Tradable Driving Credits:
car users' responses towards an innovative pricing measure in the Netherlands and China

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Tradable Driving Credits: car users' responses towards an innovative pricing measure in the Netherlands and China

Verhandelbare Kilometerrechten:
effecten van een innovatieve beprijzingsmaatregel op autogebruik
in Nederland en China

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht
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ingevolge het besluit van het college voor promoties in het openbaar te verdedigen
op vrijdag 8 december 2017
des middags te 12.45 uur

door

Nicolaas Jan Dogterom

geboren op 16 september 1987
te Leiden

Promotor: Prof.dr. M.J. Dijst

Copromotor: Dr. D.F. Ettema

Contents

Preface

It is only in thinking about what it would take to get people out of their cars that we can see the enormous transformations that automobility has wrought in the social organization of time, space, and social life. Overall, although many people 'love' their car, the system that it presupposes is often unloved, resisted, and raged against.

– John Urry (2007, 131)

The last proceeding of reason is to recognise that there is an infinity of things which are beyond it.

– Blaise Pascal (1958/1667, 77)

Today's mobility systems offer us many benefits, making our lives much easier and more pleasant – I'm realising this all the more now I am writing this preface in Zurich. The sociologist John Urry, who was professor at Lancaster University and greatly inspired me through his thinking on mobility and society, wrote extensively about the ways mobility systems transformed the lives of individuals and shaped the paths of societies, reflecting on the many ways we have adapted ourselves to the conveniences brought by these systems. Yet, in these mobility systems, a paradox can be found. The more people seek to enjoy the benefits of mobility, the more these systems tend to backfire and seem to limit one's freedom – a perfect example of the classic 'tragedy of the commons'.

This paradox particularly becomes apparent in the automobility system. The daily traffic jams are subject of public frustration and a popular item in daily conservations. Consequently, together with the traffic jams, also the measures that are believed to be essential to solve these jams are a much-beloved subject of everyday discussions. Opinions diverge widely as to the measures that should be taken by the government to deliver a free flow on our roads, and people are usually eager to express their personal wisdom on these matters. This book fuels these discussions and debates by discussing another type of measure, based on the idea of tradable driving credits. While some academic researchers can find in their research subject an effective conversation killer, it was my experience that mentioning my research subject was often likely to trigger a lively and enjoyable discussion.

I worked on this book inspired by a lifelong fascination for mobility and transport. When I would have filled this book with drawings of maps of imaginary countries and cities, highways and railroads, this book could have easily reached the same size. I doubt whether the assessment committee would have approved such a manuscript, however, I am sure a scientific investigation of these materials would be very interesting. I am glad that I had the opportunity to learn a lot about the role and meaning of today's mobility systems during my Bachelor, Master and PhD studies, in Utrecht, Lancaster and Beijing, and I aspire to continue working in this fascinating field in the time to come. Therefore, I hope that finishing this thesis does not mark the end of an era in my personal life.

At the same time it does, of course. It is the end of a period of studying and learning, a long period of time that culminates in achieving a PhD degree. It is the end of a 4-years period of doing my own research, being granted great personal freedom in pursuing own academic interests. Now I finished writing this thesis, I want to acknowledge the help, guidance and support of many persons, without which finishing this thesis would not have been possible.

First of all, I want to thank my supervisors: dr. Dick Ettema and prof. Martin Dijst. Dick, you brought me back to the academia after I finished my Master studies, when you asked me to assist in writing a research proposal for an international research project. After that, you offered me the opportunity to continue with this PhD project and I thank you for your trust and confidence at that time and during the course of the project. As my daily supervisor, I relied much on your in-depth knowledge of the fields of transport and statistics and your enthusiasm for doing research. I greatly appreciate your help in finding my way in the academic community. Martin, you have acted as a tutor since I entered the university. I still remember well how I, as a first year student, and as part of the Honours Programme, attended meetings in which you discussed the work of your PhD candidates with them, not realising that I would be such a candidate in a later stage. During all the years that followed, you supervised my Bachelor's and Master's theses, as well as many other projects. I greatly appreciate your close involvement with the PhD project and your efforts to make me write coherently and to keep me critical and focused.

I would like to thank prof. Meng Xu and dr. Yue Bao, who were our partner researchers from Beijing Jiaotong University in the research project. You both showed a great enthusiasm for the project. It was not always an easy collaboration because of the distance and the different backgrounds, however, I am glad that this thesis includes two papers that are the results of our joint efforts. Meng, I thank you for the opportunity you offered me to visit your group in Beijing, the hospitality you showed and the many diners you invited me to. Yue, I thank you for helping me getting familiar with Beijing and for introducing me to the Beijing food. Without your help, finding my way in this city would have been much more difficult and my application for the visa extension would certainly not have succeeded.

I would also like to thank prof. Susan Grant-Muller (Leeds University), who was involved in parts of the project. Susan, it is very unfortunate that our data collection in the UK did not provide us with a sufficient number of participants to carry out proper analysis and that, as a consequence, an investigation in the UK could not be part of this thesis. However, I am grateful for your investments in time and effort and your assistance during the preparation and execution of the data collection. In this context, I would also like to mention Olivier Boelman (Accent MR), who was very helpful in coordinating the data collection in the UK and was always quick to respond to whatever questions and issues we had.

Joram Dees and Renske Goedbloed (Simplefly) developed the online application for the data collection on which Chapters 3 and 4 rely. Thanks for your excellent assistance and adequate responses during the whole project. I also thank Rens Poesse, who developed the data collection tool that was used to gather the data on which Chapters 5 and 6 are based. Maria Pantsidou (Panelclix) showed much flexibility in facilitating a rather unconventional participant recruitment process, which appeared quite challenging at times.

I would like to express my gratitude to the assessment committee, consisting of prof. Jillian Anable, prof. Erik Verhoef, prof. Bert van Wee, prof. Henk Meurs and prof. Theo Arentze. I am grateful for your interest in the thesis and your time to read the manuscript.

Haoran, it was great to have you as my roommate during the past 4 years. We had many nice discussions about our research projects, Chinese issues and many other interesting topics. I especially remember the Chinese New Year party we had at your apartment. Sarah, we were only roommates for a short period, but I also thank you for the company. Thanks to all my colleagues and my fellow PhD candidates Marijke, Ineke, Nynke, Marianne, Anouk, Marielle, Zidan, Joost, Lars, and many others for our inspiring and enjoyable discussions, lunches and drinks together. Marijke, I really enjoy having our defences at the same day, which marks the end of our PhD trajectories that perfectly matched each other in time. I also thank my colleagues of AGORA magazine, which provided an inspiring platform for geographic thinking and research. Additionally, I want to thank my colleagues during my time in the PhD councils Prout and UGG, especially Marco, Sophie, Tina and Haoran, for their pleasant cooperation.

My friends are of great importance to me and offered me support, much-needed distraction and advice in many aspects of life. Many thanks to all.

Lastly, a special thanks to my family. As a little child, I was present at the PhD defence of my father and I'm proud that I followed in his footsteps. My parents, Dorothea, Marieke and Maurits, you showed much warmth and support, reminded me of seeing the ability to study as a gift, and always made me aware of the infinity of things that transcend the search for knowledge, especially the love of God. Sisters, it is an honour and pleasure to have you at my side as my paranimphs!

1 Introduction

1.1 Tradable driving credits as an alternative road pricing policy

The concept of tradable driving credits presents a rather unconventional and innovative approach to mitigating problems associated with growing car traffic volumes. A tradable driving credits scheme would basically privatise road access, treating it as a scarce resource, and would allocate individual shares to be used or traded to participating car drivers (for more details, see Box 1.1). In view of the magnitude of the problems of congestion and car-based pollution in many cities and countries around the world, together with the limited success of many existing measures to effectively address these problems at a significant scale, there is an urgent need to consider alternative perspectives on handling the growth of car traffic.

Transport scientists and planners have suggested various strategies to address the growth of car traffic volumes. Increasing road capacity might at first seem an obvious tool to alleviate congestion. However, it is generally expensive, does not address the environmental aspects of traffic *per se*, and often generates new traffic that consumes the added capacity. This latter phenomenon, the induced demand effect (Noland & Lem, 2002; Noland 2001), has become manifest in, for example, the Netherlands, where despite the construction of new roads in recent years, levels of congestion have rapidly reached the old levels again in a time of renewed economic growth after the recession (ANWB, 2017).

Alternatively, instead of adding capacity, countries and cities can seek to manage car traffic volumes through measures collectively known as travel demand management (TDM) measures (Kitamura et al., 1997). Examples include providing incentives for alternative travel modes and making car use less attractive through the introduction of fees or by rationing car use. While some of these measures have been successful in various situations (see for instance Buehler et al., 2016; Olszewski, 2007), other initiatives have proven to be ineffective or to have significant adverse side effects. Among the most dramatic examples are the rigorous vehicle ownership and use restrictions, especially popular in Asian cities, where the problems of congestion and air pollution associated with accelerating motorisation trends (caused by rapid economic growth and reinforced by the strong intrinsic appeal of the car) urgently call for strong and swift action. However, measures such as the Shanghai license plate auction and the Beijing license plate-based driving restriction have resulted in considerable welfare losses, an increase in second car purchases and a high level of non-compliance (Nie, 2016, L. Wang et al., 2014).

Road pricing constitutes another, and much debated, class of TDM measures. Road pricing is attractive because of a strong supportive rationale in economic theory and because of its proven effectiveness. In principle, transport economists view congestion and car-based pollution as external costs that result from market failures. They therefore argue for a corrective tax to internalise these external costs to arrive at an effective and sustainable solution (De Palma & Lindsey, 2011; Tsekeris & Voß, 2009; Rouwendal & Verhoef, 2006; Vickrey, 1969; Pigou, 1920). Instead of such first-best

Box 1.1: The concept of tradable driving credits

Tradable driving credit (TDC) schemes, as typically understood, allocate credits to participants within the boundaries of the system to be spent on car driving. Participants, who might be defined as individuals, households, car owners, etc., need to redeem credits to, for example, use the road network, enter a designated zone, or drive on a certain stretch of road throughout the day or in a particular time period. Credits might represent a unit of distance, a unit of fuel consumption, passing a particular point, etc. The allocation of credits is regulated by an authority that defines a cap (e.g., in terms of total kilometres, CO2 emissions, total number of times passing a point) and allocates credits to participants, representing an individual share of the capped quantity, each week, month or other unit of time.

