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Karla Münzel

Wouter Boon

Koen Frenken

Jan Blomme

Dennis van der Linden

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Karla Münzel
Wouter Boon
Koen Frenken
Jan Blomme
Dennis van der Linden

Innovation Studies, Copernicus Institute of Sustainable Development, Utrecht University
Heidelberglaan 2, 3584 CS, Utrecht, The Netherlands
Corresponding author: k.l.munzel@uu.nl | +31 30 253 7301

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Abstract: We analyze the diffusion of carsharing across 177 cities in five Western European countries (Belgium, France, Germany, The Netherlands, United Kingdom) and identify the influence of spatial, socio-demographic and institutional city characteristics. Carsharing can partially replace private ownership of vehicles with a service that allows the use of a car temporarily on an on-demand basis. It has the potential to satisfy individualized transportation demands in a sustainable and socially beneficial way and reduces urban problems like traffic and parking pressure in growing cities. We present the first study that explains the number of shared cars present in a city, while distinguishing between the traditional business-to-consumer (B2C) business model and the more recent peer-to-peer (P2P) business model. We find that carsharing per capita is highest in the largest cities. Moreover, carsharing is popular in cities with high educational level and many green party votes, and less popular in cities with many car commuters. Particularly striking are the differences between countries, with peer-to-peer carsharing being especially popular in French cities and business-to-consumer carsharing in Germany. We reflect on the findings in the light of (sustainable) mobility policy options.

Keywords: sharing economy, carsharing, business-to-consumer, peer-to-peer, policy

Highlights:

- Analyzes diffusion of B2C and P2P carsharing across 177 cities in five countries.
- Carsharing especially popular in larger cities.
- Larger diffusion in cities with highly educated people and green party voters.
- University and historic cities serve as niches for B2C carsharing.
- Differences in carsharing diffusion across countries are strong.

1. Introduction

Carsharing is a key example of what is called the “sharing economy”, which consists of new business models exploiting underutilized assets by replacing ownership by access (Botsman and Rogers 2010). Just as other shared mobility forms such as bikesharing and ridesharing, carsharing is growing rapidly in many places around the world (Shaheen and Cohen 2016). It is commonly assumed that carsharing has the potential to satisfy individualized transportation demands in a more sustainable way, by decreasing the demand for cars and parking, by lowering emissions through a multi-modal mobility system and cleaner car fleets, as well as by strengthening social connections within local communities (Prettenthaler and Steininger 1999; Loose 2010; Martin and Shaheen 2011; Shaheen and Cohen 2013; Frenken and Schor 2017; Nijland and van Meerkerk 2017).

Hitherto, most research on carsharing has been focused on the question which consumers opt for carsharing and why they do so (Millard-Ball et al. 2005; Nobis 2006; Burkhardt and Millard-Ball 2006; Martin et al. 2010; Efthymiou et al. 2013; Schaefers 2013; Le Vine et al. 2014a; Lindloff et al. 2014; Böcker and Meelen 2016). From a social practice theory perspective Kent & Dowling (2013) have analyzed changes to the automobility regime through carsharing use. In transportation research more specifically, there is also work on on-demand modeling and the logistic optimization of carsharing systems (for reviews, see Jorge and Correia (2013) and Sonneberg et al. (2015), respectively). More recently, management research on sharing-based business models and firm strategies has gained momentum (Firnkorn and Müller 2012; Clark et al. 2014; Cohen and Kietzmann 2014; Shaheen et al. 2015; Münzel et al. 2017).

Much less emphasis has been on the question why carsharing diffusion differs between cities and countries. Only few studies analyze urban factors affecting the diffusion and only for specific cities (e.g. Stillwater et al. 2009; Braun et al. 2016). City size and population density are often mentioned as the main factors explaining why carsharing diffuses per capita more in larger cities than in smaller cities as sharing systems require a critical mass of local users to be profitable (e.g. Millard-Ball et al. 2005; Hampshire and Gaites 2011). However, apart from size and density, other city characteristics have not been studied so far in the context of an intra-city comparison. It is interesting to analyze whether certain urban environments act as niches for the carsharing innovation, following the argument by Truffer and Coenen (2012) that spatial aspects influence transition processes. Analyzing the influence of more city characteristics next to city size and density, helps to understand differences in diffusion and can furthermore help to identify favorable policy conditions or barriers.

In this study, we analyze the diffusion of shared cars in 177 cities in Belgium, France, Germany, The Netherlands and United Kingdom. As explanatory factors, we include several city characteristics as well as country dummies. In our analyses, we will distinguish between the two main carsharing business models currently on the market: the business-to-consumer (B2C) model in which an organization owns a fleet of cars which are rented out to users, and the peer-to-peer (P2P) business models where consumers rent out their own cars through a platform organization. The business model types have important differences in organization, use and impact and may well prosper in different city environments.

We will proceed as follows. In the next section, a more extensive literature review is given on carsharing. In Section 3 we go into the possible factors affecting carsharing diffusion at the city level as well as at the national levels of the five countries included in our study. Section 4 presents the methodology and Section 5 the results. We end with some concluding remarks.

