control for age, sex, family type (single, couple), the presence of children (yes, no), urbanisation at the residence, the share of the trip in built-up areas, and a constant. The share of the trip in built-up areas is a discrete variable, ranging from 1: Completely in built-up area, to 5: completely in rural

[1] The current exchange rate is 100 EUR = 743 DKK.

area. We use this variable to control for the type of road and the corresponding speed limit. Table 2 and 3 present some summary statistics for these controls. In addition we also control for year of observation ranging from 1996 to 2001 with an about equal split of observations over years and also for regional dummies where Denmark has been divided into seven areas.

Table 1. Summary statistics: speed, distance and income

		Avg. speed			No. obs.		
Distance	Income	Low	Medium	High	Low	Medium	High
2-10		40.8	41.3	41.7	11755	10088	10707
10-50		56.6	58.2	59.6	7132	7984	7999
50-100		69.7	72.9	76.2	597	646	1201
100-150		79.8	78.4	82.8	144	172	347
150-200		82.5	83.7	88.0	35	61	121

Table 2. Summary statistics, binary control variables

Variable	N	Share	Avg. speed	Avg. distance	Avg. income
Women	24005	0.41	47.6	14.6	198.0
Men	34384	0.59	51.6	19.1	275.3
Single	7814	0.13	49.7	17.4	227.1
Couple	50575	0.87	50.0	17.2	246.0
No children	24826	0.43	49.8	18.2	234.5
Children	33563	0.57	50.0	16.6	250.2

From table 2 it is noted that men drive faster than women, they also drive longer distances and have higher incomes. Individuals who are part of a couple also drive faster and have higher incomes, although they drive slightly shorter trips. People with children drive faster and have higher incomes but drive somewhat shorter distances. It seems thus that some of the relationship between speed and income may be explained by sex, family type and the presence of children in the household. Controlling for these variables will tend to reduce the apparent effect of income on speed.

Table 3 presents summary statistics for the variables that are treated as continuous in the analysis. The urbanisation variable is measured on the place of residence. It is a seven point scale categorising the size of cities, ranging from 1 in central Copenhagen to 7 in the countryside. As we have discarded observations with trip ends within the Copenhagen region, the variable starts at 3 corresponding to cities with more than 100,000 inhabitants. The correlations presented in table 3 show that speed decreases with age and increases with decreasing city size and that income is lower in smaller cities. Speed increases as more of the trip takes place outside built-up areas.

Table 3. Summary statistics, continuous variables

Variable	Unit	Average	Median	Pairwise correlations		
				Speed	Distance	Income
Speed	Km/h	49.9	48	1.00	0.57	0.10
Distance	Km	17.3	10	0.57	1.00	0.10
Income	1000 DKK	243	228	0.10	0.10	1.00
Age	Years	43.0	42	-0.09	-0.02	0.03
Urbanisation	1-7 scale	5.4	5	0.11	0.00	-0.10
Built-up area	1-5 scale	3.1	4	0.35	0.27	-0.05

3.2. Econometric analysis

We specify two relations for the analysis, one for speed and one for distance. Note that we do not regard the first order conditions for utility maximisation as structural equations. Therefore we estimate the system in reduced form, with two equations for speed and income, each only depending on exogenous variables.

$$S=\alpha_1 X+\varepsilon_1 \quad (1)$$
$$D=\alpha_2 X+\varepsilon_2 \quad (2)$$

In general the error terms cannot be assumed to be independent conditional on X and X. Therefore we estimate the system using SUR, which allows for contemporaneous correlation in the error terms. However, in this case when the same variables enter the two equations on the right hand side, SUR is equivalent to OLS equation by equation (Wooldridge, 2002).

Table 4 presents the estimation results. Significance levels are very high reflecting on the large number of observations. t-statistics are computed from White heteroscedasticity-consistent standard errors. The goodness of fit as measured by the R-squared statistics for each equation are fine for a cross-sectional analysis.

The main point of interest is the income parameters. They are positive both for income and distance as expected and also extremely significant with t-statistics of 20 and 17. The implied income elasticity of speed is 0.044, which is in line with the results in Fosgerau (2003), where the model for speed included distance as an endogenous variable.