Besides a free allocation of credits (grandfathering), which can take place on an equal-per-capita basis or through a proportional distribution according to historic car use patterns or travel needs, credits can also be sold to participants in an auction, which would raise revenues. Participants can trade these credits with other participants in a market, where supply and demand determine credit prices. In an alternative form, credits can be sold back to the regulator at a predefined fixed price.

Based on these elements, many forms of TDC schemes are conceivable. The precise design is to be determined in relation to desired goals, technical feasibility, institutional context, and public and political influences.

The TDC scheme investigated in this research, as communicated to the participants, would allocate free credits to car owners on a monthly basis, with one credit representing one kilometre. Participants would need credits for all kilometres driven in the country, irrespective of time and place.

pricing schemes – the application of dynamic and system-wide pricing structures that perfectly equate the marginal external costs – regulators more often rely on suboptimal, second-best solutions, often at the local level. Such solutions are easier to implement, and they still provide powerful tools for steering traffic demand. Examples include cordon pricing – where drivers pay a toll when entering the city centre – in Singapore, London and Stockholm (Börjesson et al., 2012; Santos, 2005; Goh, 2002) and value pricing on certain highway stretches – where drivers can pay a toll for driving on a separate, congestion-free lane – mostly implemented in the United States (Li, 2001; Sullivan & Harake, 1998).

Nevertheless, despite its effectiveness, widespread implementation of road pricing usually faces major public and political resistance. Road pricing systems have been suggested and heavily debated in, for example, the Netherlands, the United Kingdom and Hong Kong (Vonk Noordegraaf, 2014; 2012; Smaal, 2012; Gaunt et al., 2007; Glaister & Graham, 2005). However, these proposals have all failed due to a lack of support. This lack of support is commonly attributed to public resistance to paying for what was freely available, the conviction that road pricing will not solve the problem, and the belief that road pricing is unfair and primarily meant to increase governmental funds (Schuitema & Steg, 2008; Gaunt et al., 2007; Schade & Schlag, 2003).

It is for these reasons that the concept of tradable driving credits (TDC) has recently received increasing interest in the transport literature. As a TDM instrument, it combines forms of rationing and pricing. The measure has two central features: 1) it is able to reach a given goal in car use levels because of the introduction of an absolute constraint, and 2) it is able to reach this goal at the lowest possible total social costs because of the market, irrespective of the distribution of credits. The measure is thus economically efficient, while potentially addressing the major obstacles to conventional road pricing by introducing flexibility, a positive incentive and a freely allocated credit budget.

While much research on TDC addresses theoretical issues, empirical research is scarce. This thesis is meant to fill this gap by exploring potential behavioural and attitudinal responses to a hypothetical TDC instrument. The research leading to this thesis is part of the larger research project 'Tradable driving rights[1]: an effective travel demand management tool for maintaining accessibility and sustainability', funded by NWO-NSFC. The research project was a collaboration between researchers from Utrecht University and Beijing Jiaotong University, and data were collected in both

[1] Given the sometimes problematic connotation of the term 'rights' in relation to driving – i.e., does driving exists as a fundamental right? – and the widespread use of the term 'credits' in the literature, this thesis uses the term 'credits' instead. The terms 'permits' 'quotas', and 'allowances' are also employed in the literature and can mostly be used interchangeably.

the Netherlands and China. Therefore, this thesis will discuss results from both countries.

Before the research context is discussed, the next section addresses the TDC instrument in more detail.

1.2 Tradable credits

1.2.1 Background of the tradable credits approach

The tradable credits approach to dealing with externalities originates from the field of environmental economics. Central in this approach is the notion that externalities exist because of the absence of well-defined property rights. Whereas in the Pigouvian approach the regulator should intervene in the market with a corrective tax – a Pigouvian tax is a tax equal to the marginal external costs (Pigou, 1920) – in order to restore the market failures that produce these externalities, property rights theorists argue that externalities exist because the market itself is set up incorrectly. Coase (1960), who introduced the idea of tradable property rights, demonstrated that if property rights over the use of the resource causing the externalities were to be created, and if private actors could trade these rights, the problem of externalities could be solved in a cost-effective manner. In such a context, it would be the market that defines the true value of using the resource, rather than the regulator as in the case of Pigouvian taxes, who usually does not have the necessary *a priori* information to determine the appropriate taxes.

Based on this Coase theorem, Dales (1968) and Crocker (1966) further developed the concept of tradable credits within the context of pollution control for water and air, respectively. Additionally, Montgomery (1972) theoretically proved that a predefined goal could be achieved at minimised social costs in a tradable credit market, independently of the initial allocation of the credits. This proof is of paramount importance, as discussions about regulatory measures are usually fraught with equity-related issues. Based on Montgomery's proof, authorities can now pursue certain distributional strategies with regard to credit allocation in order to enhance public support without reducing the system's performance (Hahn & Stavins, 2011).

In a typical tradable credit system – also called a cap-and-trade system – a first step is to ration the access to a certain public resource. Then, access to this resource is privatised and credits, representing shares of the access to the resource, are distributed over targeted agents. Since the theoretical foundations for the cap-and-trade concept have been laid, the concept has seen a variety of practical applications in contexts that all more or less suffer from the 'tragedy of the commons', such as fisheries, the use of water resources and land use (see Tietenberg, 2003). In the US, cap-and-trade programmes have been developed to reduce, among others, acid rain, the use of leaded gasoline and the emission of sulphur dioxide (Sovacool, 2011; Hansjürgens, 2003). The most prominent example to date is the EU Emission Trading Scheme, which has been designed to achieve reductions in greenhouse gasses set by the Kyoto Protocols (Ellerman & Buchner, 2007; Hepburn, 2007; Christiansen & Wettestad, 2003).

1.2.2 Tradable credits at the individual level

In light of climate change, cap-and-trade programmes, which have traditionally solely targeted industries and firms at the upstream level, have recently been proposed for the individual level by the climate research community. In the UK, the idea of personal carbon emission quotas was put forward in the 1990s and attracted some political attention in the 2000s, leading to a surge of (policy) publications in which the concept was developed further, practical implications were explored and initial public responses were gauged (e.g., Fawcett & Parag, 2010; Seyfang et al., 2009). The interest in the personal carbon-trading concept in the UK was largely spurred by the government's ambitious carbon reduction goals set for future years at that time. Additionally, it was inspired by a belief that engaging the public more directly by letting them manage their own carbon allowances could form a better motivational mechanism to bring about a sustainable behavioural change (Fawcett & Parag, 2010).

In a parallel body of literature, there have also appeared several proposals for the application of tradable credits in the personal transport domain, developing largely independently from the personal carbon trading literature in the UK, and therefore is less politically embedded and more varied in scope and substance. Goddard (1997), having criticised the vehicle use restrictions in Mexico City for its perverse outcomes, proposed a more flexible tradable credit-based driving-days scheme. Verhoef et al. (1997a), starting with the observation of the limited social feasibility of Pigouvian taxing in the domain of road transport, explored a number of potential applications of the tradable credits concept. Raux and Marlot (2005) and Crals et al. (2003) proposed a tradable credit application to fuel consumption to curb vehicle-based emissions. Explicitly drawing on property rights theory and the wider debate on infrastructure capacity slot assignment strategies taking place in the air and rail transport domains (see, for instance, Starkie, 1998; de Wit & Burghouwt, 2008; Verhoef, 2010), Buitelaar et al. (2007) made a case for a property right approach to come to a more efficient use of scarce road space. Other studies took equity as a starting point and proposed the creation of potentially tradable 'mobility rights' (Viegas, 2001) or a 'credit-based congestion pricing' system (Kockelman & Kalmanje, 2005) as an alternative to conventional road/congestion pricing, which is often heavily criticised as being regressive, disproportionally harming poorer households.

These proposals differ greatly in terms of what type of actions they aspire to cover. Much differentiation is possible on several key scheme design dimensions (see Santos et al. 2010), among which the most important are the following:

- Scope of the scheme: what would be represented by the credits? (type of car/transport mode use covered by the scheme; credits representing units of distance, fuel consumption, etc.);
- Spatial and temporal applicability of the scheme: area covered by the scheme (all roads/selection of road network; city, regional, national); times covered by the scheme (whole day/peak hours; duration of the scheme; period of credit validity);
- Allocation of credits: how would the credits be allocated (equal per capita/grandfathering/benchmarking; freely/per auction); who would the credits be allocated to (individuals/households; car owners/tax payers)?;
- Relation to other transport policies (fuel taxation, car ownership taxation).

Under idealised conditions, i.e., in a situation where regulators and consumers have perfect information, a system of Pigouvian taxes and a system of tradable credits applied to an equivalent setting will result in the same efficient economic outcome (Weitzman, 1974; Hepburn, 2006). In such a situation, the market dynamics will lead to the credit price reaching the same level as the appropriate tax needed to fully internalise the externalities. This ideal situation, however, will never be found in the real world and economists have outlined several advantages of tradable credits as compared to taxes (Santos et al., 2010; Wadud et al., 2008; Raux & Marlot, 2005).

First, a quantified objective would be much easier to achieve under a cap-and-trade system than under a tax system. The tradable credit scheme would set a fixed limit on a certain resource and allow the dynamic market to determine how to reach the objective. Taxes would not necessarily guarantee this outcome. This is because many taxes have demonstrated to have a relatively low elasticity, regulators often do not have the knowledge concerning the precise costs of externalities and demand functions to set appropriate taxes, and the demand for travel is dependent on many other mediating factors, such as income, complicating the prediction of the outcome. This could lead to road pricing settings in which car drivers pay money but do not experience any significantly improved travel conditions on the roads, which is usually detrimental to public support for the measure. Second, tradable credit schemes would be less likely perceived as a tax. The allocation of a free minimum of credits, the possibility for participants to financially benefit from the scheme by selling credits, and the revenue-neutrality of tradable credits schemes – where money flows back to participants rather than flowing into government funds – are generally believed to lead to higher levels of support compared to taxation. Third, as already outlined above, regulators can directly influence the allocation of credits and hence influence the credit scheme's distributional outcomes explicitly, without disturbing the efficiency of the scheme. In this way, regulators can specifically address equity concerns potentially arising under the scheme, and, for example, distribute larger shares of credits to lower-income households or to those who live in remote areas.