2. Carsharing

Carsharing can be defined as a system that allows people to use locally available cars at any time and for any duration (Frenken 2015). It differs from taxis in the way that a shared car is driven by the renter and it also differs from car rental since cars are available locally and at any time and duration. Within carsharing, various business models have been distinguished (Cohen and Kietzmann 2014; Shaheen et al. 2015). Figure 1 summarizes the different forms of carsharing business models.

The first viable carsharing initiatives started in the late 1980s in Switzerland and Germany with small projects run by environment-minded groups (Shaheen et al. 1998; Truffer 2003). These early organizations were arranged in a business-to-consumer (B2C) fashion, in which the carsharing organization (be it for-profit or not-for-profit) owns a fleet of cars that it rents out to its customers. Initially, the B2C business models were fairly similar and based on a Round-Trip (RT) system where the cars have to be returned to the same parking spot at the end of the trip as where they were rented from. Often, specific parking spots were made available to carsharing organizations by local governments as a way to promote sustainable mobility.

A new type of B2C carsharing business model emerged around 2009 when some organizations developed a One-Way (OW) system (Car2Go being the most well-known worldwide). In a One-way system the cars do not have to be returned to the spot where the trip was started but can be dropped off either anywhere in a designated city area (free-floating) or at a different station of the provider (station-based).

Around 2011, a new business model was introduced with the introduction of online peer-to-peer (P2P) platforms on which car owners can rent out their own car to fellow consumers (“peers”). The platform takes a fee for matching supply and demand and usually offers additional services like insurances (Shaheen et al. 2012). P2P carsharing is only operated in a Round-trip manner as the car is picked up from and returned to the car owner. Important to note is that P2P cars are used much less frequently than B2C cars. This difference can be explained by the zero marginal costs of supplying a P2P car, as these cars are privately owned and used and only made available for sharing when they are idle. As a consequence, many car owners offer their car online even if the car is rented out only rarely. By contrast, a B2C shared car is only offered if there is sufficient local demand to cover the investment made by the carsharing operator. Hence, the supply of a B2C car gives a rather reliable indication that the car is actually rented out often.

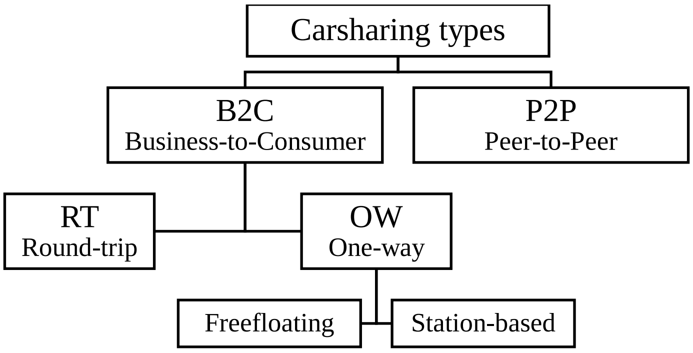

Figure 1: Types of carsharing business models

Research on spatial factors affecting the diffusion of carsharing is limited. The studies that use statistical data are either focusing on one city or on one operator, and analyze neighborhood differences rather than city-level differences. Braun et al. (2016) analyzed the diffusion of carsharing stations and the numbers of cars in the German city of Tübingen and the relation to structural factors as well as socio-demographic factors in different neighborhoods of the city. Stillwater et al. (2009) conducted a study on the influence of the built environment on carsharing diffusion by combining use-data of one US carsharing operator with GIS-data covering built-environment and demographic factors. Knie et al. (2016) analyzed booking data of a One-way provider in Munich and Berlin and the influence of structural, socio-demographic and socio-economic variables. The study by Koch (2002) shows early research on diffusion of carsharing and spatial characteristics for the city of Bremen. Coll et al. (2014) analyzed geographical and socio-economic factors that influence carsharing membership in Québec City. And Kortum (2014) analyzed the influence of socio-demographic differences in neighborhoods of Austin on the use of One-way carsharing. Table 1 illustrates which variables were considered in these studies and indicates which variables significantly influenced the diffusion of carsharing. Unlike these studies that study a single city's neighborhoods, this research aims to compare carsharing diffusion at the city-level and country-level. We also extend the range of factors that may affect carsharing diffusion.

Table 1: Studies on carsharing diffusion

	Braun et al. (2016)	**Stillwater et al. (2009)**	**Knie et al. (2016)**	**Koch (2002)**	**Coll (2014)**	**Kortum (2014**
Coverage	Tübingen, single operator	US, single operator	Munich and Berlin, 2 operators	Bremen, single operator	Québec City, single operator	Austin, single operator
Unit of analysis	Neighborhood					
Dependent variable	Data on usage location	Data on booking location	Data on booking location	Data on car location	Data on member location	Data on trip location
Structural variables of the neighborhood						
Population density	+	0		+	0	+
Rate of residentially used area					+	
Age of housing units		0				
Quality and proximity of public transit	0	+ (light rail) - (regional rail)			+	
Pedestrian-, bike- and car friendliness	0	+ (pedestrian)				
Parking quality		0				
Centrality in city	+			+		
Job opportunities in area			+	+ (large diversity in job opportunities)	+	
Availability of services			+ (medium level of services)			
Socio-demographic variables of neighborhood						
Age	+ (middle-aged)	0	+ (middle-aged)		+ (middle-aged)	
Gender					0	
Household type and composition	+ (families)	0	- (families)		+ (families)	- (household size)
Nationality or race	- (foreigners)	0				
Income		0			-	-
Education		0			+	
Personal attitudes	+ (environmentally minded)					
Mode of transport for commute		- (commute by car)				
Car ownership	0	- (+ in case of 1-vehicle households)		(-)	-	

+ positive influence - negative influence 0 no influence

3. Factors affecting the diffusion of carsharing

Carsharing is a complex and multi-sided innovation and its popularity is affected by a multitude of factors ranging from individual preferences, city characteristics and country institutions. To identify these factors, we apply a range of theories from innovation studies, transportation studies, and urban geography. We use six categories to group these variables.

