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The determinants of travel mode choice: the case of Łódź, Poland

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Abstract. In this study, potential factors influencing the decisions made by citizens of the city of Łódź, Poland, regarding the choice of transportation mode used in their daily travel activities were examined. In addition to a brief literature review, an empirical study was performed. Data from a previous quality-of-life study were used to enhance the scope of explanatory variables in a regression model. In order to identify the determinants of travel behaviour, binary logistic regression models were used. The results show that socio-demographic characteristics of respondents and household access to a car most influenced transport mode choices. Also, the relationship between geographic distances and subjective opinions regarding public transport were found to be statistically significant. The determinants for choosing either public or private transportation varied.

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1. Introduction

Modern society's rapid economic development is heavily associated with increased overall mobility. As the economic status of citizens increases, their habits regarding mode of transportation also change substantially. For instance, cars become more affordable, and car ownership in turn triggers a change in travel behaviour.

At the aggregate level, the economic growth of a country induces greater investment in transportation infrastructure. Eventually, this results in higher-quality roads, improved travel security and reduced travel times. These phenomena derive additional demand, which results in changes in citizens' travel mode choices (De Dios Ortúzar, Willumsen, 2011: 3–4). This also applies to the development of public transport. Municipalities invest in new buses and trams that are not only more effective, secure and durable but also provide greater passenger comfort. The processes described above lead to changes in citizens' travel mode choices, especially in developing cities.

The purpose of this study is to identify the factors that influence people's decisions concerning mode of transportation. The focus was on short-distance daily travel activities, such as daily commuting. A quantitative approach was used to study the empirical data. A binary logistic regression model was employed in order to scrutinise the factors that influence the frequency of choosing a particular mode of transportation. Due to the formulation of the questionnaire used, two separate econometric models were constructed: one for private modes of transportation and one for public.

The main contribution of this paper is the specific type of data used in the empirical exercise. The data were taken from the field of sociological studies, where only one part of the questionnaire was devoted to the issue of daily transportation choices. The regression analysis in this paper includes a much broader set of explanatory variables that were missing from previous standard travel studies. Therefore, new statistically significant determinants of travel behaviour could be discerned using the results. It is also worth noting that this study is one of the first in Poland to employ formal micro-econometric models to analyse travel behaviour. Therefore, the results can shed new light on the travel behaviour analysis of Polish citizens and introduce a different perspective for researching this field.

The structure of this paper is as follows. In the next section, key studies from the literature regarding travel behaviour are briefly assessed, concentrating mainly on studies conducted in Poland related to the selected modes of transportation. The following section describes the city of Łódź – a scientifically interesting case for travel behaviour studies. The fourth section describes the database and binary logistic regression model used in the empirical exercise. Afterwards, the outcomes of the study are presented and discussed. The final section concludes the paper.

2. Theoretical background

Travel behaviour studies are frequently conducted in Western Europe and the USA. Among the many papers offering quantitative approaches to travel behaviour modelling are the seminal works of Daniel McFadden (1974) and McFadden et al. (1977), who introduce the discrete choice model for studying the travel preferences of citizens in the San Francisco Bay Area. In contrast, Holz-Rau and Scheiner (2010) use structural equation modelling in order to identify the determinants of travel mode choices in the region of Cologne, Germany. Clearly, there are a wide variety of different econometric techniques in this field.

Some papers review the literature of travel behaviour determinants in a more structured manner (Curtis, Perkins, 2006; De Witte et al., 2013). The results of their analyses suggest that the determinants of travel mode choices can be divided into three main groups: sociodemographic, psychosocial and attitudinal factors. Conversely, some studies focus on land use and urban form as the factors influencing the travel behaviour of citizens (De Abreu e Silva et al., 2012; Banister, 2005: 97–128).

For this paper, special interest was directed to those studies in which empirical exercises were conducted with the use of discrete choice econometric models. In addition to the studies of McFadden mentioned above, this category include the works of Cervero (2006), De Witte and Macharis (2010),

Schwanen and Mokhtarian (2005), Asensio (2002), Van et al. (2014) and Mahmud and Rabbani (2012). The outcomes of these works suggest that discrete choice models are sufficient and proper tools for researching travel behaviour determinants.