Moreover, authors who have theorised about tradable driving credits from a psychological perspective, mostly in the context of personal carbon trading, have argued that these measures may have additional advantages over conventional pricing and regulation schemes – advantages that are more related to psychological decision-making mechanisms (see Capstick & Lewis, 2008, for an overview). Providing individuals with their own personal credit budget that is clearly linked to a shared collective goal is believed to raise awareness of the limited availability of resources and to increase the visibility of people's own actions and their consequences to an extent that taxation would not be able to reach. Furthermore, tradable credit schemes are argued to be empowering, as they would facilitate individuals to exercise personal responsibility when managing their own budget and would provide a framework for acting flexibly according to personal preferences (Seyfang et al., 2009). Moreover, these schemes are believed to help construct a sense of 'common purpose' through the potential shaping of new social norms and the creation of a moral environment for collective action (Bird & Lockwood, 2009; Fleming, 1997).

At the same time, there are also less favourable issues related to tradable credit schemes. Tradable credit schemes might be relatively expensive and technologically and institutionally complex (Santos et al., 2010). Although the rapidly advancing information and technology systems may smoothen the implementation of such schemes, significant investments would still be needed to create an institutional setting through which to allocate credits, to facilitate trading and to enforce the programme. The costs of designing and of monitoring and operating the system, together with the participants' (mental) costs of searching for information, bargaining and decision-making under the scheme may constitute significant transaction costs, that might reduce the cost-efficiency of tradable credit schemes (Nie, 2012; Wadud, 2011; Woerdman, 2001). So far, actual applications of tradable credit markets at the upstream level have shown that transaction costs can be substantial (Sovacool, 2010; Hahn & Stavins, 1992). Also, tradable credits schemes can lead to price volatility (Sovacool, 2010; Hepburn, 2006), which can cause participants to respond in a less rational and efficient manner when trading. In many cases, taxation will present agents with a much clearer price signal. In the context of road pricing, people are found to generally prefer pricing structures that are more stable and predictable (Franke & Kaniok, 2013; Bonsall et al., 2007; Jaensirisak et al., 2005). However, as Hepburn (2006) remarks, fixing the prices in situations of price regulation necessarily results in quantity uncertainty.

1.2.3 Research aim and contribution of the thesis

As the previous section clearly shows, the interest in the concept of tradable credits has produced a vast literature of conceptual explorations, of which an increasing part is devoted to the personal transport domain. However, the functioning and feasibility of such schemes in the practice of everyday travel is ultimately defined by the responses of car users themselves and therefore must be investigated empirically. Although there is a sizable collection of studies that discuss theoretical aspects of tradable driving credits (TDC) schemes (see for an overview Grant-Muller & Xu, 2014), empirical studies are remarkably scarce. Therefore, the aim of this thesis is to contribute to a small but much-needed body of work that seeks to anticipate responses to TDC schemes and, in this way, to inform and fuel the debate on TDC in the scientific, societal and political realms.

Specifically, the aim of this thesis is the following:

> *To gain insights into behavioural effects of and attitudes towards the tradable driving credits (TDC) policy.*

In addressing this aim, the contribution of this thesis is new and unique in the following respects. First, in the empirical work, specific TDC scenarios have been developed, through which TDC effects were tested in a research environment where participants were confronted with a realistic TDC scenario that had an explicit connection with their current travel patterns. The use of such stated adaptation experiments, through which drivers' responses can be quantified and generalised, is new to a literature in which TDC effects have largely been investigated through the use of general questionnaires, experiments based on decision contexts that are not linked to participants' concrete travel, or qualitative interviews. Through this experiment, the thesis is able to systematically test the effects of credit availability (shortage/surplus), credit price, and travel patterns on behavioural responses.

Second, in doing so, the empirical research is firmly embedded in the activity-based approach (see next section), thus acknowledging the inextricable links between car use and underlying activities, people's daily space-time paths and the physical and social factors shaping these paths, which most existing studies do not account for.

Third, this thesis specifically looks into the role of geographical context in car use behaviour change. It does so at a high geographical level by providing a comparison between the Netherlands and China (Beijing), which are two very different settings not only in terms of the structure of the built environment and infrastructures but also in terms of the socio-economic profile of the population, mode choice preferences and experience with car-related problems and car-oriented policies. In providing results from both the Netherlands and China, this thesis contributes to a much-needed enrichment of the road pricing literature from a non-Western context. It adds to insights into how geographical, cultural and institutional elements might be linked to differences between a European and an Asian context when it comes to car use change in response to pricing measures and attitudes towards these measures. Moreover, this thesis looks into the role of geographical factors at a lower level by accounting for factors such as the density of the residential and destination areas and the space-time flexibility of activity participation in car use (change). Geographical factors have been found to serve as important mediators of travel behaviour outcomes (e.g., Schwanen, 2003; Dieleman et al., 2002), but they have been largely overlooked in studies on TDC and even in the wider context of road pricing.

Fourth, this thesis not only looks into behavioural responses to TDC but also into attitudes towards TDC. Studies on TDC attitudes have largely concentrated on acceptability alone, without investigating how acceptability is related to other, underlying evaluations of the measure, such as expected personal outcomes, perceived effectiveness and perceived fairness. Also, when investigating car use change under TDC, this thesis gives attitudes a prominent role, particularly attitudes towards car use. Whereas most studies on road pricing have traditionally predominantly zoomed into the influencing role of objective characteristics, car use (adaptation) practices are also found to be dependent on subjective car attachment, not only instrumentally but also affectively and symbolically (Steg, 2005; Anable, 2005). Because the meaning of these factors is expected to be shaped by cultural context to a considerable extent, this thesis gives these subjective motives a prominent role in the cross-cultural comparison between the Netherlands and China.

1.3 Conceptual framework

Before discussing the specific research questions and research approach, a conceptual framework is proposed from which to approach the subject of this thesis.

TDC's principle aim is to organise total car travel more efficiently, and therefore, as with any other TDM measure, to bring about changes in individuals' car travel behaviour. In the theoretical framework of TDC's impact on travel choices presented here, the conceptual framework proposed by Gärling et al. (2002) to understand the mechanisms affecting travel choices under TDM in general will be followed to a considerable extent, with some specific modifications tailored to the TDC context (see Figure 1.1).

The travel choices made by the individual, leading to the *activity/travel pattern*, are dependent on two categories of factors. First, travel choices are influenced by the travel goals of the individual who wishes to pursue the satisfaction of certain needs, desires and obligations. Second, in pursuing these satisfactions, the individual is confronted with enabling and constraining factors that together constitute the travel decision context. This travel decision context is defined by the attributes of the travel options available to the individual as well as spatial, temporal and interpersonal dimensions of desired travel and the underlying desire for activity participation.

Travel is thus conceptualised as a derived demand, which is the fundamental tenet of the activity-based approach to travel behaviour research (Kitamura, 1988; Axhausen & Gärling, 1992; Ettema & Timmermans, 1997; McNally, 2000). This approach critiques the conventional trip-based four-step approach, that has long been the core of travel demand analysis and forecasting, for its lack of representation of the underlying travel-generating mechanisms. Instead, the activity-based approach starts with the assumption that travel is derived from individuals' and households' desire to fulfil certain needs, desires and obligations through out-of-home activities. It further states that the basic unit of analysis should be *patterns* of travel behaviour rather than single trips, as individuals'/households' activity participation plans arise from an activity scheduling process that comprises many interdependent choice aspects, e.g., where, when, in what sequence, with what mode (Doherty & Miller, 2000). It recognises that this choice process is a personal process in which not only socio-demographic characteristics but also more subjective factors, such as lifestyle and attitudes play a key role. Moreover, the activity-based approach understands the travel choice process as situated in spatial and social structures and affected by time and money budgets that together define and delimit the possibilities for activity/travel trajectories (Hägerstrand, 1970; Chapin, 1974; Cullen & Godson, 1975; Dijst, 2009; Ettema, 2009; Dane et al., 2015).

With the introduction of TDC, car travellers find themselves confronted with a new measure that impacts the travel decision context by altering the car travel costs. It affects the personal equilibrium in the current situation that reflects the outcome of the trade-off process between the individual activity participation aspirations and the travel context. The introduction of personal credit budgets demands the individual to manage her own personal budget. It implies a need to personally distribute credits over car trips in light of the number of credits allocated, the individuals' activity participation aspirations and the dynamics of the credit market (prevailing credit price and anticipated credit price uncertainty).

Although TDC would directly alter the travel costs that have already been captured by the travel decision context (a situational factor), the credit budget is represented as a separate element in the conceptual framework in order to highlight the unique char-

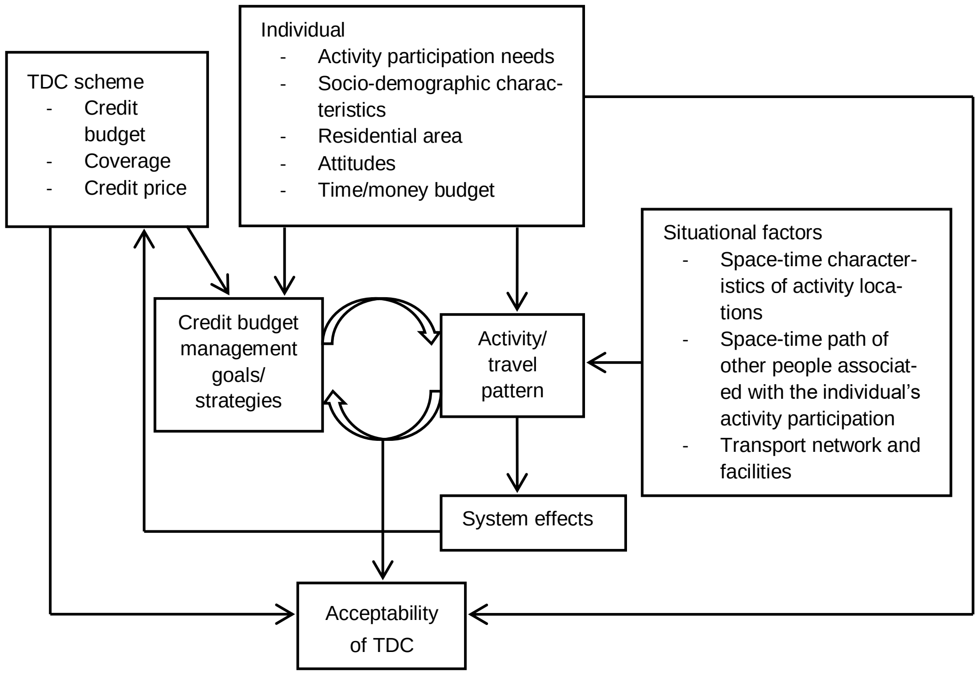

Figure 1.1: Conceptual framework

acter of managing a personal budget, which forms the central theme of this thesis. It also better visualises the distinction between the individual pursuing certain budget outcomes (realising gains or reducing losses) on the one hand and the individual pursuing certain activity/travel aspirations on the other hand. These two goals interact with each other, leading to a continuous trade-off process between both aspirations in the presence of variable credit availability and credit price, which are the outcomes of the decisions of all participants at the aggregate level (system effects).