First, Rogers' (2003) theory on the diffusion of innovation details how individual adoption is aggregated into diffusion patterns of innovations. Commonly, early adopters of new technologies or system innovations are characterized by age (younger age groups), education (higher education) and income (higher income). Earlier studies on carsharing users identified these factors as well (Prettenthaler and Steininger 1999; Lane 2005; Burkhardt and Millard-Ball 2006; Loose 2010). Knie et al. (2016), Braun et al. (2016) and Coll et al. (2014) further identify the share of middle-aged groups to have an influence on carsharing diffusion.

Second, innovation theories stress the role of niches in which innovation get the chance to nurture without pressure from incumbent rules and competitors (Hoogma et al. 2002; Geels 2012). Specific user groups have preferences in common that render them willing to pay for a particular innovation and more eager to participate in niche experimentation. Typical user groups around which niches in the context of carsharing are formed were identified by e.g. Shaheen et al. (2006) and Truffer (2003). Shaheen pointed out the early adoption by students or on college campuses. Students have fewer resources to own a car, use different transportation modes and are more open to innovations. Truffer identified members of environmental groups or others with a strong ideological background as early adopters. People with strong environmental ideologies identify carsharing as a more sustainable transportation mode and act upon these benefits. This effect has indeed been empirically supported in the study by Meelen et al. (2015) on carsharing diffusion in Dutch neighborhoods. A final user group providing a possible niche for carsharing use are families, which often are dependent on access to two cars. Instead of owning two cars, carsharing allows them to economize by substituting the second car by temporary access to a shared car. Knie et al. (2016), Coll et al. (2014) and Braun et al. (2016) found that a higher presence of families in neighborhoods increased carsharing. Similarly, one can argue that one-person households are more eager to adopt carsharing, as the fixed costs of owning a car is twice the cost for a one-person household compared to a two-person household. Meelen et al. (2015) found such an effect in their study.

Third, a city's legacy of spatial planning and in particularly the notion of *urban form* is relevant to understand the diffusion of mobility innovations like carsharing. The relevance of the built environment on mobility behavior has also been highlighted by Maat and Arentze (2012) and the studies included in Table 1. Urban form is defined as the building structure and density as well as all other structural elements that physically define a city like natural features or transportation corridors (Stead & Marshall 2001). The size and shape of a city influences transportation and the diffusion of transport innovations within. Also dense historic cities, where car use and parking may be difficult, draw people to different mobility modes than in large outspread modern-times cities, where distances are longer and car use is more feasible. The density of a city is furthermore important for an economical operation of carsharing for most firms. In dense cities it is likely that a shared car is in easy reach and the shared cars are used more frequently.

Fourth, the availability and use of different transportation modes could also be influential. If there is a strong public transit system present in the city, it is easier to live without a car or multimodal travel including carsharing might be easier. Equally interesting is the share of private car travel in the commuting modal split. Car commuters will be unlikely clients for carsharing as they depend on car use on a daily basis. Stillwater et al. (2009) also analyzed the influence of travel mode used for commute on carsharing (Table 1).

Fifth, national contexts are of importance as well given the large differences in the popularity of carsharing across countries (Shaheen and Cohen 2013). The mobility system is greatly influenced by institutions through for example infrastructure, policy measures or taxations, as well as the prevalent 'car culture'. For the five countries in our study specifically (Belgium, France, Germany, The Netherlands, United Kingdom), substantial differences have already been highlighted by Loose (2010) and Le Vine et al. (2014b). In *Belgium* professional carsharing has existed only since 2002 with a diverse landscape of operators including an environmental transport organization, an automobile club, a foreign carsharing operator and the national railway operator. Support of regional governments is strong and partnerships with local transit operators are in place. In *France* professional carsharing started in 1999. Most B2C operators focus their service on one city and a large part of the shared cars are operated in Paris, where there is strong support from the municipality (Clavel and Floriet 2009). In recent years P2P carsharing grew tremendously in France and its largest P2P operator is strongly growing and also expanding across national borders. *Germany*'s carsharing market is the largest in Europe and started already in the late 1980s. Carsharing is offered in all major cities by professional operators but also in smaller towns and villages mainly by small cooperatives (Münzel et al. 2017). There are many partnerships between operators and with public transit operators. Support differs greatly between municipalities (BCS 2014). In *The Netherlands* the first successful B2C carsharing operator was set up in 1994; and the current market is divided between only a few B2C operators. Since 2012, P2P carsharing has also grown substantially. Governmental support is available at local and national levels (Ettema and de Gier 2015), including a 'Green Deal' on carsharing that unites all stakeholders with a joint objective to have 100,000 shared cars by 2018. Finally, carsharing in the *United Kingdom* consists of a heterogeneous set of services and is less developed. While there are a number of larger B2C operators in London and some other large cities, there are many cities without any carsharing operations (Steer Davies Gleave 2015). Policies are fragmented and make it hard for operators to establish their services. P2P operators also struggle with insurance issues regarding the possibility to rent out one's own car. Based on this description of each country and the observed differences in stages of development, we hypothesize that part of the city differences in carsharing diffusion can be attributed to national differences.