The literature and empirical studies regarding Poland are rather sparse. Among the few available, the work of Gadziński (2016) discusses the accessibility of public transport and its relationship with travel behaviour for the inhabitants of Poznań. The author uses a correlation coefficient in order to conclude that travel frequency and mode choice are linked with the level of urbanisation. The residents in suburbs tend to take more trips, the majority of which are car rides. Most of the Polish studies lack empirical data (see Sierpiński, 2012; Motowidlak, 2016) or include only descriptive analyses and visualisations of the data (e.g., Suchorzewski, 1996; Monkiewicz et al., 2013; Wyszomirski, 2017). The work of Hebel (2013) presents a broad discussion of travel behaviour determinants through the use of rich statistical material regarding Polish cities. An important part of the study is the inclusion of factor analysis and association analysis in order to identify the determinants of travel behaviour for the citizens of Gdynia.

Among those rare studies that incorporate some statistical reasoning, Strawiński's (2003) study uses micro-econometric models to determine the factors influencing travel behaviour of the citizens of Gdynia. Furthermore, the work of Faron (2014) includes the estimation of ordinary least-squares models for the share of journeys by public or private transport modes for the inhabitants of the cities of Wrocław, Gdańsk and Kraków. Cheba and Saniuk (2015) apply binary logistic regression to the data for a mid-sized city in western Poland. The results of this study suggest that car ownership, type of public transport ticket and active employment status are significant predictors of the usage of public transport modes. Birr (2018) use a nested logit model to analyse the travel behaviour of the citizens of Gdańsk, Kraków and Warsaw. His results suggest that the major factors influencing mode choices are travel distances and car availability.

To sum up this brief literature review, there is a gap in the empirical studies regarding travel behaviour determinants for Poland. The use of econometric discrete choice models is a popular and appropriate method to investigate travel behaviour determinants. Therefore, this paper employs binary logistic regression to determine the factors that influence the frequency of use for particular modes of transportation in the city of Łódź.

3. Study area

The subject of the study is the city of Łódź. It is located in central Poland near the crossing of two main Polish motorways, the A1 (north–south) and the A2 (east–west). Both motorways are part of the international E-road network, corresponding to roads E75 and E30, respectively. As a result of its location near one of the most important road junctions in Poland, the city is considered to be a valuable logistics hub, resulting in the rapid development of storage and logistics enterprises near Łódź. Furthermore, a railway network recently began to be developed in the city. In the next few years, a city tunnel connecting the major train stations will be built beneath the city centre. This investment is intended to be a key factor in making Łódź an important railway junction (Wiśniewski, 2017).

Despite its infrastructural development, Łódź suffers from a high level of congestion. According to data published by the Polish Statistical Office (n.d.), in 2016 there were 525 passenger cars per 1,000 inhabitants in Łódź. This number has been systematically increasing. In 2009 there were 389 cars per 1,000 citizens, which means that over seven years this ratio increased by 35%. Taking into account the fact that Poland has the highest share of cars of more than 20 years old (33.7%) among EU member countries (Eurostat, 2018), the overall assessment of congestion and pollution in Łódź is rather negative. The issue of high congestion is also supported by the TomTom Traffic Index (TomTom International BV, 2016). The data reveal that, among cities with populations of less than 800,000, Łódź is the most congested. These facts show that the city has transportation issues. In this case, an analysis of the travel mode choices made by citizens is especially important.

As the aim of this paper is to identify the determinants of travel behaviour, it is also important to analyse the specific socio-economic characteris-

tics of the citizens of Łódź as a post-industrial city. The socio-economic characteristics are directly related to the chaotic development of the communist period of the Polish People's Republic, and an decrease in living conditions and accelerated growth in unemployment rate in the 1990s. After Poland's economic system became a free-market economy, the textile industry abruptly collapsed. As the years passed, the city of Łódź gradually regained its position, but presently the city can still be considered post-industrial. The underdeveloped transport infrastructure is one of the main consequences of this, but the socio-economic status of the inhabitants was also affected.

Łódź is the third largest city in Poland and is in the midst of infrastructural and social revitalisation. However, issues arising from its post-industrial past are still visible in the economic status of the city and its inhabitants. The unique blend of its exceptional location within Poland and the problems described above makes the city of Łódź an interesting subject for travel behaviour analysis.

4. Material and research methods

The empirical research is based on the dataset taken from the study *Quality of life of the citizens of Łódź and its spatial diversification* (Rokicka, 2013). In this study, a representative sample of 1,000 citizens of Łódź was surveyed in June 2012 with a broad questionnaire composed of about 120 questions. The topics of the survey were diverse and covered issues related to lifestyle, habits, economic and health status, security, social relations and transport. The questions of specific interest to this study were those related to frequency of usage of different travel modes during the last 12 months. The survey covered various modes of transport, but only a few of them were represented by a sufficient number of answers. Therefore, the variables used were those related to public transportation (trams and buses) and private transportation (car as a driver or as a passenger). According to these data, the share of people who declare daily or almost-daily usage of public transportation was 39.2%, compared to 31.4% for private transport.

