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Generic time- and method-interdependencies of empirical impact-measurements: A generalizable model of adaptation-processes of carsharing-users' mobility-behavior over time

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ABSTRACT

The purpose of this article is to advance empirical sustainability-evaluations of carsharing-systems. Carsharing, a frequently cited example of a product–service system (PSS), is currently morphing from a niche into a mainstream mode of transportation. Carsharing has the potential to provide a more sustainable mobility-option compared to private car usage, for example by reducing the overall motor-vehicle traffic in cities. However, the quantification of this potential is complex, and few studies have analyzed the fundamental impacts of the chosen measurement-methodology on the results of empirical carsharing-evaluations. This article analyses the time- and method-interdependencies of carsharing-studies based on a generic model structuring the adaptation of the mobility-behavior of carsharing-users over time. A paradigm shift from a static to a dynamic view on impacts of the PSS carsharing is proposed, which could support policymakers enacting carsharing-regulations in cities. The analysis of generic methodological interdependencies when conceptualizing impacts as dynamic processes is generalizable to impact-assessments of new technologies changing user-behavior over time.

1. Introduction

Private cars create negative externalities. For example, air pollution in Beijing worsened as the number of motor vehicles in the city increased from 2 million in 2004 to 4.8 million in 2010 (Chen and Zhao, 2013), which led to highway closures and health warnings by the Chinese government (Harris, 2014). To put this externality into perspective: The U.S. Embassy in Beijing monitors local air conditions on a scale from *Good* to *Hazardous* (U.S. Embassy Beijing, 2014) and in January 2014, Beijing's air pollution ranked *Beyond Index* (Wong, 2014). Other negative externalities of private car usage include parking-space shortage and traffic congestion. Studies in different cities found "between 8 and 74 percent of the traffic was cruising for parking" (Shoup, 2006, p. 479).

Efficiency gains of private cars will not solve such scale-related problems. The widespread human preference for private cars leads to tragedies of the commons (Hardin, 1968) because no matter how sustainable individual private cars are designed, manufactured, and driven, the consumption-decisions of millions of private car owners all reduce the availability of limited public goods, such as clean air and public space. Thus technology-improvements are insufficient for automakers to achieve sustainable business models (Williams, 2006, 2007) and "[a] fundamental rethinking of the entire system of personal mobility is necessary" (Vergragt and Brown, 2007, p. 1104). A special issue of the Journal of Cleaner Production on *The Automobile Industry & Sustainability* indicated that "the world is in desperate need of real and substantial progress in [the automobile industry]" (Orsato and Wells, 2007, p. 993) – but how can the automobile industry achieve real and substantial progress? How can individual mobility be provided more sustainably?

Shared cars offered via the product–service system (PSS) carsharing could contribute to a solution. Most PSS-classifications distinguish *product-oriented*, *use-oriented*, and *result-oriented* PSS-variants (e.g. Tukker, 2015; Williams, 2007), whereby carsharing is typically classified as a *use-oriented* PSS. Carsharing saves resources through two mechanisms: First, fewer cars have to be produced (in total) when people share cars driven consecutively as opposed to everyone owning a private car individually. Second, carsharing encourages low-car-usage lifestyles as the availability of

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shared cars (used selectively when required) reduces incentives to purchase private cars which – once bought – are driven more given their lower marginal usage-costs after the initial fixed-cost investment (Le Vine et al., 2014; Millard-Ball et al., 2005). A recent review in this journal concluded that "[g]reening passenger transport requires a re-think of present vehicle-centered approaches, and a focus on accessibility" (Moriarty and Honnery, 2013, p. 21) – a *focus on accessibility* is the central characteristic of the PSS carsharing.

Automakers increasingly offer carsharing-systems directly to end-customers – a disruptive innovation in one of the largest industries. Carsharing-systems have been tested by automakers in the past, for example by *Honda* operating *Honda DIRACC* in Singapore (Byers et al., 2015). However, the year 2009 marked the beginning of a large-scale shift in the automotive industry: Of carsharing-systems in operation, *Daimler* launched the first in 2009 (www.car2go.com), followed in 2010 by *Peugeot* (www.mu.peugeot.co.uk), and in 2011 by *BMW* and *Volkswagen* (https://de.drive-now.com/en/; https://web.quicar.de). In 2012–2013, *Citroën* (www.multicity-carsharing.de/en), *Ford* (www.ford-carsharing.de), *General Motors* (www.onstar.com/web/portal/relayrides-test?g=1), *Opel* (http://blog.tamyca.de/post/62323417343/tamyca-opel-carsharing), and *Kia* (www.kia.ca/student-car-share-program) launched carsharing-schemes, and in 2014, *Fiat* and *Toyota* (https://enjoy.eni.com/en/milano; http://newsroom.toyota.co.jp/en/detail/mail/3962091). This revolution in the automobile industry was summarized in 2013 by a *BMW*-manager: "You're witnessing a tipping point in the car-sharing market. It's becoming mainstream" (Gibbs, 2013).