Sixth, the popularity of carsharing can be influenced by the presence of other sharing systems. In particular, bikesharing systems can benefit carsharing in two ways. First, people can get aware and familiar with the notion of shared use of transportation modes. This effect is known as a spillover effect among innovations (Jaffe et al. 2000). Second, people get less dependent on owning a car if both bike- and carsharing systems are in place. In this respect, the use of carsharing and bikesharing systems is complementary. In addition, the coexistence of B2C carsharing and the younger P2P carsharing may be influential. One the one hand, a negative effect can be hypothesized as the two business models compete for users. On the other hand, in a city with B2C carsharing system, many inhabitants are already familiar with carsharing which may lower the barriers to offer and use shared cars through a P2P platform as well.

4. Research design

The diffusion of carsharing, as dependent variable, is assessed by counting the number of shared B2C and P2P cars on offer in each city. This measure reflects the extent to which carsharing has diffused. Other possibilities to measure the diffusion of carsharing are possible: Shaheen & Cohen (2016) for example refer to customer numbers in their overview of the carsharing market. Moreover, the number of bookings could give the most precise measure of the diffusion because it would correct for customers who are not using the service regularly (both in B2C and P2P systems) and for cars not being used regularly (especially in the P2P system). Unfortunately, a complete database with customer numbers or bookings for each carsharing provider is not publicly available

Following the factors affecting carsharing diffusion derived from theory in the preceding section, we constructed fourteen independent variables. Table 2 presents the variables and how these have been collected and measured. Note that we did not include the share of single-households in a city as independent variable, because this variable showed signs of multicollinearity and was therefore excluded from the analysis.

Table 2: Variables included in model to explain carsharing diffusion

	Theory	Variable	Indicators	Data source
1	**Innovation adoption**	Young age	Percentage of inhabitants aged 20-34 years	Eurostat
		Middle age	Percentage of inhabitants aged 35-49 years	Eurostat
		Higher education	Percentage of inhabitants (aged 25-64) with high level of education (ISCED 5 or 6[1])	Eurostat
2	**Innovation niches**	University presence	Binary (1=university is present)	CWTS Leiden Ranking
		Green party votes[2]	Percentage of votes for green party	Official national election statistics; municipal election statistics for Belgium
		Families	Percentage of households with children	Eurostat
3	**Urban form**	City size	Number of inhabitants	Eurostat
		Population density	Number of inhabitants per km²	Statistics Belgium, Belgium; Insee, France; DEStatis, Germany; CBS, The Netherlands; ONS, UK;
		Historic city (larger than 10,000 inhabitants before 1800)	Binary (1=historic city)	De Vries (1984)
4	**Modal split**	Car use	Percentage of commute trips done by car	Eurostat, CBS for The Netherlands
		Public transit use	Percentage of commute trips done by public transit	Eurostat, CBS for The Netherlands
5	**Institution**	Country	Country dummies	
6	**Spillover effects**	Bikesharing presence	Binary (1=bikesharing present)	Google search, Bikeshare.com
		Presence of B2C carsharing	Binary (1= at least one B2C car is present in city)	Own database

With these independent variables and the two dependent variables (number of B2C shared cars and P2P shared cars), an extensive database was set up that covers carsharing activities in 177 cities in five European countries: Belgium, France, Germany, The Netherlands, and the United Kingdom. As carsharing is mostly a city-phenomenon (Shaheen and Cohen 2007), only cities with more than 150,000 inhabitants are included in the database. The numbers of shared cars in each city are drawn from the carsharing firm websites as well as through requests to these firms by phone or mail between November 2015 and April 2016. The firms are identified by an extensive internet search with relevant names and translations of ‘carsharing’ in combination with the included cities[3] and through membership registers of

[1] International Standard Classification of Education (ISCED) 5&6 equals a bachelor’s degree or similar.
[2] A similar operationalization of attitude towards the environment is followed by Braun et al. (2016).
[3] “Carsharing +city name”; “autodelen +city name”; “car clubs +city name”; “autopartage +city name“; “voiture en libre service + city name”

umbrella organizations[4], and are categorized by their business model (P2P, B2C)[5]. The independent variables were primarily drawn from the European Eurostat database and national statistics databases.

To test which factors affect carsharing diffusion several regression analyses are carried out. First, we analyze the two business models separately since the number of cars for each business model is not comparable directly. As stressed in the theory section, P2P cars are used rather infrequently, while B2C cars are used frequently. Second, to compare the diffusion of both types of shared cars nevertheless, we also run a combined model using an estimation of usage for each type of shared car. The number of cars of the different business models are weighted to correct for a more frequent assumed use of B2C over P2P cars. Since these weightings are not backed by precise usage data but by information for specific operators, several regressions with different weighting schemes are carried out to check for the robustness of the results.

