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Factors influencing modal split of commuting journeys in 34 medium-sized European cities

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Abstract

The paper attempts to identify factors that influence modal split for journeys to work in cities with populations of between 100 thousand and 500 thousand in Germany, the Netherlands, Switzerland and the UK. The sample consisted of 34 cities. The analysis revealed a significant negative correlation between modal shares of motorised modes and public transport. A negative correlation between motorised modes and non-motorised modes, albeit to a lesser degree, was also found. Public transport- and non-motorised mode share, however, were not correlated.

1. Introduction

Sustainable transport has become an important point on most national, regional and local governments' agendas. Sustainability in transport, typically defined along economic, environmental and social (or equity) dimensions (European Commission, 2008, p.12), can be achieved with sustainable modes of transport (as well as with sustainable travel behaviour). In general, there is consensus that the private car does not enhance sustainability, whereas public transport and non-motorised modes, such as walking and cycling, do. It is therefore important to understand what drives people *towards* and *away from* the private car, public transport and non-motorised modes. Once this is done appropriate policies can be designed in order to enhance transport sustainability.

This paper works towards that objective by analysing the factors that influence the modal split for journeys to work in medium-sized cities in Germany, the Netherlands, Switzerland and the UK. These were (somewhat arbitrarily) defined as cities with populations of 100,000 to 500,000.

Following Rodrigue et al. (2009, pp. 241, 336) we define *modal split* as the proportion of trips that is made by each transport mode and *modal share* as the relative contribution of a single mode to the total traffic volume. *Modal shift* or *modal switch* shall stand for modal split alterations in favour of one, and at the expense of another mode. *Journeys to work* or

commuting journeys are defined according to the European Commission (2004, p. 46) as the shortest trips from home to work.

Newman and Kenworthy (1999, p. 86) explain that journeys to work account for most peak demand on road networks. Likewise, Santos et al. (2010b, p. 84) point out that addressing commuter trips is essential for relieving congestion in urban areas. However, solely concentrating on journeys to work tends to overstate public transport, since it is particularly strong in that market (Kenworthy et al. 1999, p. 17).

This paper attempts to answer the following questions:

- What factors reduce the share of motorised modes?
- What factors increase the share of non-motorised modes?
- What factors encourage a switch from the private car to public transport?
- Do any substitution or complementary effects exist between the modes?

Section 2 reviews the most relevant literature for this study; Section 3 presents the model and describes the data used; Section 4 analyses the results and Section 5 summarises the main findings, together with some policy recommendations and suggestions for further research.

2. Literature review

Modal split is closely related to other traffic indicators such as individual mode choice, car use, travel demand and public transport demand (Kitamura 2009, White 2009). Newman and Kenworthy (1989) and Cervero (1998) point out the importance of urban density for the viability of public transport and non-motorised modes, whereas Cervero (1998) also emphasises land use diversity. Balcombe et al. (2004), however, do not regard urban diversity as influential for public transport demand. Scheiner (2010) and White (2009) note a positive effect of city size for undertaking non-motorised journeys.

Car ownership appears to increase the share of motorised trips (Balcombe et al. 2004, Scheiner 2010), although Kitamura (2009) and White (2009) report contradicting figures. Restricting and pricing road- and parking space may achieve substantial shifts from the private car to other modes (Hass-Klau et al. 2003 and Newman and Kenworthy 1989). With regard to parking charges Santos et al. (2010a) are more sceptical. Hass-Klau and Crampton (2002) suggest positive influence from extensive pedestrian zones on public transport use. White (2009) reports a positive relationship between public transport subsidies and public transport ridership, whereas Newman and Kenworthy (1999) anticipate a negative association. Opinions on the merits of light rail diverge. Newman and Kenworthy (1999) and Steer Davies Gleave (2005) observe inherent limitations of bus-based systems concerning the

potential of attracting car users. Richmond (2001), however, emphasises the inflexibility and inferior financial performance of light rail, and Cervero (1998) insists that the urban environment favours rail in some cases, and buses in others. Buchanan (1964) expects a noticeable modal shift from low public transport fares, whereas Asensio (2000) and Cervero (1998) expect higher influence from frequent services. Balcombe et al. (2004) regard high frequencies and affordable tickets as equally influential in the long term and do not consider vehicle comfort as particularly decisive. Finally, Hass-Klau and Crampton (2002) and White (2009) emphasise the importance of integrated ticketing for public transport patronage.

Table 1 gives an overview of the above factors' considered influence on the modal share of public transport and non-motorised modes. The opposite direction of influence applies to motorised modes.

Factor	Author	Suggested association
Urban density	Cervero (1998)	+
	Newman and Kenworthy (1989)	+
Mixed land-use	Balcombe et al. (2004)	=
	Cervero (1998)	+
City size	Scheiner (2010)	+
	White (2009)	+
Car ownership	Balcombe et al. (2004)	--
	Kitamura (2009)	=
	Scheiner (2010)	--
	White (2009)	=
Parking space limitations	Hass-Klau et al. (2003)	+
	Newman and Kenworthy (1989)	+
	Santos et al. (2010b)	+
Parking charges	Hass-Klau et al. (2003)	+
	Santos et al. (2010a)	=
Pedestrian zones	Hass-Klau and Crampton (2002)	+
Public transport subsidy	Newman and Kenworthy (1999)	--
	Santos et al. (2010b)	+
	White (2009)	+
Light rail presence	Cervero (1998)	=
	Newman and Kenworthy (1999)	+
	Richmond (2001)	--
	Steer Davies Gleave (2005)	+
Public transport fares	Asensio (2000)	=
	Balcombe et al. (2004)	--

	Buchanan (1964)	--
	Cervero (1998)	=
Public transport service frequency	Asensio (2000)	+
	Balcombe et al. (2004)	+
	Cervero (1998)	+
	White (2009)	+
Public transport vehicles	Balcombe et al. (2004)	=
Integrated ticketing	Hass-Klau and Crampton (2002)	+
	White (2009)	+