In this trade-off process, dissatisfaction with the activity/travel pattern might arise, and as a consequence, the individual might want to adopt certain car travel adaptation strategies to conform the realised travel pattern to the individual's goals (Gärling et al., 2002). Research suggests that in doing so, individuals evaluate travel alternatives available to them according to the cost-minimisation principle (Loukopoulos et al., 2004; 2006). This principle asserts the existence of a hierarchy in alternatives that vary in terms of associated costs, which besides monetary costs also involve costs measured in time and effort. First, the less costly alternatives are selected. The more costly alternatives are only selected if a discrepancy between the travel pattern and the formulated goal of car use change remains after adoption of the previously chosen alternatives.

This is believed to be an iterative process, in which the individual tries out strategies, constantly in search of a suitable solution when dissatisfaction recurs or circumstances change (Cao & Mohktarian, 2005). Also, it is important to stress that the cost-hierarchy of alternatives is situation- and individual-dependent, that is, it varies for different trip purposes and personal contexts (Loukopoulos et al., 2006).

With regard to TDC acceptability, first, the design of the policy itself is believed to largely determine people's acceptance of the policy (Schuitema & Steg, 2008; Schade & Schlag, 2000; Jones, 1991). Second, individual characteristics have an impact on acceptability. In the domain of conventional road pricing, for example, age, income and residential location have been found to have an effect on the acceptability of the pricing policy (Jaensirisak et al., 2005; Rienstra et al., 1999; Verhoef et al., 1997b). However, individuals' attitudes related to the policy, for example, with regard to problem awareness, perceived effectiveness and perceived fairness, have been found to have a much larger effect on the acceptability of a pricing policy than socio-demographic characteristics (Schade & Schlag, 2003; Jaensirisak et al., 2005; Gärling et al., 2008). Third, it is expected that the way the measure affects people's activity/travel pattern has an effect on acceptability as well. Individuals with a lower credit demand level or with a higher capacity to adjust their travel to the budget management goals they set might have a more favourable opinion towards the measure.

1.4 Research questions

Based on the research aim as put forward in Section 1.2, the following research question is formulated:

What behavioural changes and attitudes towards the measure can be expected under TDC?

Four sub-questions were derived from this general research question, that are addressed in the individual chapters of this thesis.

1. *What are the current insights into possible behavioural effects related to TDC?*

Before starting the empirical part, Chapter 2 addresses the current insights into TDC effects. The aim of this literature review is twofold. First, it presents an overview of empirical studies on personal travel-related tradable schemes carried out to date by discussing results as well as the methodologies used. Second, it identifies three elements of TDC that make the concept radically different from conventional road pricing, and it discusses how these elements might activate certain behavioural decision-making mechanisms. These elements are 1) the opportunity to realise gains and losses under the same measure, 2) the introduction of a personal credits budget, and 3) the trading mechanism. Current studies on individual-based tradable credit schemes have hinted at additional behavioural effects that might be expected beyond the price effect alone based on these elements (e.g., Harwatt et al., 2011; Capstick & Lewis, 2010), but a systematic and comprehensive review that brings these possible effects together has been absent to date. Therefore, in the second part of Chapter 2, an overview of behavioural concepts from behavioural economics and cognitive psychology – fields that are addressing issues of rewarding, budgeting and decision-making over time and under uncertainty – that are relevant in a TDC context is provided. Such a discussion fits well within a recent growing interest in behavioural concepts and theories that have implications that deviate from the conventional rational choice-based theories that have long dominated the travel behavioural literature (Ben-Elia & Avineri, 2015; Ramos et al., 2014; Avineri, 2012; Metcalfe & Dolan, 2012). In short, Chapter 2 is meant to discuss current research, to identify research gaps and to present a research agenda for the empirical investigation of TDC effects.

One of the identified research gaps is the lack of realistic and individually tailored TDC scenarios that are grounded in the activity-based approach. As such, anticipated effects are not embedded in people's actual activity-travel patterns, as shaped by personal needs and situational factors (see conceptual model), and hence, they lack realism. It is especially this research gap that this thesis is meant to fill. This will be done together with addressing the issue of the potential of realising gains and losses under the measure, which is identified as one of the three distinctive characteristics of TDC. Addressing the other research gaps and future research avenues as identified in Chapter 2 is beyond the scope of this thesis and is therefore left open for future research.

The stated adaptation experiments used in this research have been developed to investigate TDC effects from an activity-based approach. Based on these experiments, the thesis will first look into willingness to change and the magnitude of change under TDC and its determinants. To do so, the following research question is formulated:

2. *To what extent are car drivers' willingness to change behaviour and size of change under TDC affected by credit availability, credit price, socio-demographic characteristics, residential characteristics and car dependency?*

This research question will be answered in Chapter 3 and Chapter 5. These chapters report the results of separate experiments. Whereas Chapter 3 presents the results of a detailed experiment based on an extensive travel diary carried out in the Netherlands only (experiment I), Chapter 5 is based on a less elaborate experiment that took place in both the Netherlands and China (experiment II). Section 1.5 discusses these experiments in more detail. But here, it is important to note that Chapter 3 and Chapter 5 serve different aims, and their content should be interpreted accordingly. Chapter 3 discusses willingness to change and size of change in the context of a realistic TDC scheme, with a collective kilometre reduction aim and the amount of gains and losses faced by the participants depending on their kilometres travelled. Chapter 5 compares willingness to change under TDC between the Netherlands and China based on more generally formulated experiments, with a particular focus on possible differences from their different geographical, institutional and cultural contexts.

After the analyses of willingness to change and size of change, in a next step, Chapter 4 focuses on how concrete adaptations are made on the activity/trip level. Chapter 4 revolves around the following research question:

3. *Which adaptations do car drivers make under TDC, and how are these adaptations affected by credit availability, socio-demographic characteristics, residential characteristics and activity/trip characteristics?*

Only data from experiment I are used to answer this research question, as this is the experiment in which participants recorded their actual car use in a detailed travel diary and could select concrete short-terms adaptation options if they wanted to change behaviour in response to the scenario. The aim of Chapter 4 is to come to an understanding of what activities are changed when car drivers want to make changes in response to the TDC scenario, what kind of adaptation option they choose when changing an activity/trip, and what factors influence these choices. Not only will Chapter 4 look into the responses of participants in different categories of financial gains and losses under the measure, also the factors that are often highlighted in activity-based research as important constraining and enabling elements in travel behaviour (presence of others, frequency, flexibility of location, time and travel mode) will be given a place in modelling adaptation choice.

In the last chapter, TDC acceptability and its determinants are addressed, based on the fourth research question:

4. *To what extent do car drivers evaluate the TDC policy as acceptable, and how is TDC acceptability affected by socio-demographic characteristics, residential characteristics and attitudes towards car use and TDC aspects?*

This research question is addressed in Chapter 6, and similar to Chapter 5, a comparison between the Netherlands and China (Beijing) is a central theme. Chapter 6 thus relies on data gathered in experiment II. The experiment was followed by a short questionnaire on attitudes towards the measure in terms of perceived effectiveness, perceived fairness, expected personal outcome and attitudes towards more general car use items, such as the car-related problem perception (congestion, pollution) and car dependency. In doing so, Chapter 6 is aligned with psychological research on the acceptability of travel demand management measures (e.g., Eriksson et al., 2006; Fujii et al., 2004; Jacobsson et al., 2000) and seeks to establish to what extent the role of TDC attitudes fit in or divert from what has been found in other road pricing contexts. Special attention is paid to the positioning of TDC in reference to alternative pricing/rationing measures: the existing license plate-based driving restrictions in Beijing and the hypothetical, much debated kilometre charge in the Netherlands.

1.5 Research design

In this section, the design of the experiments, the research contexts and the samples will be discussed.

1.5.1 Experiments

As already stated, the empirical part of the thesis relies on two types of experiments that were both designed as a stated adaptation experiment. The stated adaptation approach refers to a class of experiments in which the current behaviours of participants are confronted with a new, hypothetical situation and in which participants are asked to indicate how they would act if this new situation were in place. Typically, stated adaptation-based research in the travel behaviour field starts with the collection of present behaviours through questionnaires, diaries, interviews or GPS tracking, after which a scenario of the measure under investigation is presented in a customised fashion and responses are recorded in an interactive interview or an experiment (Nijland et al., 2009; Arentze et al., 2004; Faivre D'Arcier et al., 1998; Lee-Gosselin, 1996).

Experiments I and II were both web-based, and in both experiments, participants' car use during 7 days was recorded as a starting point for the scenarios. However, there are also important differences between the designs of the two experiments, given their different aims, as outlined in the previous section. Both experiments are discussed in more detail below, and a summary of the most important differences is given in Table 1.1.