The same database was used in the study by Wójcik (2017), who utilised multinomial logistic regression models to analyse the determinants of usage frequency of particular modes of transportation. Contrary to that study, the present study used binary logistic regressions, which achieve higher precision and more interpretable results. The most important difference is the extension of the database with the usage of ArcMap software. The analysis was enhanced with spatial and time distances linking the geographical centre of the city of Łódź with respondents' addresses. Moreover, time distances were calculated for car travel and for the shortest journey by public transport. The extension of the dataset in this way significantly improved the final results.

The empirical exercise was performed with the use of the binary logistic regression model (Cameron, Trivedi, 2009: 463–478). In this case, the dependent variable y_i could take one of two possible values:

$$y_i = \begin{cases} 1 & with\ probalility\ p_i \\ 0 & with\ probabilty\ 1 - p_i \end{cases} \quad (1)$$

where 1 means that the particular respondent used the considered mode of transportation every day or almost every day and 0 denotes less or no usage. Probability p_i depends on the regressor vector x and the parameter vector β. In general, for binary outcome dependent variables, p_i can be denoted as a conditional probability:

$$p_i \equiv Probability(y_i = 1 \mid x) = F(x_i'\beta) \quad (2)$$

where $F(\cdot)$ is a specified mathematical function. To assure that $0 \leq p_i \leq 1$, the function $F(\cdot)$ should be a cumulative distribution function (cdf). In the case of logistic regression, the logistic cdf is used:

$$p_i = \Lambda(x_i'\beta) = \frac{e^{x_i'\beta}}{1+e^{x_i'\beta}} \quad (3)$$

where e is an Euler's constant.

The parameters of the model were estimated with the maximum likelihood method.

5. Results

The results of the estimations are presented in Table 1. Due to the nonlinearity of the logistic regression, the values of the parameters could not be interpreted simply. Therefore, the average marginal effects (AME) are also presented, which can be interpreted as the changes in probabilities of y=1.

The outcomes presented in Table 1 are the final results of the iterative procedure of removing statistically insignificant variables. The statistical properties of the models were also tested. Both models achieved high McFadden Pseudo-R^2 values, which confirms the reliability of the outcomes. Also, the signs of the parameters can be assessed as theoretically correct in comparison to other studies in this field. Table 1 contains only the models composed of statistically significant variables (at the level of significance α=0.05), as the complete list of independent variables is fairly broad. Thus, in order to maintain the requirements on article length, the full list of variables is omitted.

The results of the estimations suggest that the sociodemographic characteristics of respondents played a major role in describing the propensity to use a particular mode of transport on a daily basis. For the frequency of private transport usage, the nonlinear (parabolic) effect of age was observed. This means that as age increased, the probability of regular use of private transport also increased up to a certain age, and then a decline was observed. In this case, the highest probability was obtained for the respondents of 35–44 years old. The effect of age was linear for the public transport model. A

Table 1. Logistic regressions estimates

	Public Transport			Private Transport		
	Parameter	**p-value[a]**	**AME**	**Parameter**	**p-value[a]**	**AME**
Age	-0.021	0.000	-0.004	0.172	0.000	-0.0001
Age^2	-	-	-	-0.002	0.000	-
Sex (female)	0.452	0.003	0.088	-1.590	0.000	-0.210
Employed	0.850	0.000	0.166	0.421	0.047	0.053
Married	-	-	-	-0.338	0.094	-0.041
Student/pupil	1.27	0.000	0.256	-	-	-
Education (higher)	-0.545	0.013	-0.103	0.981	0.000	0.130
Financial situation assessment (moderate)[b]	0.572	0.004	0.109	-	-	-
Financial situation assessment (poor)[b]	0.538	0.023	0.102	-	-	-
Own one car	-1.240	0.000	-0.246	2.340	0.000	0.357
Own two or more cars	-1.060	0.009	-0.187	-1.790	0.000	0.247
Public transport offer assessment	0.633	0.000	0.125	-	-	-
Distance to the city centre	-0.068	0.027	-0.013	-	-	-
Constant	-0.248	0.583	-	-4.730	0.000	-
Pseudo-R^2		0.154			0.378	
N		965			992	
Wald chi^2		149.05			245.20	
p-value (Wald)		0.000			0.000	

[a] *P-values based on the robust variance estimates.*
[b] *Base category for financial situation assessment is a 'good financial situation'.*

Source: own calculation

one-year increase in age reduced the probability of choosing public transport by 0.004.