Table 1: Association of urban environment, car ownership, traffic restraint and public transport factors for using public transport and non-motorised modes according to the reviewed literature; (+) stands for positive association, (--) for negative association and (=) for no association

3. Model and data

3.1 Data sources

This paper utilises data from Eurostat's urban audit. The database is freely accessible at: <http://www.urbanaudit.org/index.aspx>. It covers 336 variables and three spatial levels. *Core cities* refer to areas of local government responsibility, *larger urban zones* or *functional urban areas* usually exceed the core city boundaries and *sub-city districts* are used for comparing disparities within cities (European Commission 2004, pp. 5, 9, 12). Although larger urban zones would be the most suitable spatial reference, due to limited data availability core city data were used instead (European Commission 2004, p. 11). The data used in this study corresponds to the year 2004, whenever such data were available, or to 2001, when data for 2004 were unavailable.

Online sources were accessed for retrieving public transport fare and public transport subsidy information and for light rail- and traffic restraint data. Unfortunately the data corresponds to different years for different items and different cities, but always within the period 2004 to 2010.

A number of local authorities were contacted by email with queries on:

1. Number of parking spaces (on-street and off-street) in the area being considered as the city centre or the central business district
2. The minimum charge for one hour parking within the city centre or the central business district
3. The length of the pedestrian zone (where motorised individual traffic is exempt) within the city centre or the central business district

4. The authority's annual financial support for bus services and concessionary tickets

5. The total length of light rail lines within the administrative city boundary

Some local authorities failed to answer some questions due to lack of data. Most of the responses referred to the year 2010.

The data collection yielded a sample of 34 cities (17 from Germany, 2 from the Netherlands, 4 from Switzerland and 11 from the UK), listed on Table 2. Dutch cities are underrepresented as the result of few responses from local authorities.

Country	Cities
Germany	Augsburg; Bielefeld; Bochum; Dresden; Erfurt; Freiburg; Gottingen; Karlsruhe; Leipzig; Magdeburg; Monchengladbach; Mulheim; Nurnberg; Regensburg; Saarbrucken; Wiesbaden; Wuppertal
Netherlands	Enschede; The Hague
Switzerland	Bern; Geneva; Lausanne; Zurich
UK	Bradford; Bristol; Cardiff; Coventry; Exeter; Newcastle; Portsmouth; Stoke-on-Trent; Wolverhampton; Wrexham

Table 2: The sample cities

3.2 Data collection

Modal split figures were exclusively obtained from Eurostat's urban audit, which covers the variables *automobile share*, *motorcycle share*, *bicycle share*, *walking share* and *public transport share*. Data for Germany and the Netherlands refer to 2004 and those for Switzerland and the UK, to 2001.

Figures for *resident population*, *total land area*, *water and wetland* and *proportion of green surfaces* were exclusively retrieved from Eurostat's urban audit. The latter two were required for meaningful density calculations, since agricultural surfaces, meadows, forests, and water surfaces do not belong to urban land (Kenworthy et al. 1999, pp. 38-39). No suitable indicators could be identified for mixed land-use and urban design. Thus, no such data were collected.

The variable *registered cars per 1000 residents* was retrieved from Eurostat's urban audit, and all data refer to 2004. The inconsistency in reporting publicly and privately owned parking spaces by local authorities forced us to omit the variable parking space limitations. Parking prices, however, are represented by the variable *minimum one hour parking charge in the city centre*, wherefore solely daytime charges were considered. These were mainly

collected from local authorities and, to a lesser extent, from online sources and mainly refer to 2010.

The variable *length of pedestrian zone in the city centre* was predominantly obtained from direct inquiries to local authorities. Besides, Hass-Klau and Crampton (2002, p. 124) indicate the pedestrian street lengths for 35 cities. These figures are included for Freiburg, Leipzig, Regensburg, The Hague, Newcastle and Nottingham. The value for Geneva is derived from measuring the length of sections on a map (Ville de Geneve 2009) in combination with a scale available from Google Maps (2010). The sources of for the urban environment variables are listed on Table 3.

Country	City	One hour parking charge in the city centre	Length of the pedestrian zone in the city centre
Germany	Augsburg	Hösle (2010)	Hösle (2010)
	Bielefeld	Fabian (2010)	Fabian (2010)
	Bochum	Bremer (2010)	Bremer (2010)
	Dresden	Ziesch (2010)	Ziesch (2010)
	Erfurt	Strutz (2010)	Strutz (2010)
	Freiburg	Gutzmer (2010)	Hass-Klau and Crampton (2002, p. 124)
	Gottingen	Krieger (2010)	Krieger (2010)
	Karlsruhe	Wagner (2010)	Wagner (2010)
	Leipzig	Radke (2010)	Hass-Klau and Crampton (2002, p. 124)
	Magdeburg	Rudolph (2010)	Rudolph (2010)
	Monchengladbach	Clages (2010)	Clages (2010)
	Mulheim	Jansen (2010)	Jansen (2010)
	Nurnberg	Deller (2010)	Deller (2010)
	Regensburg	Weiler (2010)	Hass-Klau and Crampton (2002, p. 124)
	Saarbrücken	Schöndorf (2010)	Schöndorf (2010)
	Wiesbaden	Conrad (2010)	Conrad (2010)
	Wuppertal	Holstein (2010)	Holstein (2010)
Netherlands	Enschede	Groenewolt (2010)	Groenewolt (2010)
	The Hague	Qpark (2010)	Hass-Klau and Crampton (2002, p. 124)
Switzerland	Bern	Noack (2010)	Noack (2010)
	Geneva	Malacorda (2010)	Ville de Genève (2010);