Experiment I

When participants agreed to take part in the experiment, they were asked to record each trip they made by car in an online travel diary in the 7 days that followed. For each trip, participants were asked to provide the activity location in a Google Maps interface, which was used to calculate the travelled distance. Participants were also

Table 1.1: Description of the experiments

	Experiment I	Experiment II	
	Netherlands	Netherlands	China
Participants	Frequent car commuters	Car owners	
Aim	To simulate a realistic TDC scheme with a predefined kilometre reduction aim for the sample as a collective. Level of credit shortage/surplus was based on intensity of individual car use.	To test the effect of credit availability on participants' responses in isolated cases: credit availability was not a function of the behaviours of the sample as a collective.	
Travel diary (base for scenarios)	Participants reported information on each trip made during 7 days. Kilometres were calculated by Google Maps.	Participants reported the number of trips and kilometres driven per activity type for the previous 7 days. Kilometres were estimated by the participants.	
Scenarios[1]	Two scenarios. In scenario 1 the total credit availability represented a 15% reduction aim of total kilometres driven; in scenario 2, this reduction aim was 30%.[2] The number of credits available was equal to all participants.	One scenario. Participants were randomly assigned one of the following 4 options: -30% credit shortage -15% credit shortage -15% credit surplus -30% credit surplus relative to reported car kilometres.	Two scenarios. Each participant was presented a scenario with a credit shortage of 50 credits and a credit surplus of 50 credits.
Credit price	Three levels: 0.10, 0.15 and 0.20 Euros per credit. Participants were randomly assigned one level.	Three levels: 0.10, 0.15 and 0.20 Euros per credit. Participants were randomly assigned one level.	Three levels: 0.5, 0.8 and 1.0 Yuan per credit. Participants were randomly assigned one level.
Response options	Participants could reorganise the activity-trip pattern by rescheduling activities, cancelling activities or choosing alternative travel modes.	Participants could indicate whether they would make changes in separate activity categories.[3]	Participants could indicate whether they would make changes in separate activity categories.[3]
Number of participants	308	474	660
Period of data collection	October-December 2015	June 2016	July 2016
Chapter presenting results	Chapter 3; Chapter 4	Chapter 5; Chapter 6	Chapter 5; Chapter 6

[1] Only the scenarios of which the results are used in this thesis are described here. In the case of the Dutch version of experiment II, additional scenarios addressed situations in which credit availability and credit price were uncertain. No comparison with China was possible on these additional scenarios; therefore, they are not included in this thesis. In the case of the Chinese version of experiment II, there were two additional scenarios, one with a 25 credits shortage and one with a 25 credits surplus. These scenarios were considered not distinctive enough compared to the 50 credit shortage/surplus scenarios to warrant a separate analysis. Moreover, a size of 25 credits was considered relatively small, so the scenarios based on the 50 credit shortage/surplus were chosen for analysis.

[2] The actual credits availability turned out to represent a 17.5% and 32.2% reduction of total kilometres driven in the first and second scenarios, respectively. This is because the data from some participants had been removed before the analysis due to incomplete and faulty travel diaries, which generally had lower reported distances. See Chapter 3.

[3] Some additional responses were possible (see text); in this table, the response options that are reported in this thesis are given.

asked to provide information on additional activity/trip attributes, such as activity type; flexibility of the activity/trip in terms of time, location and travel mode; frequency; and the presence of passengers. Geographic information was available through the locations reported in the travel diary.

After participants had recorded their car trips, the total kilometres travelled by the whole sample was calculated. Based on reduction aims of 15% and 30% for a first and second scenario, respectively, individual credit budgets were defined. These reduction aims were considered realistic and in line with the approach of similar simulation experiments in the context of personal carbon trading (cf. Zanni et al., 2013; Capstick & Lewis, 2010). The credit budget size was equal for each participant, so it was possible for the participants to have a credit shortage or surplus, according to the discrepancy between individual kilometres travelled and the fixed amount of allocated credits.

In the second part of the experiment, participants were presented with their recorded activity/trip patterns, together with the allocated credits, credit price and consequential financial balance. If participants were dissatisfied with this situation, they could change their activity/trip pattern by selecting one of the predefined adaptation options: cancel activities, reschedule activities (give the activity another place in the activity sequence), or select an alternative travel mode. It was possible to select multiple options for one activity. Feedback about the updated credit balance was provided immediately.

Experiment II

Experiment II was developed for the Netherlands-China comparison. Because of practical considerations, experiment II was less elaborate. In contrast to experiment I, it did not explicitly link reported change to individual activities and specific adaptation actions, but its main aim was to gauge some general TDC responses in an explorative comparison between the Netherlands and China

Instead of requiring participants to record their individual car trips, in experiment II, participants were asked to estimate their number of activities and car kilometres travelled for different activity categories in the past 7 days at the start of the experiment. Furthermore, there were some differences between the Dutch and Chinese versions of experiment II due to practical issues and because of the considerations of the researchers from Beijing Jiaotong University, who developed the Chinese version of the experiment.

In the Netherlands, the TDC scenario leading to the results presented in this thesis used a setting in which the amount of the credits available for the whole week was a function of participants' reported car kilometres, and in which participants could either face a credit shortage or a surplus. One of the two situations was randomly assigned to the participants. In response, participants could indicate whether they would make a change in car kilometres travelled for each of the activity categories, and if so, by what percentage they wanted to lower/increase their car kilometres. This scenario was part of a series of scenarios in which responses were also tested in the context of hypothesised uncertain credit availability and uncertain credit price. However, because the Chinese version of the experiment did not include these additional scenarios, the results of these additional scenarios are not presented in this thesis.

In China, each participant was presented both a credit shortage and a credit surplus scenario, with the amount of credits available being equal for all participants, irrespective of kilometres driven. Similar to the Netherlands, Chinese participants could indicate the percentage of change in kilometres for different activity categories if they wanted to make changes in their reported car use, with the additional ability to state how they would realise these changes (change route, change destinations, change transport). Unfortunately, due to some problems with the implementation of the experiment, data on the size and type of change appeared not to be useful, restricting us to an analysis of willingness to change and its determinants.

Both experiment I and experiment II ended with a short questionnaire on attitudes that was designed to answer research question 4. This questionnaire included 14 questions/statements on car use and TDC attitudes that had to be answered on a 7-point Likert scale. Only the data from the questionnaire following experiment II is discussed in this thesis, as research question 4 was answered within a context of comparison between the Netherlands and China. Including the results from experiment I, with a different experimental procedure and a focus on a different group of participants, would have made such analysis rather complicated. In the translation process, the formulation of some questions/statements and their answer options differed between the Dutch and the Chinese case. Chapter 6 will discuss this issue in more detail.

1.5.2 Samples

Experiment I

The data collection process in the case of experiment I was rather unconventional due to the unique design of the experiment. Participants were recruited by Panelclix/Euroclix, which sent an invitation to their panel members. Panel members were introduced to the subject and procedure of the experiment, after which they could register for the experiment if they met the selection criteria (car owner, commute per car at least three times a week, fixed work location). In total, 1,297 persons registered for the experiment by creating a username and password by which they could access the experiment. After they had received an invitation to start the experiment from the researchers, 918 (70.8%) participants started the experiment. When the credit budgets were determined after the travel diaries had been gathered, an invitation for the second part of the experiment (scenarios) was sent out. Of those having started the experiment, 567 (61.8%) completed the whole experiment. An investigation of the personal characteristics reveals that lower-educated participants were overrepresented in the drop-out group. The drop-out rates were 51.6%, 46.0% and 30.2% for the groups with lower professional or high school education, middle professional education and university/higher professional education, respectively.

Due to various reasons, a significant share of the (adapted) travel dairies were not useful for analysis, leading to the data of 308 participants (54.4% of those who completed the experiment) being useful for analysis (see Chapter 3 for more details). Again, lower-educated participants were overrepresented in the group with incomplete/inconsistent data. Participants with useful data of those who had completed the experiment represented 47.6%, 51.8% and 57.4% of the lower, middle and higher education groups, respectively. The experiment was rather complex and time-consuming, demanding a high level of understanding and commitment, which might have contributed to lower-educated people being more likely to give up.

Experiment II

In contrast to experiment I, experiment II aimed at car owners in general. Therefore, the samples are more representative for the population as a whole, at least when the car driving population is considered (note that in Beijing car ownership is largely limited to the middle and upper class). The design of the experiment was straightforward and the participants could finish the experiment at once and in a much shorter time span than experiment I. As for the Dutch version of the experiment, 516 car owners were recruited, again through Panelclix/Euroclix, of which the data of 474 participants were useful for analysis. Participants who reported having made more than 100 car trips and who reported having made at least one trip for each of the 16 defined activity categories in the experiment were excluded because this behaviour was assessed unrealistic. In Beijing, data of 660 participants were collected and used for analysis.

1.5.3 Context

Important geographical, cultural and institutional differences exist between the Dutch and Chinese research contexts, to which this thesis will pay appropriate attention when interpreting the results. The area of research in China was limited to the city of Beijing alone, whereas for the Netherlands, participants were recruited from the entire country. Beijing is a mega-city with a population of 21.5 million inhabitants, whereas the Netherlands, with a total population of 17.1 million people, has a polycentric urban structure. Beijing is a city with one of the highest levels of congestion and car-related pollution in the world. In response, the city has already implemented some rigorous measures to manage the growth of car use. The most prominent measures are the license plate distribution system and the license plate-based driving restriction, which have received much criticism for being unjust and ineffective (Nie, 2017; 2016; L. Wang et al., 2014; De Grange & Troncoso, 2011). This makes studying the effects of and attitudes towards TDC as an alternative measure highly relevant in Beijing. Having a nation-wide representative sample in the case of China would be meaningless, given the sheer size of the country, the highly varying levels of car ownership and congestion over the country, and the fact that many TDM measures are implemented at the city level (Hao et al., 2011; Ng et al., 2010). The small size and polycentric nature of the Netherlands, leading to more evenly spread levels of congestion over the country, together with a recent debate on nation-wide road pricing, makes an investigation of TDC at the national level more relevant in the Dutch context.

Another meaningful context-specific factor in a Netherlands-China comparison is the socio-cultural position of the car. In China, car ownership and use have a strong appeal as a status symbol. In China's growing economy, the car is widely considered a symbol of freedom, wealth and financial stability that many people who have recently entered the middle class are eager to show off (Williams & Arkaraprasertkul, 2016; Yang et al., 2014; Belgiawan et al., 2014). This is different in the Netherlands, where there are smaller gaps in the socio-economic positions of the population and where the car is expected to serve more instrumental functions rather than symbolic aspirations. The context-specific functions of the car might lead to unique relationships between people's circumstances and TDC responses. Therefore this thesis will give car attitudes a prominent place when it comes to a comparative analysis.

1.6 Structure of the thesis

This remainder of this thesis consists of five research articles and a final chapter that presents an overall conclusion and discussion of the results. Because the articles have been written for publication in scientific journals, they show some overlap, especially in the introductions and literature reviews.

Chapter 2 offers a literature review on current research on TDC and relevant behavioural approaches for future TDC research. Chapter 3 presents the results of the analyses on willingness to change and size of change based on experiment I. After a discussion of figures of change for the whole sample, the effects of scenario and personal characteristics on willingness to change and size of change are analysed using logit and Tobit regression models. Chapter 4, based on the same dataset, discusses the adaptation patterns on the activity/trip level and uses a mixed logit modelling approach to assess the impact of activity/trip, scenario and personal characteristics on type of adaptation choice. In Chapters 5 and 6, the Netherlands-China comparison is provided, based on the data of experiment II. Chapter 5 addresses willingness to change and its determinants using logit modelling. Chapter 6 focuses on attitudes towards TDC. After discussing public attitudes towards TDC in a descriptive way, the determinants of TDC acceptability are analysed by use of ordinary least square regression models. Chapter 7 ends with an overall conclusion and discussion.