Since the dependent variable (number of shared cars) is a count, negative binomial regression analysis is performed, which more accurately analyzes the influence of the independent variables. The negative binomial regression analysis corrects for the overdispersion in the data through a dispersion parameter added to the Poisson distribution. This analysis method is used in the model concerning the number of P2P and B2C cars. In the usage analysis where the numbers of cars are weighted depending on the business model, a linear regression is operationalized with the logarithm of the weighted numbers of cars as a dependent variable. The variable on city size is log-transformed in all regressions to normalize for the outlying very large cities and optimize model fit.

5. Results

5.1 Descriptive statistics

Table 3 provides the descriptive statistics of dependent and independent variables. The mean number of shared cars in cities is 135 for B2C cars, 187 for P2P cars and 322 for the total number of shared cars. Many cities feature rather small numbers of shared cars, with 74 cities who have fewer than 50 shared cars available. P2P cars are present in all but two of the 177 cities, whereas there are no B2C cars available in 33 cities. Figure 2 further shows the large differences between countries. In France we see the largest numbers of shared cars in cities due to an exceptionally high number of P2P cars. This stands in contrast to the situation in Germany where most cars are operated in a B2C model. In the other three countries, the number of shared cars are more equally divided between P2P and B2C models. Overall, the United Kingdom lags behind in the number of shared cars. Table 4 lists the cities where carsharing is most diffused. The large diffusion of B2C cars in Germany and P2P cars in France can also be observed here. The largest total amounts of shared cars can be found in the capital cities, whereas the leading cities in ratio of cars per capita are other, smaller cities.

[4] Germany: Bundesverband Carsharing; Belgium: Autodelen.net
[5] Few firms offer both B2C and P2P carsharing. The respective cars were then counted separately in the applicable category.

Table 3: Descriptive statistics of number of shared cars and city characteristics

	N	Min.	Max.	Mean	Std. Dev.
Number of cars (total) Dependent variable	177	0	11,477	322.0	980.0
Number of cars (B2C) Dependent variable	177	0	3,961	134.7	441.6
Number of cars (P2P) Dependent variable	177	0	7,516	187.3	619.2
Young age % of people between 20-34 years old	177	15.8	35.4	21.9	3.6
Middle age % of people between 35-49 years old	177	22.6	32.2	27.4	1.9
Higher education % of working age population qualified at level 5 or 6 ISCED	166	13.1	60.3	33.3	9.1
University presence Dummy variable if university is present (1) or not (0)	177	0	1	0.5	
Green party votes % of votes in last election for Green party	177	0	19.8	6.5	4.5
Families % of households with children	163	12.4	40.0	24.2	5.7
City size City population in 100,000	177	1.5	83.6	4.7	8.7
Population density Population density in 1,000 people/km²	176	0.3	8.8	1.8	1.3
Historical city Dummy variable for cities that had over 10,000 inhabitants before 1800 (1) or not (0)	177	0	1	0.6	
Commute by car % of journeys to work by car	175	12.9	86.1	61.3	13.3
Commute by public transport % of journeys to work by public transport	175	4.2	69.4	18.5	9.7
Bikesharing present Dummy variable if bikesharing is present (1) or not (0)	177	0	1	0.5	
B2C carsharing present Dummy variable if minimum 1 B2C car is present in city (1) or not (0)	177	0	1	0.81	
Country Dummy Belgium	177	0	1	0.03	
Country Dummy Germany	177	0	1	0.30	
Country Dummy France	177	0	1	0.26	
Country Dummy The Netherlands	177	0	1	0.07	
Country Dummy United Kingdom	177	0	1	0.34	
Valid N	155				