			Google Maps (2010)
	Lausanne	Lausanne (no year a)	Lausanne (no year b)
	Zurich	Marzolini (2010)	Marzolini (2010)
UK	Bradford	Moore (2010)	Moore (2010)
	Bristol	Day (2010)	Terry (2010)
	Cardiff	Shipton (2010)	Shipton (2010)
	Coventry	Coventry and Warwickshire (2010)	Jones (2010)
	Exeter	Hussey (2010)	Hussey (2010)
	Newcastle	Skeen (2010)	Hass-Klau and Crampton (2002, p. 124)
	Nottingham	Nottingham City Council (2009)	Hass-Klau and Crampton (2002, p. 124)
	Portsmouth	Todd (2010)	Lumley (2010)
	Stoke-on-Trent	Buckton (2010)	Buckton (2010)
	Wolverhampton	R&T Transport Strategy (2010)	R&T Transport Strategy (2010)
	Wrexham	Rodgers (2010)	Rodgers (2010)

Table 3: Sources of the variables one hour parking charge in the city centre and length of pedestrian zone in the city centre

Data on public transport subsidies were derived from transport operator annual reports, local authority statements of accounts and budget proposals and local authority direct inquiries. The former approach was predominantly pursued for the German and Swiss cities and The Hague, wherefore income- and expenditure accounts were reviewed. For Bielefeld, Dresden and Zurich, the data were indirectly derived from public transport revenue and cost coverage figures.

In most UK cities and Enschede, the data represent local authority expenditures for concessionary fares and socially necessary bus services and were collected from local authority statements of accounts or through local authority inquiries. For Coventry, Newcastle and Wolverhampton, subsidies reflect city council levies to the public transport authority of the metropolitan area. The value of Bradford refers to concessionary fare- and bus service subsidies divided by the population of the West Yorkshire metropolitan area. The data corresponds to different years, always falling in the period 2004 to 2010.

Light rail line kilometres were used for measuring the presence of light rail. Hass-Klau et al. (2003, pp. 28-40) present a table of light rail systems in the world which was used for indentifying those cities with no such infrastructure. Data were also obtained from online

sources or local authority direct inquiries. The figures have reference years between 2004 and 2010. Since Nottingham introduced a new system in 2003 (Hass-Klau et al. 2003, p. 33), no light rail provision was indicated for this city.

The variable *monthly ticket fare* indicates public transport price levels, whereby specifically non-transferrable non-concessionary adult standard class tickets for an inner city zone were considered. For the German and Swiss cities as well as The Hague, Bradford, Newcastle and Wolverhampton, transport authority websites were consulted. For the remaining UK cities and Enschede, data refer to private bus operators. The reference year is always 2010.¹ The sources for the public transport variables are shown on Table 4.

City	Annual public transport subsidies	Light rail line kilometres	Monthly ticket fare
Augsburg	Stadtwerke Augsburg (2009, p. 7)	Stadtwerke Augsburg (2010, p. 7)	Augsburger Verkehrs- und Tarifverbund (2010, p. 1)
Bielefeld	MoBiel (no year, p. 2); Stadtwerke Bielefeld (2010, p. 90)	MoBiel (2010a, p. 1)	MoBiel (2010b)
Bochum	Bremer (2010)	Bremer (2010)	Verkehrsverbund Rhein-Rhur (2010)
Dresden	Dresdener Verkehrsbetriebe (2009, p. 1)	Dresdener Verkehrsbetriebe (2009, p. 2)	Dresdener Verkehrsbetriebe (no year)
Erfurt	Stadtwerke Erfurt Gruppe (2009, p. 39)	SWE EVAG (2009a)	SWE EVAG (2009b)
Freiburg	Gutzmer (2010)	Gutzmer (2010)	Freiburger Verkehrs AG (no year)
Göttingen	Stadtwerke Göttingen (2009, p. 78)	Hass-Klau et al. (2003, p. 30)	Göttinger Verkehrsbetriebe (2010)
Karlsruhe	Verkehrsbetriebe Karlsruhe (2005, p. 31)	Karlsruher Verkehrsverbund (no year)	Karlsruher Verkehrsverbund (2010)
Leipzig	Leipziger Verkehrsbetriebe (2010, p. 84)	Leipziger Verkehrsbetriebe (2010, p. 111)	Leipziger Verkehrsbetriebe (no year)
Magdeburg	Magdeburger Verkehrsbetriebe (2005, p. 25)	Magdeburger Verkehrsbetriebe (2010)	Magdeburger Verkehrsbetriebe (2008, p. 2)
Monchengladbach	Clages (2010)	Hass-Klau et al. (2003, p. 31)	Verkehrsverbund Rhein-Rhur (2010)

¹ Since fares could change over time, the validity of such data in relation to older modal share figures is questionable.