2 Tradable credits for managing car travel: a review of empirical research and relevant behavioural approaches*

Abstract – Recently, there has been a surge of interest in tradable credits (TC) as an alternative measure to manage the growth of personal car use. This paper summarises the results and methodologies of studies that have sought to anticipate the behavioural responses to several proposed TC schemes that target personal travel. In a critical reflection on this work and in an attempt to inspire future research, we argue that prospective empirical studies on TC behaviours can greatly benefit from insights from the fields of behavioural economics and cognitive psychology. Therefore, in the second part of the paper, we bring together behavioural concepts from these fields that are relevant in a TC decision-making context. Based on observations from current TC studies and the behavioural mechanisms identified in the second part of the paper, we propose promising directions for future research on understanding the impact of TC on personal car travel.

2.1 Introduction

Car traffic continues to increase rapidly worldwide, contributing to steadily rising levels of congestion and harmful emissions in many urbanised areas. Among the policy responses that have been suggested to curb the negative externalities caused by growing car use, road pricing has been given most of the attention, given pricing's appealing capacity to make drivers pay for the social costs they impose on others. Although attractive in theory, road pricing is often perceived highly controversial due to its limited social acceptance when it comes to implementation (Schade & Schlag, 2003; Jones, 1998). Therefore, finding policy tools that can potentially manage the demand for car travel in an effective and sustainable but politically and socially feasible manner remains high on the research agenda. Currently, a growing number of researchers and

* This paper is co-authored with Dick Ettema and Martin Dijst and is published in *Transport Reviews*.

policymakers identify tradable credits (TC) as a promising powerful and innovative alternative (e.g., Raux, 2004; Viegas, 2001; Verhoef et al., 1997a).

As typically understood, a TC scheme in the personal car transport context sets a constraint on the total car use (e.g., quantified in units of distance or fuel consumption) in a specified area and time period and distributes credits, representing a proportion of this total car use, to eligible participants who need to redeem them when driving their car. The scheme allows credits to be traded, activating a market mechanism that let credits flow to those with the highest value of car use, whereas those with the lowest abatement costs will benefit by selling their credits. Such cap-and-trade programmes are economically attractive because of their ability to reach a certain reduction goal at minimised aggregate costs (Dales, 1963; Baumol & Oates, 1988; Tietenberg, 2003). Compared to strict car use rationing programmes, TC schemes introduce flexibility and provide an incentive to reduce car travel even beyond the suggested standard. Compared to traditional road pricing measures, which are often perceived as unfair and as serving only governmental bodies to increase their funds, TC schemes enable participants to financially benefit from the system and ensure that money circulates among participants instead of flowing to regulating authorities.

Although cap-and-trade programmes have been implemented in various economic sectors, e.g., the EU Emission Trading Scheme, fishing quotas (Costello et al. 2008; Newell et al., 2005) and airport slot allocations (Wit & Burghouwt, 2008; Fukui, 2010), to date, their application on the individual level of personal travel has been only theoretically discussed. Studies that discuss the potential of TC in the transport context can be broadly classified into three domains. The first domain includes studies that propose and conceptually discuss transport-tailored TC schemes in terms of scheme design, implementation and credit distribution (e.g., Viegas, 2001; Raux, 2004; Raux & Marlot, 2005; Wadud et al. 2008; Goddard, 1999). A second set of studies takes a mathematical programming approach, studying user equilibrium and market equilibrium in the context of traffic flows and credit price under different assumptions, for example fixed/elastic demand, homogeneous/heterogeneous travellers, different initial credit allocations (e.g., Yang & Wang, 2011; Nie, 2012; Xiao et al., 2013; G. Wang et al., 2014). The third domain consists of studies that empirically investigate travel behaviour under TC schemes on the individual level.

Recently, two review papers have been published on travel-related TC schemes. Fan and Jiang (2013) provide a comparative summary of different TC schemes and evaluate them with respect to credit delineation, market mechanisms and equity issues. Grant-Muller and Xu (2014) discuss to what extent the literature suggests TC could be feasibly implemented in a context of road traffic congestion management and has advantages over other congestion mitigation instruments, mainly relying on network studies that used a mathematical programming methodology. As these review studies cover the first and second domain, a comprehensive review of studies in the empirical domain is still absent.

The aim of this paper is to bring together these empirical studies and, after a critical reflection on this work and the identification of several current gaps when it comes to understanding decision-making under TC schemes, to set a research agenda for prospective work. In doing so, we bring in insights from the decision-making literature in the fields of behavioural economics and cognitive psychology, whose relevance for travel behaviour research is increasingly being acknowledged (e.g., Avineri, 2012; Metcalfe & Dolan, 2012; Ben-Elia & Avineri, 2015; Gaker & Walker, 2011). We demonstrate that work on behavioural concepts such as asymmetrical sensitivities to losses and gains, mental accounting and time preference can be highly relevant in understanding decision-making under TC. This work is largely overlooked in existing empirical studies, which mostly use static and rather abstract stated preference-based experiments. The next section discusses existing empirical travel-related TC studies. The third section reviews relevant behavioural theories and approaches from behavioural economics and cognitive psychology and its relation to TC decision-making. The last section presents a conclusion and discusses promising directions for future research.

2.2 Travel-related responses under tradable credit schemes

Table 2.1 presents an overview of the studies discussed in this section and provides information about the type of scheme under investigation, the methodology used and the main results found by these studies. This section discusses not only studies that examine the behavioural effects of schemes exclusively designed for application in the transport domain but also studies that examine the effects of schemes that have been developed for wider application, such as Personal Carbon Trading, targeting all personal carbon production (cf., Fawcett & Parag, 2010).

2.2.1 Empirical results

The work by Wallace et al. (2010) was one of the first explorations of behavioural responses to a Personal Carbon Trading (PCT) scheme. These authors asked respondents to state the degree of likelihood they would engage in several carbon-saving actions if such a scheme would apply and found a relatively large resistance to making travel-related changes compared to home-based changes. With regard to travel-related changes, the respondents were more inclined to use a small or fuel-efficient car than to use public transport or to cycle. In their experiment, Capstick and Lewis (2010)

Table 2.1: Summary of transport-related tradable credit studies

Study	Methodology	*N*	Location	TC scheme	Compared measure
Wallace et al. (2010)	Survey questionnaire and interviews	334 (survey)	English Midlands, UK	Personal Carbon Trading (PCT)	none
Harwatt et al. (2011)	Interviews	60	Leeds, UK	PCT (only personal transport)	Fuel price increase (FPI)
Capstick and Lewis (2010)	Simulation experiment	64	UK	PCT	none
Parag et al. (2011)	Experimental survey questionnaire	1,096	UK	Personal Carbon Allowance (PCA)	Energy tax and Carbon tax
Zanni et al. (2013)	Simulation experiment	189	Southeast England, UK	PCT	Carbon tax
Raux et al. (2015a)	Stated choice experiment	~ 300	France	PCT (only personal transport)	Carbon tax
Raux et al. (2015b)	Stated choice experiment	900	France	PCT (only personal transport)	Several policies, including bonus-malus and tax
Kockelman and Kalmanje (2005)	Survey questionnaire	500	Austin, Texas, US	Credit-Based Congestion Pricing (CBCP)	Congestion pricing
Aziz et al. (2015)	Experimental game	unknown	Purdue, Indiana, US	Personal Mobility Carbon Allowance	none

Table 2.1: Continued

Study	Main results	Link with behavioural economics / cognitive psychology
Wallace et al. (2010)	Lower willingness to change travel compared to other carbon-saving actions	none
Harwatt et al. (2011)	Presenting comparable costs to achieve a certain carbon emission aim in 2030, total reduction in car kilometres was 29% under PCT versus 11% under FPI	Risk aversion: people may conserve more credits when future credit availability is uncertain
Capstick and Lewis (2010)	Total carbon reduction levels of 18.8% and 22.1% were achieved when participants received credits for carbon consumption 20% respectively 40% lower than current consumption	Mental accounting: the presence of a budget may encourage people to keep carbon consumption within the limits of the budget
Parag et al. (2011)	- Higher willingness to reduce travel under PCA (65%) than under energy tax (44%) and carbon tax (45%) - Lower willingness to reduce car travel compared to other carbon-saving actions under PCA	- Framing: greater stated carbon reductions under measures that make carbon consumption visible - Mental accounting and social norms: might explain responses under PCA
Zanni et al. (2013)	- Average carbon savings were 13.3% under PCT and 10.9% under carbon tax - Under PCT, average carbon savings were 11.4% for transport and 13.8 for domestic energy	Loss aversion: higher willingness to change behaviour found for those who faced a loss than those who faced a gain under PCT
Raux et al. (2015a)	- No difference in effectiveness between PCT and the carbon tax - Car travel reductions mainly achieved in short and frequent trips	none
Raux et al. (2015b)	- Less probability to choose the more emitting travel modes under PCT than under bonus-malus and tax - The level of loss or gain under PCT has no effect	Framing: different economic and psychological policy framings lead to different choice outcomes
Kockelman and Kalmanje (2005)	CBCP could compete with other transport policy measures to alleviate congestion	none
Aziz et al. (2015)	Development of experimental game to include market dynamics	Learning effects: spending of credits improves over time

presented participants with two trials consecutively, in which participants were given credits for carbon consumption 20% and 40% lower than their calculated current yearly carbon footprint, and found carbon reduction levels of 18.8% and 22.1%, respectively. The participants could choose several carbon-saving actions, including reducing personal car mileage; unfortunately, however, the study did not provide information on the relative contribution of these separate actions to the total carbon reduction.