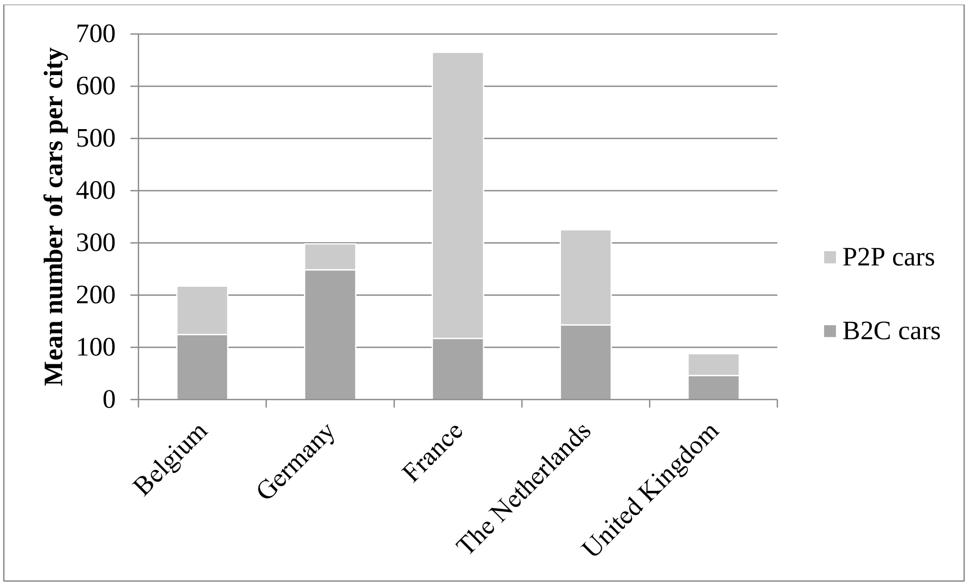

Figure 2: Country differences in numbers of shared cars

Table 4: Top 5 carsharing cities

	Shared Cars per 1,000 inhabitants			Shared Cars		
	total	**B2C**	**P2P**	**total**	**B2C**	**P2P**
1	Karlsruhe (2.37)	Karlsruhe (2.23)	Montpellier (2.02)	Paris (11,477)	Paris (3,961)	Paris (7516)
2	Utrecht (2.14)	Stuttgart (1.52)	Bordeaux (1.77)	London (3,390)	Berlin (2,676)	Lyon (1,453)
3	Montpellier (2.11)	Amsterdam (1.25)	Versailles (1.75)	Berlin (3,221)	London (1,955)	London (1,435)
4	Amsterdam (2.10)	Köln (1.19)	Toulouse (1.71)	Amsterdam (2,172)	München (1,589)	Lille (1,386)
5	Bordeaux (2.04)	Heidelberg (1.16)	Nantes (1.62)	München (1,806)	Hamburg (1,449)	Bordeaux (1,295)

Recall that we took all cities into account with at least 150,000 inhabitants. Before including the variables in the model, correlations and multicollinearity between the independent variables were checked. Some variables correlate significantly, but multicollinearity shows no signs of these variables significantly influencing the precision of the model with all VIF scores lower than 5 (Rogerson 2010). The correlation matrix is provided in the appendix. When analyzing the data for outliers using the Cook's distance[6] no case was identified as having a too large effect on the results, with all Cook's measures well below 1. But when analyzing the residuals of the models, a better model fit could be reached when excluding Paris. Paris is therefore considered an outlier and is excluded from all regression models.

[6] The Cook's distance measures the influence of a single observation on the overall model (Cook and Weisberg 1982).

5.2 Regression results on the number of shared cars

In the regression results, we report the exponents of the regression coefficients (*Exp(B)*) to indicate the effect with a value larger than one indicating a positive influence and a value smaller than one a negative influence. Model 1 in Table 5 shows the regression results for the number of B2C cars in cities. Three sub-models (1.1-1.3) were run, because not all independent variables were available for all cities. Model 1.3 includes all fourteen independent variables but only for 155 out of the 177 cities. Model 1.2 includes almost all cities (174) and uses all variables but two, while Model 1.1 includes all 177 cities but excludes five variables in order to achieve this full case set. Model 2 repeats the regression analysis for the number of P2P cars, using the same sub-models as Model 1.

In all models city size has, as expected, a large and significant influence on the diffusion of carsharing. This means that the number of shared cars *per capita* increases with city size. Population density, unexpectedly, has no significant influence in five of the submodels. Only in model 2.2 a weak significant influence is identified.

Table 5: Negative binomial regression models for P2P and B2C carsharing

	Model 1.1		Model 1.2		Model 1.3		Model 2.1		Model 2.2		Model 2.3	
Dependent variable	number of B2C cars		number of B2C cars		number of B2C cars		number of P2P cars		number of P2P cars		number of P2P cars	
N	177		174		155		177		174		155	
Pearson Chi²/df	1.311		1.232		1.205		1.034		1.195		1.257	
	Exp(B)	sig	Exp(B)	sig	Exp(B)	sig	Exp(B)	sig	Exp(B)	sig	Exp(B)	sig
Young age	1.13	***	1.06		0.97		1.08	***	1.04	*	1.02	
Middle age	1.20	**	1.11		1.01		1.06		1.01		0.99	
Higher education					1.05	**					1.03	***
University presence	1.88	**	1.26		1.01		0.87		0.83		0.72	**
Green party votes	1.10	***	1.09	***	1.10	***	1.02		1.01		1.00	
Families					1.01						0.98	
City size (log)	12.99	***	18.98	***	38.98	***	13.26	***	12.43	***	13.86	***
Population density			0.89		0.99				0.91	*	0.93	
Historic city	1.66	**	1.23		0.96		1.41	***	1.20		1.10	
Commute by car			0.92	***	0.93	***			0.97	***	0.98	*
Commute by public transit			0.96	*	0.95	**			1.00		1.00	
Bikesharing presence	1.58	*	1.52	*	1.63	**	0.95		0.88		0.96	
Presence of B2C carsharing							1.14		1.17		1.19	
Belgium	2.30		4.45	***	4.40	**	3.88	***	4.43	***	3.88	***
Germany	3.75	***	2.62	***	3.40	**	1.99	***	1.62	***	1.44	
France	1.69		1.13		0.88		26.32	***	22.31	***	18.41	***
The Netherlands	2.90	**	0.43		0.39		10.15	***	5.54	***	5.13	***
United Kingdom (reference)	1		1		1		1		1		1	