Mulheim	Jansen (2010)	Mülheimer Verkehrs- gesellschaft (no year)	Verkehrsverbund Rhein- Rhur (2010)
Nurnberg	Verkehrs-Aktiengesellschaft Nürnberg (2010, p. 94)	Deller (2010)	Verkehrsverbund Grossraum Nürnberg (2010)
Regensburg	Stadtwerke Regensburg (2009, p. 42)	Hass-Klau et al. (2003, p. 31)	Regensburger Verkehrsverbund (2010); Regensburger Verkehrsverbund (no year)
Saarbrücken	Versorgungs- und Verkehrsgesellschaft Saarbrücken (2009, pp. 52, 58)	Schöndorf (2010)	Saarländischer Verkehrsverbund (2010)
Wiesbaden	ESWE Verkehrsgesellschaft (2005, p. 20)	Hass-Klau et al. (2003, p. 32)	ESWE Verkehrsgesellschaft (no year)
Wuppertal	Wuppertaler Stadtwerke (2010, p. 46)	Wuppertaler Stadtwerke (no year, p. 1)	Verkehrsverbund Rhein- Rhur (2010)
Enschede	Groenewolt (2010)	Hass-Klau et al. (2003, p. 32)	Connexxion (2010)
The Hague	HTM (2009, p. 52)	UrbanRail (no year)	HTM (2010)
Bern	Bernmobil (2007, p. 19)	Bernmobil (2007, p. 18)	Bernmobil (no year)
Geneva	Transport publics genevois (2007, p. 52)	Transports publics genevois (2007, p. 68)	Transports publics genevois (2010)
Lausanne	Transport publics de la région lausannoise (2010, p. 42)	Transports publics de la région lausannoise (2010, p. 31)	Mobilis (no year)
Zurich	Verkehrsbetriebe Zürich (2006, p. 21); Zürcher Verkehrsverbund (2010a, p. 23)	Verkehrsbetriebe Zürich (2010)	Zürcher Verkehrsverbund (2010b)
Bradford	Moore (2010); West Yorkshire Lieutenancy (2005)	Hass-Klau et al. (2003, p. 33)	Metro (no year)
Bristol	Bristol City Council (2008, p. 36)	Hass-Klau et al. (2003, p. 33)	First Group (2010a)
Cardiff	Cardiff (2005, p. 110)	Hass-Klau et al. (2003, p. 33)	Cardiff bus (no year)
Coventry	Coventry City Council (2007, p. 24)	Hass-Klau et al. (2003, p. 33)	National Express West Midlands (2010)
Exeter	Hussey (2010)	Hass-Klau et al. (2003, p. 33)	Stagecoach (2009)

Newcastle	Newcastle upon Tyne (2005, p. 58)	Bridges (2010)	Nexus (2010)
Nottingham	Morgan (2010)	Hass-Klau et al. (2003, p. 33)	Nottingham City Transport (no year)
Portsmouth	Carnell (2010)	Hass-Klau et al. (2003, p. 33)	First Group (2010b)
Stoke-on-Trent	Edwards (2010)	Hass-Klau et al. (2003, p. 33)	City of Stoke on Trent (no year)
Wolverhampton	Wolverhampton City Council (2005, p. 127)	R&T Transport Strategy (2010)	Network West Midlands (no year)
Wrexham	Wrexham County Borough Council (2005, p. 44)	Hass-Klau et al. (2003, p. 33)	Arriva (no year)

Table 4: Sources for annual public transport subsidies, light rail line kilometres and monthly ticket fares

3.3 Framing the analysis variables

The variables *resident population*, *length of the pedestrian zone in the city centre* and *cars per 1000 population* enter the analysis unadjusted. The modal share figures were reclassified according to Kenworthy et al. (1999, p. 44) into *motorised modes* (car and motorcycle), *non-motorised modes* (bicycle and foot) and *public transport* (original class retained).

In order to calculate the urban residential density, *population size* was divided by the developed urban area which was in turn calculated from the *total land area*, the *proportion of green surfaces* and the *area of water and wetland*.

The figures for annual public transport subsidies, parking charges and public transport ticket fares refer to each country's local currency (Euro for Germany and the Netherlands, Swiss Franc for Switzerland and Pound Sterling for the UK) and a specific year which is always 2010 in the case of parking charges and ticket fares. In order to ensure comparability, all values were converted to Pound Sterling at the average exchange rate for the specific reference year.^{2,3} Inflation was also taken into account for public transport subsidies.⁴

² The exchange rates used were taken from Bank of England (2010a).

³ The 2009 value was used for 2010, since an annual average was not yet available when we conducted the analysis.

⁴ Average annual inflation rates were retrieved from Bank of England (2010b) in order to calculate the value of one Pound Sterling relative to 2010.

Finally, annual public transport subsidy values were divided by *resident population* in order to obtain *annual public transport subsidies per capita*, and light rail kilometres were divided by the urban land area in order to obtain *light rail line kilometres per urban land area*. All variables are listed on Table 5.

Variable	Abbreviation
Share of motorised modes for journeys to work (%)	MSMOT
Share of public transport for journeys to work (%)	MSPT
Share of non-motorised modes for journeys to work (%)	MSNON
Resident population	RESPOP
Urban residential density (people per km ²)	RESDENS
Registered cars per 1000 population	CAROWN
Length of pedestrian zone in city centre (km)	PEDZONE
1 hour parking charge in the city centre (£)	PARKING
Annual public transport subsidies per capita (£)	PTSUBS
Monthly ticket fare (£)	PTFARE
Light rail lines per urban land area (km/km ²)	LRAIL

Table 5: Overview of the variables covered in the analysis

3.4 Applying correlation and regression analyses

Since all variables are at least interval-scaled, multiple linear regression analyses were employed. The one-sample Kolmogorov-Smirnov test for normal distribution reveals that only the variable PTSUBS significantly differs from a normal distribution ($p_{Ho} = 0.039$). Nevertheless, one might ignore the normal distribution premise, since violating this assumption generally does not have adverse effects (De Vaus 2002, pp. 78-79).

The dataset contains 16 outlier values beyond 2 standard deviations from the mean and 5 beyond 3, respectively. For the analyses, all values in the dataset above ± 3 standard deviations from the mean are recoded to exactly mean ± 3 standard deviations, according to Tabachnick and Fidell (1983) cited in De Vaus (2002, pp. 94-95). Calculations with unadjusted outliers as well as the more stringent threshold of mean ± 2 standard deviations are also made and will be mentioned, if they yield different results.

High absolute correlation values can be expected from modal share figures, since they sum up to 100%. Consequently, one should focus on directions and relative strengths of correlations rather than interpreting absolute values.

4. Results and analyses

4.1 Data description

In this section, the data are briefly described. The descriptive statistics for each variable are given on Table 6.