Other studies on PCT have estimated the relative performance of the scheme in comparison with other pricing measures. Parag et al. (2011) investigated the stated intentions to reduce carbon consumption under an energy tax, a carbon tax and a personal carbon allowance trading scheme. The results showed that under a trading scheme more people indicated a willingness to realise carbon reductions by changing the temperature of the home (83%) and the temperature of the washing machine (78%) than by reducing personal mileage (65%). However, the relative increase in stated willingness to change behaviour under a trading scheme compared to both taxes was much larger in the case of personal mileage than for the other actions. With regard to socio-economic effects, older respondents were less willing to change their mileage than younger participants in the trading condition. Zanni et al. (2013) also found a relative hesitance to realise savings in the travel domain, including air travel. In their experiment, a PCT scheme achieved an 11.4% carbon reduction in the travel domain, whereas overall, the reduction in participants' initial carbon footprint was 13.3%. The authors compared the PCT with a carbon tax, with an equivalent per carbon unit price, and concluded that, although fewer participants were willing to change their behaviour under a PCT scheme (72% versus 80%), the average savings of participants' initial carbon footprint was higher under the PCT scheme (13.3% versus 10.9%). They further found that people being employed and living in larger households were more willing to change behaviour, whereas people with higher incomes and owning a car were less likely to reduce their carbon consumption.

Harwatt et al. (2011) analysed the potential effects of PCT in comparison with an equivalent fuel price increase necessary to achieve a desired reduction in total fuel consumption in 2030 in the UK. The results from an experiment based on a one-week travel diary showed that the respondents' stated changes would lead to a 29% reduction in the number of kilometres travelled by car under a credit scheme in 2030 whereas the fuel price increase would lead to an 11% reduction. Under a credit scheme, the respondents would especially travel more kilometres by cycle (+51%) and by train (+38%). Because the sample was small and biased towards those with higher education and income levels, the results were mainly explorative.

Although all research discussed above was conducted in the UK, where individual carbon trading received some political attention a decade ago (see Fawcett & Parag, 2010), Raux and colleagues started to research the behavioural effects of travel-related TC in France. In contrast to the studies hitherto discussed, Raux et al. (2015a) did not find a significant difference in the effectiveness of a TC and carbon tax when they asked respondents to indicate the number of trips they would cancel over a year when the scheme or the tax would apply. They found a strong preference for the status quo, and people who showed a willingness to eliminate car trips showed a tendency to reduce their commute and shopping trips over weekend and holiday trips. The tendency to maintain the status quo was significantly stronger for respondents aged 50-65 compared to younger respondents. Raux et al. (2015b) compared the effects of multiple measures and framings on the preference for different travel modes in a controlled laboratory experiment. They found that the provision of information about emissions and the presentation of a social norm were highly effective in reducing the preference for the most emitting modes but that, especially in the case of the car, the addition of financial incentives (carbon tax, bonus-malus or credit trading scheme) strikingly seemed to decrease the previous effects. When comparing the different financial incentives, the credit-trading scheme was more effective in preference reduction than the other financial incentives for all travel modes.

Kockelman and Kalmanje (2005) proposed a Credit-Based Congestion Pricing (CBCP) scheme that would function under congested road conditions in a US context, and investigated the perceptions of and likely reactions to such a scheme in comparison with other transport policies. In one scenario related to the CBCP measure, the respondents had to imagine commuting on a 20-mile stretch during peak hour for 20 weekdays, each day costing $5 in terms of credits, while they were allocated credits that accommodated all trips. When the respondents were asked how many days they would change their peak hour car trip if they could retain the money at the end of month, a mean of 3.58 days was found. Younger respondents and those with a lower income and lower vehicle ownership were more willing to modify their trips in order to save credits. Comparing the results on willingness to change car use under and support for the CBCP and normal congestion pricing, the authors concluded that CBCP may be well able to compete with transport policy alternatives.

2.2.2 Methodologies

In the absence of real-world applications of TC schemes in the context of travel, the studies reviewed here rely on methodologies that have been developed to identify behavioural responses to TC schemes in simulated choice situations. Insight into the manner in which current studies have methodologically approached TC behaviours is important because the differences in the empirical results, discussed in the previous subsection, may be attributed to some extent to the ways in which the studies presented the policy, defined the choice situations and confronted the participants with the consequences of their choices. Broadly, three types of methodologies used by these studies can be distinguished.

The first category consists of studies that obtained data from questionnaire-based surveys. Wallace et al. (2010) used a postal survey in which respondents were asked to express the likelihood that they would choose several carbon-lowering actions. In the questionnaire developed by Parag et al. (2011), respondents received a version based on either an energy tax, carbon tax or personal carbon allowance scheme, each imposing identical carbon costs, and were asked whether and, if so, to what extent they would reduce their yearly personal car use (£35 per 1,000 miles), space heating (£30 per 1°C) and washing machine use (£5 per 10°C). Kockelman and Kalmanje (2005) designed a survey that included questions on general travel choices, perceptions of and support for Credit-Based Congestion Pricing (CBCP) and other transport policies, and travel responses to these policies. To obtain information on reactions to CBCP, scenarios applying to a certain set of hypothetical trips under CBCP were posed to the respondents. Because of the static nature of traditional questionnaire-based surveys, these studies were only able to explore very general patterns of responses to the TC scheme under consideration, given that they posed decision contexts that were defined very broadly and that were rather distant from respondents' actual lives.

A second category of studies has employed computerised experimental surveys. Most of these surveys enable the introduction of individual-tailored scenarios and the functioning of interactive feedback elements to realise more detailed and personalised TC decision settings. Harwatt et al. (2011) applied a computer-based tool that was designed to assist during qualitative interviews. The tool was used to calculate carbon consumption from personal travel recorded in a one-week travel diary, to present the measure, and to display the consequences of choice options. Capstick and Lewis (2010) similarly first calculated participants' current carbon footprints. Then, participants were confronted with two simulation runs in which they could select carbon-saving actions from a pre-defined list and view their updated carbon consumption.

Other studies using computerised experiments have taken a more econometric approach, relying on larger sample sizes. Similar to the strategy of Capstick and Lewis, Zanni et al. (2013), comparing a PCT and a carbon tax scheme, first calculated participants' current carbon consumption and then presented several carbon-saving actions together with their monetary consequences to participants. They estimated regression models to link carbon reduction choices to participants' socio-economic characteristics, attitudes, current transport use, housing tenure and perceived abatement costs. Three different price levels per tonne carbon were used in the scenarios and, in the PCT scenario, equal credit allowances were allocated to participants, implying that total carbon costs (or gains, given that the least carbon producers were allocated more credits than required) differed for each participant.

In comparing the level of change in car travel behaviour under a PCT and a carbon tax scheme, Raux et al. (2015a) presented participants with personalised trade-offs in which the level of car travel reduction that could be chosen, tax/credit price per litre of gasoline and size of the free allowance (specified in litres of gasoline, applied to both PCT and carbon tax) varied. After participants' travel habits had been recorded during interviews, their car trips for a full year were categorised based on distance, and options for car travel reductions were defined as a percentage of the number of trips in these distance categories. Conditional logit models were used to estimate respondents' choices based on trip attributes and socio-economic characteristics. Raux et al. (2015b) also used a stated choice methodology; however, their approach was different from the studies hitherto described in that they investigated the effects of six different policy frames in a controlled laboratory experiment. The authors asked respondents for their preferred travel mode in the case of a hypothetical 1,000 kilometre holiday trip.

The work by Aziz et al. (2015) is an example of the third methodological approach to studying behaviours under TC schemes, aiming to establish experimental games that allow participants to interact with each other. Both travel decisions and trading patterns were investigated in a real-time online experimental game in which the subjects participated in an auction-based credit market. The researchers used random parameter models to estimate cost functions for heterogeneous travellers and count data models to analyse the market dynamics. The study had a limitation in that its subjects were only students on whom different levels of money availability, values of time and numbers of trips were imposed. However, the development of an experimental design that integrated a dynamic market environment is a significant contribution to the analysis of TC behaviours, given that the trading component is a key element in the functioning of TC schemes.

2.2.3 Conclusion

The studies reviewed in this section show that TC schemes applied in the personal travel context are able to achieve changes in people's car use. The majority of the studies has evaluated the effects of TC schemes in parallel with the effects of an equivalent tax and conclude that credit-based schemes can bring about levels of behavioural change that are comparable to or even beyond the levels that could be achieved by the tax when it comes to willingness to change car use and the size of change (see Table 2.1). In terms of socio-economic characteristics influencing responses, common findings are an age and income effect, with behavioural change decreasing with older age and higher incomes, which are effects that are also reported in the wider road pricing literature (e.g., Gehlert et al., 2011; Ubbels & Verhoef, 2005; Washbrook et al., 2006). At the same time, one should be cautious to draw robust conclusions about the (relative) effectiveness figures from these studies as they considerably differ with respect to the operationalisation of the TC concept and response options, and the methodologies used.

First, with regard to measuring behavioural change, the present set of studies on individual TC responses represents a very diverse body when it comes to the unit of analysis: annual carbon consumption/distance/number of trips (Parag et al., 2011; Capstick & Lewis., 2010; Zanni et al., 2013; Raux et al., 2015a), set of activities/trips (Harwatt et al., 2011; Kockelman & Kalmanje, 2005; Aziz et al., 2015) or a single trip (Raux et al., 2015b). Unfortunately, studies that measure individual TC effects using a fictitious base situation (e.g., a hypothetical trip) or at an aggregate scale (e.g., annual carbon consumption or annual number of trips) remain rather distant from peoples' actual lives and reduction capacities. It has become increasingly evident that travel choices and adaptations are the outcome of a complex interplay between experienced travel needs and desires, resources and constraints (Axhausen & Gärling, 1992; Jones et al., 1990; Gärling et al., 2002), and empirical approaches that do not study car use adaptations in the framework of daily structures might lead to biased outcomes. To reach a richer understanding of TC behaviours, future research should therefore examine travel changes more closely in the context of the concrete activity/travel patterns and alternatives that people have.

Second, the current studies mostly employ static and closed stated preference experiments that are not able to account for the dynamic nature of TC schemes and the complexities embedded in TC decision-making. Essentially, a TC scheme brings multiple and subsequent trip decisions under one budget, requiring people to constantly balance their credit availability, current and future travel needs, current and future credit price, and the uncertainties that accompany them. Understanding these behaviours requires more dynamic and interactive research settings, more similar to the approach taken by Aziz et al. (2015). Moreover, understanding these behaviours also requires the incorporation of behavioural concepts that can explain effects that are additional to those resulting from the TC's price signal alone. Drawing on the behavioural economics and cognitive psychology literatures, we argue that due to the unique and dynamic nature of TC schemes, additional behavioural effects can be expected. We will discuss these literatures in the next section.