But how will "becoming mainstream" affect the sustainability of carsharing-systems? As of December 2014, there are as yet no long-term measurements of the effects of automakers selling mobility instead of cars. Currently, empirical carsharing-evaluations face two central methodological challenges: First, it takes years after a carsharing-system's launch until the impacts stabilize – early impact-studies are therefore no indicator for long-term impacts. For example, a longitudinal study on the carsharing-provider *City CarShare* (San Francisco, USA) found diametrically opposed impacts measured 2 years vs. 1 year after the launch. Two years after *City CarShare*'s launch, the study concluded that "[e]vidence of travel suppression stands in stark contrast to first-year impacts wherein members' average VMT [vehicle miles traveled] had increased. Early adopters – many drawn from the ranks of environmentalists and avid cyclists who owned no car – began logging vehicle miles on the streets of San Francisco; over time (…) induced travel appears to have been replaced by reduced travel" (Cervero and Tsai, 2004, pp. 125–126). Similar findings have been reported since the beginning of carsharing-research (e.g. Katzev et al., 2001; Walb and Loudon, 1986). However, *increased* car usage after the launch of carsharing-systems is assumed to be outweighed by *reduced* private car ownership in the long-term (e.g. Martin and Shaheen, 2010; Meijkamp, 1998). Therefore, following a carsharing-system's launch, the combination of fast adaptation-processes (e.g. zero-car households starting to drive carsharing-cars) and slow adaptation-processes (e.g. households abolishing private cars) shapes the overall carsharing-impact unfolding *over time* – an unsolved measurement-challenge. A second methodological challenge for evaluations of carsharing-systems is the lack of standards: As of December 2014, not a single study-design in the field of empirical carsharing-research has ever been replicated, even so all measured carsharing-impacts strongly depend on the applied measurement-method (Firnkorn, 2012). In addition, empirical carsharing research has so far been dominated by static research designs evaluating carsharing-impacts at a single point in time.

This article proposes a paradigm shift from a static to a dynamic view on impacts of the PSS carsharing based on a framework structuring *static* carsharing-evaluations and a generic model of *dynamic* adaptation-processes of the mobility-behavior of carsharing-users over time. In this article, "framework" refers to a logical structure describing the relationship between research designs, target-parameters, and carsharing-studies, whereas "model" refers to a representation of a real-world phenomenon (Frigg and Hartmann, 2012): Carsharing-induced adaptation-processes of the mobility-behavior of new carsharing-users. The term "generic" is used to indicate an applicability across carsharing system-variants (e.g. with/without fixed vehicle-stations) and across target-parameters (e.g. carsharing-impacts on emissions, modal splits, or private-vehicle holding).

The objective of this article is to advance empirical sustainability-evaluations of carsharing-systems, given that PSS-scholars have repeatedly called for more empirical PSS-research. For example, Boehm and Thomas reported "a lack of quantitative empirical research designs" (Boehm and Thomas, 2013, p. 256), Mont and Tukker indicated that "[t]he challenge in the coming years is to make the research in the PSS field more rigorous and truly systemic in nature" (Mont and Tukker, 2006, p. 1454), Lindahl et al. pointed out a "clear need for publishing more research quantifying the environmental as well as economic benefits" (Lindahl et al., 2014, p. 289), and also Tukker concluded that "[i]t is striking, however, that quantitative research methods (…) are still rarely applied" (Tukker, 2015, p. 88). Given the rare application of quantitative methods, very few analyses of quantitative-empirical research methodology exist in the field. The present article contributes to closing this gap by focusing on the methodological research question: Which generic time- and method-interdependencies exist when shared-mobility impacts are empirically evaluated over time?

The authors of the present article hope that the proposed paradigm shift from a static to a dynamic view on carsharing-impacts does not only remain a theoretical contribution, but rather that this perspective is adopted by policymakers enacting carsharing-regulations in cities. To the knowledge of the authors, *dynamic* adaptation-processes of the mobility-behavior of carsharing-users have so far conceptually and empirically received limited consideration in carsharing-studies, and accordingly, many policymakers currently judge carsharing-schemes with a static view. To maximize the long-term sustainability-gains through carsharing (e.g. private-car reduction), cities may, however, have more success when considering the dynamic and asymmetric unfolding of carsharing-impacts over time as the base for carsharing-related policy-decisions.

Section 2 explains generic carsharing system-variants operating today, gives an up-to-date overview of the growing carsharing-industry, and contrasts the state of theoretical vs. empirical shared-mobility research. Section 3 proposes a framework structuring static carsharing-studies and a generic model of dynamic adaptation processes over time. Section 4 expands the analysis by the consideration of environment-stability. Section 5 summarizes the methodological contributions, and Section 6 reflects on future research.

2. Overview of an expanding mobility-disruption

2.1. Carsharing system-variants

Carsharing-systems exist in three generic system-variants. Sorted by increasing user-flexibility, these are (a) "station-based round-trip"-systems requiring users to return cars to the same station (or zone) where a rental began, (b) "station-based one-