	MS MOT	MS PT	MS NON	RES POP	RES DENS	CAR OWN	PED ZONE	PARK ING	PT SUBS	PTF ARE	LRA IL
Min	23.9	5.0	1.7	115200	2658	275.0	0.48	0.00	18.7	34.38	0.00
Max	94.4	62.6	34.0	498491	12560	479.0	8.00	2.23	478.7	72.00	2.43
Median	67.5	15.8	12.9	261186	4553	400.0	2.00	0.89	53.7	46.44	0.28
Mean	65.2	20.6	14.0	272387	4876	400.7	2.50	0.97	93.8	47.23	0.50
Std. Dev.	16.4	13.3	7.6	119482	2051	49.4	1.84	0.51	106.5	8.94	0.63

Table 6: Basic descriptive statistics of all variables considered in the analysis

In all but five cities, the share of motorised modes for journeys to work (MSMOT) exceeds 50%. The lowest value corresponds to Bern (23.9%), followed by the other Swiss cities and The Hague. The median of 67.5% underscores the dominance of motorised modes for journeys to work across the sample cities. The share of public transport for journeys to work (MSPT) only exceeds 50% in Zurich (62.6%) and Bern (53.9%). The median equals 15.8%, and the minimum corresponds to Enschede (5%). The share of non-motorised modes for journeys to work (MSNON) does not exceed 50% in any city. However, the median (12.9%) is just below the median for public transport (15.8%). The maximum corresponds to Enschede (34%) and the minimum, to Cardiff (1.7%).

As already explained, only cities with populations of 100,000 and 500,000 were sampled. However, some are the centres of much larger conurbations, such as Newcastle for the Tyne and Wear Metropolitan Area, with 1.075 million inhabitants (Hass-Klau et al. 2007, p. 126). Urban residential density (RESDENS) ranges from 2658 people per square kilometre (Erfurt) to 12560 (Geneva), with a median of 4553. As a tendency, the UK cities feature higher values than their German counterparts.

The number of registered cars per 1000 population (CAROWN) ranges from 275 in Nottingham to 479 in Saarbrücken with a median of 400. On the whole, higher levels exist in Germany than the UK. The lengths of pedestrian zones in city centres (PEDZONE) range from 0.48km in Portsmouth to 8km in Freiburg with a median of 2km. In general, more extensive ones are found in Germany. Fees for one hour parking in the city centre (PARKING) range from free of charge in Göttingen and Regensburg to the equivalent of

£2.23 in The Hague. The median value is 0.89. Both, German and UK cities are located at either end of the spectrum.

The variable annual public transport subsidies per capita (PTSUBS) was not uniformly defined for each city, which could reduce its comparability. However, remarkable differences exist considering the standard deviation of 106.5. The maximum corresponds to Lausanne (478.8) and is greater than the minimum in Enschede (18.7) by a factor of 25. The UK cities in the sample rank at the lower end of the table, whereas in Germany and, particularly, Switzerland, higher values prevail.

Monthly ticket fares (PTFARE) range from the equivalent of £34.38 in Magdeburg to £72 in Bradford. One can observe marginally higher levels in the UK than Germany. Finally, 20 of the 34 sample cities possess operating light rail systems, and The Hague features the highest number of light rail line kilometres per urban land area (LRAIL).

4.2 Correlation of the modal share variables

This section focuses on the correlations between motorised mode-, public transport-, and non-motorised mode share for journeys to work. Initial conclusions should be drawn about whether complementary or substitution effects exist between the transport modes. One would anticipate a positive correlation for the former and a negative correlation for the latter. Table 7 shows the Pearson-r correlation coefficients for each modal share pairing alongside the probability for the null hypothesis of no correlation.

	MSMOT/ MSPT	MSMOT/ MSNON	MSPT/ MSNON
Pearson-r correlation	-.878	-.607	.158
significance (2-tailed)	.000	.000	.371

Table 7: Pearson-r correlation coefficient and significance for each modal share pairing

The data suggest a significantly ($pH^{\circ} = 0.000$) negative correlation between motorised mode-, and public transport share for journeys to work. For motorised modes and non-motorised modes, the correlation is also significantly ($pH^{\circ} = 0.000$) negative, albeit to a lesser extent. In contrast, no significant ($pH^{\circ} = 0.371$) association exist between the shares of public transport and non-motorised modes.

The data support the findings of Simma and Axhausen (2001) and Scheiner (2010) about the existence of substitution effects between motorised modes and public transport. The negative correlation between motorised- and non-motorised modes could imply that both require different urban environments regarding distance and density, as outlined by Bertolini and Le Clercq (2003). However, in contrast to Bertolini and Le Clercq (2003), Naess and Sandberg (1996) and Newman and Kenworthy (1989), the data neither imply a positive nor a negative association between public transport- and non-motorised mode share. Hence, walking and cycling may not be supported or absorbed by public transport.

4.3 Linear regression for motorised mode share

4.3.1 Results

In this section, we describe the regression for the share of motorised modes for journeys to work (MSMOT) and the 8 explanatory variables listed on Table 5. Outliers are kept constant above ± 3 standard deviations from the mean. All variables enter the model, whereupon the least significant ones are step-wise removed. These are: PTFARE, RESPOP, PEDZONE, CAROWN, RESDENS and PARKING. The variables PTSUBS and LRAIL with $pH^0 < 0.05$ are retained. The model parameters are given on Table 9.

Variable	Coefficient	Significance	Tolerance	VIF	R ² adjusted	Durbin-Watson
PTSUBS	-.090	.000	.812	1.231	.592	2.372
LRAIL	-10.158	.004	.812	1.231		
Constant	78.615	0.000	-	-		

Table 8: Model parameters for the regression on motorised mode share (MSMOT)

According to De Vaus (2002, p. 382), a *tolerance* value below 0.2 and a *variance inflation factor (VIF)* above 5 indicate a high risk of multi-collinearity between the explanatory variables. This is not the case herein. The model's independent variables explain 59.2% of the variance. The Durbin-Watson statistic (2.372) does not indicate critical residual auto-correlation (Field 2009, pp. 220-221). The scatter plot of standardised residuals against standardised predicted values is illustrated on Figure 1. It reveals that more residuals lie above zero than below, and absolute residual values slightly increase from low to high motorised mode share. Hence, the criterion for normally distributed residuals may not be entirely fulfilled.