Gender differences were clearly visible in the results of this study. Women were more likely (by 0.09) than men to use public transportation on a daily basis. For use of a car, the probability was 0.21 lower for women. It is worth noting that this was the strongest negative determinant of regular private transport choice.

Active employment status was a significant positive determinant of regular commuting. Its effect on public transport (0.166) was approximately three times higher than for private transport. This means that, all things being equal, the ordinary commuter tended to choose public transportation more often than private cars.

Respondents' marital status also seemed to be an important determinant of travel behaviour. People who were married had a lower probability of choosing to use a private car, but this effect was significant only at significance level $\alpha=0.1$ (p-value <0.1).

We can try to explain this effect by the extended scope of reasons to use a car related to the needs of children and family itself.

The status of being a student or pupil had a significant impact on the regular usage of public transportation. The probability of everyday usage of public transport rose by 0.256 for students or pupils. This had the highest positive effect among all of the public transportation determinants. This phenomenon could be explained by student and pupil discounts on public transportation.

The respondents who declared their highest achieved level of education as a bachelor or master's degree had a higher probability of regular usage of private transportation. This effect can be explained by a higher level of income, which was not directly available in the dataset (many respondents refused to answer). Level of income can also be described by the subjective financial situation assessment. This variable was revealed to be significant only for the public transport model. The results show that moderate and poor financial situation assessments positively stimulated the choice of cheaper transport modes.

Car ownership was the strongest positive determinant of choosing private transportation (0.357). This also significantly decreased the probability of using public transport. Unsurprisingly, the effect of owning two or more cars also increased the daily use of private transportation. But the strongest effect was observed for the first car in the household.

Regarding subjective opinions on public transportation, only one variable was revealed to be significant. People who viewed public transport positively had a higher probability (0.125) of choosing public transport than people who felt that the public transport options were unsatisfactory.

The inclusion of spatial variables revealed a significant effect of the distance between the city centre and the respondent's place of residence. We can conclude that for every 1 km increase, the probability of the regular use of public transport would decrease by 0.013. This effect was not significant for private transport, which is more flexible regarding travel time and route choice.

6. Conclusions

The main goal of this study was to identify the determinants of frequency of usage of particular transport modes for citizens in Łódź. This goal has been achieved with the use of the binary logistic regression model.

The results are in line with the findings of the studies discussed in section 2. This means that despite the post-industrial infrastructure and social character of the city of Łódź, the travel mode choices of the citizens remain similar to those made by their counterparts in more developed countries. This result is especially interesting if we take into account the fact that studies on the post-socialist countries of central and eastern Europe are still very rare.

Unsurprisingly, the most important stimulant of regular private transport use at the expense of public transport use is the ownership of a car by someone in the respondent's household. Travel behaviour is also strongly affected by the socio-demographic characteristics of the respondents, their civil and work statuses and financial situation assessments. In the model dedicated to public transport, we also observed the significant effect of the geographical distance between the respondent's house and the city centre as well as people's opinions regarding public transportation choices.

The study did not include the determinants of using a bicycle as a mode of daily transportation. The reason for this is that a very small number of respondents declared daily usage of bicycles. This shows that, despite local government actions to popularise biking in the city, the use of this transport mode is still low. It is worth noting that the data were collected in 2012 before the introduction of the bike sharing system in Łódź (which began in April 2016). Also, the size of the cycling infrastructure has grown since that time. We can expect that this has increased the number of trips made by bike by the citizens of Łódź. On the other hand, the results of a recent study for Polish cities show that the share of bike trips remains low in Poland compared to Western Europe (Bartosiewicz, Pielesiak, 2019)

The contribution of this study is mainly the specific dataset it uses in the empirical exercise. The data were taken from a sociological study that allowed us to examine a broader set of explanatory variables than in traditional travel behaviour studies. This is also one of the first quantitative analyses performed for the Polish market. The fact that the data were collected in 2012 does not mean that the conclusions are outdated. We argue that demographic and economic changes are too slow to significantly affect the validity of the outcomes. However, we believe that the results of this study will stand as a valuable point of comparison for further research on Polish cities in this field.

Developing quantitatively-oriented research on Polish data will result in a deeper understanding of the specifics of Polish citizens' travel behaviour. The outcomes of the analysis can be used by local governments to shape urban policy. Moreover, this information can be a crucial asset for inducing a change in citizens' travel behaviour towards more sustainable mobility. In addition, the clarity and usability of the results of quantitative travel behaviour studies can encourage local governments to finance and conduct regular travel behaviour surveys, which are still rare in Poland.

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