*significance at the 0.1 level; ** significance at the 0.05 level; ***significance at the 0.01 level

Looking at B2C cars, we observe that more cars are shared when the portion of highly educated people in a city is larger. In Model 1.3, in which all cities (but not all variables) are included, we see significant positive effects of higher rates of young and middle aged population groups as well as positive effects of the city being historic and having a university. We also found B2C carsharing to be adopted more in cities with many green party voters. There are, as expected, clear negative effects of a large car commute share, but rather unexpectedly also a weak significance of a negative effect of the share of commutes by public transit. The presence of a bikesharing system seems to positively affect the numbers of shared B2C cars. The main differences in B2C seem to stem, next to city size, from country differences with Germany, as well as Belgium and the Netherlands having higher numbers of shared cars compared to the United Kingdom. In contrast to some of the previous studies, we did not find any effect of the share of families.

Similar to the B2C case, more P2P cars are shared where the proportion of higher educated people is larger. A positive effect of certain age groups is in the P2P case only observed for young age groups in model 2.1 and 2.2. A positive effect of a city being historic is observed in model 2.1 while, in contrast to the B2C model, the presence of a university has a negative effect in model 2.3. Green party votes, the share of families as well as the presence of a bikesharing system, or of a B2C organization in the city do not show an effect on the number of P2P cars. A large effect can again be observed for the country variable, with significantly larger numbers of P2P cars in all other countries compared to the United Kingdom, with France showing the largest differences.

5.3 Regression results on the use of shared cars

To be able to analyze the overall *use* of shared cars in cities, we combine the data of P2P and B2C carsharing. Since no user data is available we apply different weighting schemes as we assume that P2P cars are used much less frequently than B2C cars. This difference can be explained by the marginal costs of supplying a P2P car. By contrast, a B2C shared car is only offered if there is sufficient local demand as to cover the investment made by the carsharing operator. Our assumption is also backed by a Dutch P2P platform owner who reported in public that P2P cars are rented out only seven times a year on average.[7] In contrast, a study of a B2C Round-trip provider in Berlin shows use patterns for the cars of 0.71 to 0.81 bookings per day (Lawinczak and Heinrichs 2008), while another study finds for Munich and Berlin that B2C Round-trip cars are in use 31-35% of a day and cars of a One-way provider at 12-21% of a day (Knie et al. 2016). Though the figures are imprecise, it is clear that P2P cars are indeed rented out less frequently than B2C cars.

To analyze the use of shared cars in cities, we add up the number of P2P and B2C shared cars using different weighing schemes. In Model 3.1 we use as a benchmark an equal weighting scheme, in Model 3.2 we assume that a B2C car is used 10 times more than a P2P cars (so we count a B2C car ten times), in Model 3.3 that a B2C car is used 30 times more than a P2P car, and Model 3.4 that a B2C car is used 100 times more than a P2P car. We also used other weightings and the results remained robust.

From the regression reported in Table 5, using OLS regression, one can again observe the positive effects of city size, highly educated inhabitants and green party votes. Another result

[7] Interviewed on stage at the car sharing symposium on June 3rd 2015 in Utrecht.

is the negative influence of the share of commutes done by car or public transit. Finally, we see strong country differences with carsharing diffusion greatly lagging behind in the United Kingdom and The Netherlands compared to the Belgium, Germany and France. In all, the result on the use patterns support the earlier conclusions based on the analysis of the number of shared cars on offer in Table 4.

Table 5: OLS regression on usage of shared cars for B2C and P2P combined

	Model 3.1 P2P (1x) B2C (1x)		**Model 3.2** P2P (1x) B2C (10x)		**Model 3.3** P2P (1x) B2C (30x)		**Model 3.4** P2P (1x) B2C (100x)	
R^2	0.89		0.82		0.78		0.73	
N=155	B	sig	B	sig	B	sig	B	sig
Young age	0.00		0.00		0.00		0.01	
Middle age	0,01		0.02		0.03		0.04	
Higher education	0.02	***	0.02	***	0.02	***	0.03	***
University presence	-0.19	***	-0.17		-0.15		-0.13	
Green party votes	0.02	**	0.03	**	0.03	**	0.03	*
Families	0.00		0.01		0.01		0.01	
City size (log)	1.41	***	1.61	***	1.72	***	1.88	***
Population density	-0.03		0.01		0.02		0.02	
Historic city	0.02		0.06		0.08	*	0.10	
Commute by car	-0.02	***	-0.03	***	-0.04	***	-0.04	***
Commute by public transit	-0.01	*	-0.02	***	-0.03	***	-0.04	**
Bikesharing presence	0.00		0.04		0.09		0.16	
Belgium	0.66	***	0.85	***	0.95	***	1.07	***
Germany	0.45	***	0.72	***	0.80	***	0.87	**
France	1.04	***	0.69	***	0.50	***	0.32	
The Netherlands	0.22		-0.12		-0.23		-0.32	
United Kingdom (reference)	1		1		1		1	

*significance at the 0.1 level; ** significance at the 0.05 level; ***significance at the 0.01 level

6. Concluding remarks

In this research a unique data set was constructed showing the urban supply of peer-to-peer (P2P) and business-to-consumer (B2C) carsharing in 177 cities in Western Europe. Our study provides one of the first quantitative insights on city level factors that affect the popularity of these two types of carsharing business models while covering a wide range of cities and variables. As expected, city size is important for the number of shared cars in a city indicating that the number of shared cars per capita grows with city size, an example of urban scaling (Bettencourt and West 2010). We also found that carsharing is popular in cities with many highly educated inhabitants and slight positive effects of younger age groups. B2C carsharing is further supported by green party voters, a historic city center and the presence a bikesharing scheme.