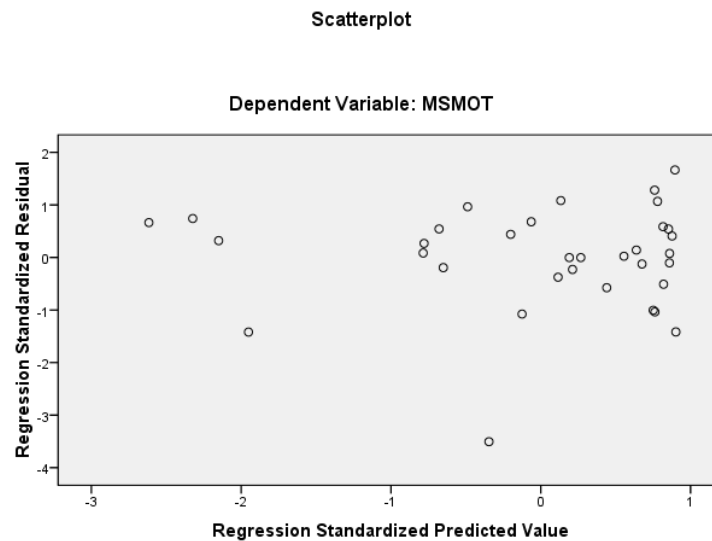


Figure 1: Standardised residuals plotted against standardised predicted model values for motorised mode share (MSMOT)

4.3.2 Discussion

Population size does not appear to influence motorised mode share, contrary to the views of Scheiner (2010) and White (2009). However, effects could still exist outside the sample cities' range (100,000 to 500,000). The data do not suggest influence from urban residential density either, which contrasts with the findings of Cervero (1998) and Newman and Kenworthy (1989). The latter, however, draw their conclusion from analysing not only European, but also American and Asian cities, whose residential densities are different (Newman and Kenworthy 1989, p. 128). Consequently, the data imply that, within the margins of the analysis sample, planning efforts for influencing urban density do not result in substantial commuter modal shifts from motorised modes.

Car ownership does not appear to exert strong influence, a result in line with Kitamura (2009) and White (2009), but different from the conclusions presented by Balcombe et al. (2004) and Scheiner (2010). Naess and Sandberg (1996, p. 577) argue that car owners may deliberately choose public transport for commuting, but not for other purposes. Thus, concentrating on journeys to work might disguise the overall importance of car ownership. The data do not imply noticeable impacts from pedestrian areas or parking charges in city centres, which supports the arguments presented by Santos et al. (2010a) rather than the conclusions by Hass-Klau et al. (2003).

Annual public transport subsidies per capita are negatively associated with motorised mode share for journeys to work. This coincides with White (2009) and Santos et al. (2010b) and contrasts with Newman and Kenworthy (1999). It is unlikely that public transport subsidies exert influence via the other public transport factors covered in this analysis, since monthly ticket fares are excluded from the model on grounds of insignificance, and no critical multi-collinearity exists with light rail presence. Hence, one may assume that public transport subsidies influence modal split through higher service frequencies, as argued by Balcombe et al. (2004) and White (2009).

The data reveal a negative association between light rail presence and motorised commuting. This coincides with the conclusions of Newman and Kenworthy (1999) and Steer Davies Gleave (2005), but contrasts with Richmond (2001). One possible explanation is that light rail can provide higher frequencies than buses with the same amount of subsidies. Alternatively, light rail might be capable of attracting car users by a more appealing image, as argued by Steer Davies Gleave (2005). Cervero (1998), however, would not consider this scenario as highly realistic.

The inclusion of parking space limitations into the model would likely produce more accurate results, since Naess and Sandberg (1996, p. 565) argue that public transport and parking space provision strongly affect motorised mode share. The effects of mixed land-use, however, may be less pronounced, since Cervero and Kockelman (1997, p. 217) estimate that neighbourhood characteristics primarily influence non-work trips.

4.4 Linear regression for public transport share

This section reports a linear regression analysis for public transport share for journeys to work (MSPT) and the 8 predictor variables. Outliers are restricted to mean ± 3 standard deviations. All variables enter the model, wherefrom the least significant ones are step-wise excluded. These are: RESPOP, PARKING, PEDZONE, RESDENS, CAROWN and PTFARE. In contrast, PTSUBS and LRAIL are retained which is identical to motorised mode share. The model parameters are given on Table 10.

Variable	Coefficient	Significance	Tolerance	VIF	R ² adjusted	Durbin-Watson
PTSUBS	.081	.000	.812	1.231	.546	2.579
LRAIL	5.523	.051	.812	1.231		
Constant	10.436	0.00	-	-		

Table 9: Model parameters for the regression on public transport share (MSPT)

The values for *tolerance* (0.812) and *VIF* (1.231) do not imply multi-collinearity between the predictor variables (De Vaus 2002). The adjusted R-square figure indicates that the independent variables in the model explain 54.6% of the variance in the share of public transport for journeys to work. The Durbin-Watson statistic (2.579) suggests marginally higher residual auto-correlation compared to motorised mode share (De Vaus 2002). A scatter plot of standardised residuals against standardised predicted model values is given on Figure 2.