Otherwise the results show that both speed and distance decrease with age, these parameters are also estimated with extremely high significance levels. The presence of children reduces speed and distance. Singles tend to drive shorter distances but speeds are not significantly different from people living in couples. Women drive both slower and shorter than men.

The urbanisation variable is three in cities with more than 100,000 inhabitants and this category is taken as the base. In relation to this, people living in cities with 10-100,000 inhabitants drive faster but shorter distances People living in smaller cities drive even faster and shorter distances.

The proportion of the trip taking place in built-up areas acts as expected, with increasing speed and distances as more of the trip takes place outside built-up areas. There is an exception to this where trips completely outside built-up areas are both slower and shorter than trips with 75% outside built-up areas. This may be explained by completely rural trips using minor roads, where interurban trips more often have roads of a higher class available.

It is interesting to look at the correlation of the residuals from the two regressions, shown in table 5. They are quite highly correlated such that an individual who drives longer than expected from the model also is likely to drive faster. This can be explained by unobserved factors such as the type of road but also unobserved individual characteristics.

Table 4. Estimation results. t-statistics in parentheses computed from White heteroscedasticity-consistent standard errors.

	Speed	Distance
Log income	0.044(20)	0.10(17)
Age	-0.0029(27)	-0.0046(17)
Children	-0.027(9.2)	-0.11(14)
Single	0.00052(0.13)	-0.0080(0.79)
Female	-0.063(24)	-0.13(19)
Urbanisation=4	0.014(2.7)	-0.11(8.4)
Urbanisation>4	0.027(5.4)	-0.19(15)
Built-up =1	-0.31(86)	-1.1(117)
Built-up =2	-0.22(45)	-0.69(59)
Built-up =3	-0.092(22)	-0.26(23)
Built-up =5	-0.031(6.5)	-0.19(14)
Year=1997	0.016(3.6)	0.040(3.6)
Year=1998	0.0051(1.2)	0.021(1.8)
Year=1999	0.0047(1.1)	0.034(3.0)
Year=2000	0.031(7.3)	0.064(5.6)
Year=2001	0.0085(1.9)	0.046(3.9)
Area>6	0.029(7.0)	-0.019(1.7)
Area>5	-0.010(2.5)	0.045(4.2)
Area>4	-0.0083(1.9)	-0.0014(0.12)
Area>3	0.033(6.9)	0.021(1.6)
Area>2	-0.0016(0.33)	0.12(9.4)
Area>1	-0.017(0.66)	-0.19(2.5)
Constant	-0.25(8.6)	2.7(32)
R-squared	0.18	0.22

Table 5. Correlation of residuals

	Speed	Distance
Speed	1.00	0.59
Distance	0.59	1.00

4. Concluding remarks

We have amended the analysis in Fosgerau (2003) by analysing the relationship between speed and income when the choice of speed and distance is considered as a simultaneous choice. The results confirm the finding that speed increases with income, here with an estimated income elasticity of speed of 0.044, which is in the range found previously. The fact that a positive income elasticity is found in cross-sectional data gives support to the expectation that average motorway speeds will continue to rise in the future, ceteris paribus.

The estimated elasticity may seem somewhat small. However, income increases 2.45 times between the 10% and the 90% income percentile. This translates into an average speed difference of 4% or more than 4 km/h on motorways which is noticeable.

As discussed in Fosgerau (2003) the relationship between speed and income has implications for the design of sanctions against speeding. Thus income dependent fines could remove at least part of the reason that rich people drive faster than poor. In the present analysis, this can be seen by replacing β by $w\beta$ in the theoretical model, whereby the cost of speed would become income dependent.

It is tempting to attempt to improve the power of the models estimated here by including distance as an independent variable in the speed equation and vice versa. This would improve the fit of both models, as is evident looking at the correlation of the residuals from the two equations. However, as argued above, this would assume a structural relationship between speed and distance. This is not a valid assumption when the choice of both variables is made simultaneously by the same individual.

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