Population density is most often mentioned as one of the most important factors for a carsharing system to function. We therefore expected that population density would support carsharing in cities, next to sheer city size. Nevertheless, population density shows no significant positive effects neither on the number of P2P shared cars nor on the number of shared B2C cars. One explanation for this finding could be that the dataset covers only cities with more than 150,000 inhabitants where a certain density threshold might already be reached. Another point to consider is the influence of measuring population density between neighborhoods instead of at a city level. The studies by Braun et al. (2016) and Koch (2002) did find significant influence of population density on the diffusion of carsharing when analyzing differences between neighborhoods of one city. This shows that the argument that carsharing is supported by dense neighborhoods is not rejected by our city-level findings.

Finally, the effects of country dummies suggest that the national context plays a key role. This finding supports qualitative reports on the state of carsharing in different European countries by Loose (2010) and Le Vine et al. (2014). Differences across countries can be observed in the history of the market, the background of operators and their networks, the operation area of provider (local vs. national providers), insurance markets, and public policies. A further finding holds that countries also differ in the specific type of business model that is most popular. Notably, P2P sharing is especially booming in French cities, while German and Belgian cities are leading in B2C carsharing. German cities are especially leading in the One-way carsharing type with German car manufacturer backed carsharing operators present with large fleets in several cities. In particular, P2P carsharing has been hampered by strict insurance regulations in the United Kingdom. The striking differences suggest that there is ample room for policies to support carsharing diffusion, both at the municipality level and at the national level.

Several ideas for future research can be proposed. First, carsharing is a relatively recent phenomenon in mobility systems with most of its growth occurring in the last decade. Developments may take different paths depending on future policies, technological innovations and business strategies. Prospective analysis would therefore complement our diffusion analysis. Second, our analysis can be extend to include other countries across the globe. Future research depends heavily on the quality of data. We already highlighted the limitations inherent to the use of the number of shared cars as a proxy for diffusion. Especially in the P2P case, the supply of cars can be highly different from the actual use. Ideally, real usage data is required from carsharing providers or through large-scale surveys, as to understand the different appeal to users in different spatial contexts, and for different carsharing business models. Third, future analysis could focus especially on smaller towns and rural regions, where carsharing is often community-based and driven by personal involvement and ideological motives (Truffer 2003; Millard-Ball et al. 2005; Nobis 2006). Fourth, in our present study, the political and institutional variables were broad-brushed (as captured by green party votes at the urban level and country dummies), and should be made more granular in future studies. This necessitates systematic data collection on city-specific tax, parking and carsharing policies as well as national differences in taxes and regulations regarding insurance and shared use.

All in all, the results make clear that carsharing diffusion differs substantially between cities and between countries, and between the older B2C variant and the more recent P2P variant. To understand the future potential of carsharing as an environmental innovation that supports the transition towards a sustainable mobility system, one thus needs to understand the transition process geographically and at different spatial (neighborhood, city, country) levels (Truffer and Coenen 2012). It becomes clear that besides physical and socio-demographic factors, political orientations and institutions as well as national markets and industries are greatly influencing the diffusion of carsharing.

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Appendix

Correlation matrix (two-sided Pearson Correlation)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Shared P2P cars	1														
2	Shared B2C cars	.699**	1													
3	Young age	0.119	.177*	1												
4	Middle age	-0.115	.167*	-.425**	1											
5	Higher education	.337**	.257**	.589**	-.182*	1										
6	University present	.189*	.296**	.573**	-0.128	.496**	1									
7	Green party votes	0.036	.247**	.351**	0.075	.336**	.389**	1								
8	Families	0.083	-.336**	-.269**	-0.141	-.253**	-.484**	-.561**	1							
9	City size (log)	.519**	.662**	.204**	-0.020	.185*	.523**	0.144	-.189*	1						
10	Population density	.402**	.537**	.336**	.162*	.191*	.335**	.175*	-.187*	.486**	1					
11	Historical city	.203**	.199**	.369**	-.437**	.444**	.416**	.257**	-.272**	.388**	0.107	1				
12	Commute by car	-.352**	-.530**	-.545**	-0.118	-.643**	-.528**	-.437**	.524**	-.353**	-.561**	-.328**	1			
13	Commute by public transit	.486**	.685**	.267**	.195**	.388**	.431**	.441**	-.351**	.589**	.581**	.280**	-.697**	1		
14	Bikesharing present	.198**	.251**	.243**	0.021	.290**	.452**	.403**	-.456**	.257**	.207**	.259**	-.524**	.379**	1	
15	Presence of B2C carsharing	0.056	0.146	.263**	.187*	.166*	.363**	.192*	-.313**	.256**	.253**	0.099	-.307**	.192*	.248**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).