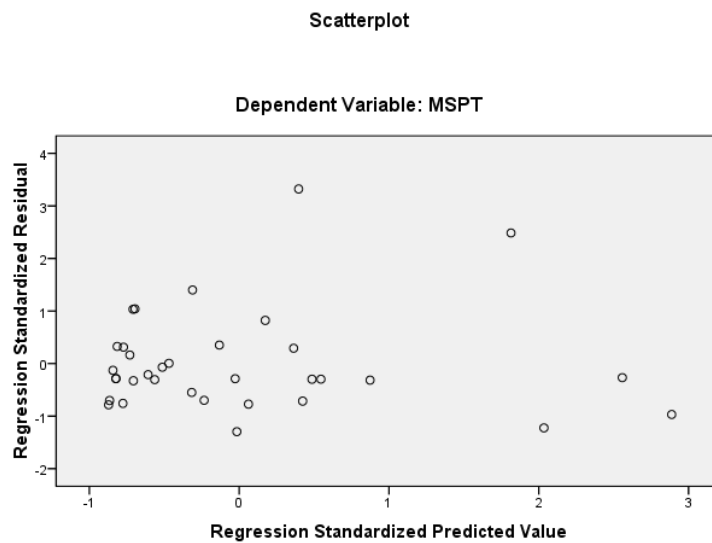


Figure 2: Standardised residuals plotted against standardised predicted values for public transport share (MSPT)

More negative than positive residuals exist, but the latter tend to have higher absolute values. Also, a slight trend towards more negative residuals with increasing public transport share can be observed. Hence, the residuals are unlikely to be normally distributed which may violate the assumptions for a linear regression.

Public transport share for journeys to work are not associated with monthly ticket fares, in line with the conclusions by Asensio (2000) and Hass-Klau and Crampton (2002) but in contrast with Buchanan (1964) and Balcombe et al. (2004). However, we found a positive correlation between public transport share and public transport subsidies. One may assume that this is accomplished through higher service frequencies, as argued by Serebrisky et al. (2009) and White (2009). Light rail presence is associated with public transport share, and no multicollinearity with public transport subsidies was found.

If outliers are restrained to mean ± 2 standard deviations, light rail presence becomes insignificant. Also, the variable *registered cars per 1000 population* enters the model, where it exerts a negative influence, and the adjusted R-square value rises to 0.666. This new result coincides with Balcombe et al. (2004) and Scheiner (2010). Moreover, the coefficient for public transport subsidies also rises. Hence, if public transport share decreases with growing car ownership, increasing public transport subsidies for higher service frequencies could be an effective counter-strategy.

The data do not suggest any influence from population size or urban residential density which differs from the findings of Cervero (1998) and Newman and Kenworthy (1989). Similarly, the analysis does not indicate associations with the length of pedestrian zones and parking charges in city centres and, therefore, contradicts Hass-Klau and Crampton (2002).

4.5 Linear regression for non-motorised mode share

This section reports a linear regression analysis for non-motorised mode share for journeys to work and the 8 predictor variables. Outliers are held constant above mean ± 3 standard deviations. We included all the explanatory variables initially but removed the non-significant ones at 5% level. These were: RESDENS, PTSUBS, CAROWN, RESPOP, PARKING and LRAIL. On the other hand, the variables PEDZONE and PTFARE were retained. The model parameters are presented on Table 11.

Variable	Coefficient	Significance	Tolerance	VIF	R ² adjusted	Durbin-Watson
PEDZONE	1.903	.003	.870	1.150	.402	2.241
PTFARE	-.288	.026	.870	1.150		
Constant	22.832	.002	-	-		

Table 10: Model parameters for the regression analysis on non-motorised mode share (MSNON)

Tolerance (0.87) and the *variance inflation factor* (*VIF*: 1.15) do not indicate critical multi-collinearity between the independent variables (De Vaus 2002). The predictors are capable of explaining 40.2% of the variance in non-motorised mode share for journeys to work. The Durbin-Watson statistic of 2.241 does not imply a high risk of auto-correlated residuals. The scatter plot of standardised residuals against the standardised predicted model values is presented on Figure 3 and reveals a fairly constant and unsystematic spread of positive and negative residuals.

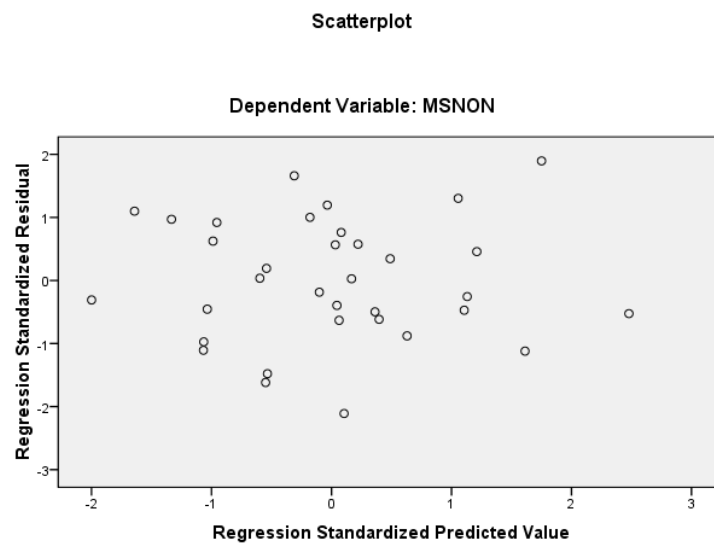


Figure 3: Standardised residuals plotted against standardised predicted model values for non-motorised mode share (MSNON)

Resident population and urban residential density do not appear to exert influence on the modal share of non-motorised modes for journeys to work in the sample cities. Newman and Kenworthy (1999, p. 103), however, consider the existence of a logarithmic relationship and, thereby, obtain a stronger correlation (*R*-square: 0.608). Hence, the above results may only reject the possibility for a linear association. Car ownership and parking charges in city centres do not appear influential either. The variable length of pedestrian zones in city centres is positively associated with non-motorised commuting, albeit at a moderate level. One may suspect that this effect is accentuated for other trip purposes such as shopping or recreation.

The analysis does not suggest any influence from annual public transport subsidies and light rail presence. However, monthly ticket fares are negatively associated with non-motorised mode share at a considerably flat rate. This may reflect combined policies for facilitating public transport, cycling and walking rather than a causal relationship or can be the result of the discrepancy in the data reference years.

Since the model explains less than half of the variance, one should also consider factors that are not covered therein. For instance, Hopkinson and Wardman (1996) cited in Santos et al. (2010b, p. 59) outline that the perceived safety risk is a deterrent for cycling and possibly outweighs any time saving potential. Thus, cycling could be fostered through clearly marked exclusive lanes, safe and convenient bicycle parking facilities and lower overall speed limits for motorists (Santos et al. 2010b, p. 60). In order to attract walking, Santos et al (2010b, p. 60) highlight the need for reducing crime and increasing perceived security in neighbourhoods.

5. Conclusions and policy recommendations

This paper identified factors influencing for the modal split for journeys to work in cities with populations of 100,000 to 500,000 from Germany, the Netherlands, Switzerland and the UK. Previous studies were reviewed, and data on urban density, city size, car ownership, parking charges, pedestrian zones, public transport subsidies, public transport fares and light rail presence were collected. The main data sources were Eurostat's urban audit, public transport operator- and local authority websites and email inquiries to local authorities. The sample consisted of 34 cities.

The analysis revealed a significant negative correlation between modal shares of motorised modes (car and motorcycle) and public transport. A negative correlation between motorised modes and non-motorised modes (walking and cycling), albeit to a lesser degree, was also found. One may, therefore, suspect the existence of substitution effects between motorised modes and public transport as well as between motorised modes and non-motorised modes. Public transport- and non-motorised mode share, however, were not correlated.

Hence, policies in favour of public transport might yield the greatest potential for reducing the share of motorised modes for journeys to work, although improvements for cyclists and pedestrians appear also capable. Public transport and non-motorised modes do not seem to substitute or complement each other for journeys to work. Thus, individual policies for both modes might be more effective than combined ones.

Urban residential density does not appear to be associated with any modal share variable. This contrasts with some of the reviewed studies, such as for example, Cervero (1998) and Newman and Kenworthy (1989). One may conclude that land use policies in favour of higher residential densities do not have an effect on the modal split for journeys to work within the sample cities' range (26.58-125.6 people per hectare). However, no such conclusion should

be drawn for cities outside this margin. The analysis did not imply any influence from city size either which is also contrary to previous studies (Scheiner 2010, White 2009). One may assume that planning policies have potentially similar impacts in medium-sized cities. Thus, if a particular intervention results in modal shifts in one place, this might also succeed in another.

Car ownership was not found to be associated with motorised mode share and non-motorised mode share, but to a small degree with public transport share, if a strict approach to outliers was employed. This finding is fairly in line with the literature (Balcombe et al. 2004, Scheiner 2010 and White 2009). One may, therefore, only anticipate minor modal shifts from policies which address car ownership.

The analysis implied that pedestrian zones in city centres positively affect non-motorised mode share for journeys to work. However, no associations were found with motorised mode share and public transport share. It appears to be likely that pedestrian zones in city centres foster non-motorised modes for other trip purposes to a greater extent than for commuting. Parking charges were not associated with any modal share variable which coincides with Hass-Klau et al. (2003) and Santos et al. (2010a). One may conclude that this pricing measure has only minor effects despite the fact that the modal split and parking charge data used herein refer to different years.

Public transport subsidies were negatively associated with motorised mode share, positively associated with public transport share and not associated with non-motorised mode share. This is partly in line with Santos et al. (2010b) and White (2009). It is likely that public transport subsidies exert an influence on the modal split via higher public transport service frequencies. In times of financial stringency, however, local authorities may find it difficult to subsidise public transport.

Light rail presence was negatively associated with motorised mode share, not associated with non-motorised mode share and positively associated with public transport share, if outliers were retained below mean ± 3 standard deviations. This partly follows the argumentation of Newman and Kenworthy (1999) and Steer Davies Gleave (2005). One might conclude that light rail achieves modal shifts through either higher service frequencies for a given amount of subsidies, or a more appealing image.

Public transport fares were negatively associated with non-motorised mode share. This might either reflect combined policies in favour of public transport- and non-motorised modes or differences in the data reference years. No association, however, was found with motorised mode- and public transport share. This partly follows Asensio (2000) and Cervero

(1998). Hence, low public transport fares might not result in large modal shifts from commuters.

Public transport service frequency, parking space limitation and mixed land-use have not been analysed in this paper. It is likely that the former two factors exert negative influence on motorised mode share and positive influence on public transport- and non-motorised mode share. The effects of mixed land use, however, are less clear (Cervero and Kockelman 1997, Santos et al. 2010b, White 2009). An overview of the associations derived from the analysis is given on Table 11.

Factor	Association with motorised mode share	Association with public transport share	Association with non- motorised mode share
Urban residential density	=	=	=
City size	=	=	=
Car ownership	=	= / --	=
Parking charges	=	=	=
Pedestrian zones	=	=	+
Public transport subsidies	--	+	=
Light rail presence	--	+ / =	=
Public transport fares	=	=	+

Table 11: Overview of the discovered associations between modal shares for journeys to work and the factors mentioned in the literature; (+) represents positive association, (--) negative association and (=) no association

There are some caveats in this study. First, it would have been preferable to have data for exactly the same year, rather than for different years within a period. Second, it would have been more accurate to conduct the analysis for ‘functional urban areas’ rather than for ‘cities’ as defined by the ‘administrative city boundaries’. Traffic does not recognise administrative boundaries. Also, traffic problems would be better addressed by considering functional urban areas (Bratzel 1999). Third, we had great difficulty in collecting data regarding public transport service frequencies and city centre parking spaces. Many authors, however, consider these factors very influential, which justifies their inclusion future analyses.

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