2.3 Behavioural approaches to decision-making under tradable credits

Some studies reviewed in the previous section have already hinted at or even empirically addressed potential additional behavioural mechanisms at work under a TC policy. For example, Capstick and Lewis (2010) aimed to test the presence of budgeting behaviour in decision-making under TC and Harwatt et al. (2011) hinted at risk aversion at work in their interviewees' stated responses (see Table 2.1 for an overview). Additionally, mathematical studies investigating TC effects on the network level have incorporated some behavioural notions, such as loss aversion and learning (Bao et al., 2014; Ye & Yang, 2013). However, a fundamental, comprehensive discussion of these mechanisms and their potential impact on decision-making under TC is lacking in the transport literature. Therefore, in this section, we provide a systematic overview of behavioural concepts from behavioural economics and cognitive psychology that are relevant in the context of three central characteristics of TC schemes:

(1) The opportunity to realise gains and losses under the same measure;
(2) The budget with credits, functioning as a parallel currency, which needs to be managed;
(3) The trading mechanism, presenting challenges in terms of decision-making under uncertainty and time.

We will discuss relevant theoretical insights for each characteristic in the following paragraphs.

2.3.1 Facing gains and losses

2.3.1.1 Gains and losses

A first key characteristic of TC schemes is that they present both incentives and disincentives to participants: those who exceed their budget face financial losses, given that they need to buy additional credits, whereas those who remain within the budget can make actual financial gains by selling their unused credits.

Psychological research on learning and motivation, studying the influence of incentives on, for instance, employee productivity and educational achievements, asserts that rewarding behaviour is equally or more effective in influencing behaviour than punishing undesirable behaviour (e.g., Berridge, 2001; Geller, 1989). In travel behaviour research, positive incentives to achieve behavioural change have been applied only on a very limited scale, for example, in the context of safe driving (Mazureck & van Hattem, 2006; Bolderdijk et al., 2011) and the provision of free tickets for public transport (Fujii & Kitamura, 2003; Thøgersen & Møller, 2008). To date, the 'peak avoidance' experiment in the Netherlands is the largest programme that used rewards in a real-life road pricing setting (Ettema et al., 2010; Ben-Elia & Ettema, 2011; Knockaert et al., 2012). Frequent morning peak hour drivers were asked to volunteer in the experiment and could earn money or credits to earn a smartphone at the end of the experiment each time when they did not longer travel during morning peak hour. Although most studies in the travel behaviour literature have focused on either a fine or a reward, Tillema et al. (2013) compared the 'peak avoidance' experiment with a hypothetical time-differentiated distance charge and concluded that the reward measure appeared to lead to higher levels of off-peak travel. However, due to the differences in the scheme design and participant groups the results of this comparison should be interpreted with some caution. The same applies to most of the studies mentioned above: the lack of a direct comparison of the effects of gains and losses makes it difficult to derive their relative value and to predict the effectiveness of both gains and losses in a TC scheme context.

Prospect theory, on the other hand, is a prominent theory in cognitive psychology and behavioural economics that has incorporated influential assumptions about the gain-loss relationship, challenging the standard microeconomic assumption of identical price elasticities for both price increases and decreases. Experiments by Kahneman and colleagues revealed that people tend to be persistently loss averse, attaching greater weight to losses than to equivalent gains (Kahneman & Tversky, 1979; Kahneman et al., 1991). An essential assumption in prospect theory is that utility is not determined by the final outcomes but by the relative change from a reference point. Given that prospect theory has become an important behavioural paradigm in understanding consumer behaviour, studies on travel behaviour have also recently started to incorporate prospect theoretical concepts and have found support for the idea that the asymmetrical utilities drawn from gains and losses are also present in the decisions of travellers (Senbil & Kitamura, 2004; Schwanen & Ettema, 2009). Additionally, reference-dependence choice models, which have been developed in the context of departure time choice and value of travel costs, also suggest evidence of loss aversion and generally show a better fit when accounting for referencing (De Borger & Fosgerau, 2008; Stathopoulos & Hess, 2012).

In a TC context, loss aversion would mean that a person facing a loss due to credit shortage would show a higher propensity to reduce car use, lowering his or her credit usage, than a person in a situation of credit surplus. In current empirical TC studies, only Zanni et al. (2013) have explicitly addressed the relative impact of facing a loss and a gain on choice outcomes and indeed found that the total price had a greater effect on the choice to reduce carbon consumption for respondents in a loss situation than for those in a gain situation.

In addition to the relative impact of losses and gains *per se*, another relevant issue is the impact of the amount of the financial (dis)incentive. Zanni et al. (2013) found evidence for diminishing sensitivity as the importance of total gain/loss in determining the probability of employing carbon consumption actions decreased with an increase in total price. This finding resonates with the study by Tillema et al. (2013), which also demonstrated a decrease in the magnitude of behavioural adjustments relative to the increase in costs/gains. They concluded that this observation may indicate a ‘shock effect’, i.e., a behavioural effect that can be merely attributed to the introduction of the policy. At the same time, the psychologists Gneezy and Rustichini (2000a) argued that in case of rewards, incentives are effective only when they are sufficiently large. Future research should further examine the marginal effectiveness of the amount of gain/loss under TC and the potential presence of threshold values.

2.3.1.2 Endowment effect

A well-known and robust observation made in many trading experiments in behavioural economics is the discrepancy between willingness-to-pay (WTP) and willingness-to-accept (WTA) (Horowitz & McConnell, 1999; Kahneman et al., 1991), which is another violation of standard economic theory and a supportive indication of loss aversion. The tendency of people to overvalue what is in their possession is what Thaler (1980) termed the *endowment effect*. In a TC context, this effect may imply a tendency to conserve credits (i.e., lower car use), leading to fewer transactions than expected under market conditions. However, empirical research has shown different levels of the effect under various trading conditions and these findings are important to consider for a more nuanced understanding of the potential endowment effect in a TC context.

First, the endowment effect seems to be most pronouncedly at work in open markets, with unfixed prices and room for negotiation, whereas in market settings with fixed prices and more standardised transactions, the effect is much lower or even absent (Kahneman, 1992). The implication is that the endowment effect could be expected under TC schemes that allow credit prices to vary according to market dynamics, in contrast to TC schemes that operate with fixed prices. Second, experiments by List (2004) showed that the effect decreased when traders had more market experience. This result could mean that endowment effects might be visible at the introduction, but may diminish or even disappear as soon as participants become familiar with the scheme, participants can estimate the consequence of their decisions more accurately, and transactions become more routine (see also subsection 3.3.4). Third, the endowment effect is more prominent in trading circumstances that involve consumer goods, goods that derive their value from utilisation and are not easily replaceable, than in trading circumstances that involve exchange goods, goods that are held for the purpose of resale (Kahneman, 1992; Kahneman et al., 1991). The implication of this finding in a TC context is not straightforward. Credits may be conceived as exchange goods, given that they do not have value in themselves. However, given that the credits can not only be exchanged for money but also for car trips, they can simultaneously be treated as consumer goods. A larger tendency to hold onto credits (i.e., lower car use) can therefore be expected when people interpret their credits more in terms of car travel potential; in contrast, a reduced manifestation of the endowment effect

Table 2.2: Summary of the behavioural effects discussed in this review

Behavioural effect	Key references	Explanation	Potential effect in TC context
Loss aversion	Kahneman and Tversky (1979)	Losses weigh more than equivalent gains	A higher propensity to reduce credit usage in a situation of credit shortage than of credit surplus
Endowment effect	Thaler (1980); Kahneman et al. (1991)	People ascribe more value to objects or resources when they are in their possession	Increased reluctance to trade credits
Framing	Tversky and Kahneman (1981); Levin et al. (1998)	The presentation of an equivalent situation or outcome in a different format leads to a different outcome	Credit spending patterns depend on the framing of the policy by participants and regulating bodies
Mental accounting	Thaler (1999); Heath and Soll (1996)	Money and resources are psychologically categorised based on different codes and labels	Credits are not equal to the money that they represent; the suggested budget limit may encourage credit conservation
Endowment effect under uncertainty	Kahneman and Tversky (1979); Van Dijk and Knippenberg (1999)	Endowment effects tend to be stronger in trades that involve uncertainties	Uncertainty over the future credit price and travel may encourage credit conservation
Complexity aversion	Tversky and Kahneman (1984)	People tend to act less rationally and rely more on decision heuristics in complex decision contexts	The more people encounter difficulties in estimating credit costs, the more people will make decisions that satisfy rather than optimise
Regret aversion	Bell (1982); Loomes & Sugden (1982)	People anticipate the possibility of regret felt if a alternative choice option would result in a better outcome and try to avoid choice options with larger anticipated regret	In TC decision-making contexts with increasing levels of uncertainty, regret aversion might play a more prominent role
Immediacy effect	Keren and Roelofsma (1995); Green and Myerson (2004)	People tend to attach greater value to immediate rewards than to equivalent rewards that arrive later	People may overspend their credits at the start of a TC period
Learning effect	Erev and Barron (2005)	People learn from their past decisions through feedback	Credit spending may change over time based on how satisfied people are with earlier outcomes

may be expected when people regard their credits in a simple currency exchange system (Capstick & Lewis, 2008). This credit interpretation is an issue of framing.

2.3.1.3 Framing

Framing is the manner in which equivalent situations or outcomes are presented in a different format. Experimental psychological studies have demonstrated many instances in which the manipulation of the information context results in differentiations in behaviour, with the impact of negatively framed information being considerably stronger than that of the same information framed positively (Tversky & Kahneman, 1981; Levin et al., 1998). For example, Hardisty et al. (2010) labelled a price increase to cover the costs of personal carbon emissions as a 'carbon tax' and a 'carbon offset' and found this framing to impact the WTP. As discussed in the previous section, Parag et al. (2010) and Raux et al. (2015b) attempted to isolate the effects of framing of TC and found larger stated carbon consumption reductions under TC than under other types of pricing measures with equivalent costs. At the same time, it is important to note that a TC scheme itself can be framed in different fashions, for example, by emphasising its ability to generate individual financial benefits, appealing to people's financial interests, or by stressing its capacity to realise environmental goals on a collective basis, addressing motivations related to social norms and shared responsibility.

Of course, participants' own subjective framing of the scheme may guide behavioural responses as well. As noted in the previous subsection, participants may perceive the credits as a perfect substitute of money, which can be easily exchanged (exchange good), or as a distinct travel resource, which has a monetary value different from its market value (consumer good). Furthermore, participants may view their given budget as a virtual resource that obtains its financial value only when being traded; realised gains can then be viewed as a type of refund. However, when credits are treated as additional income, whose monetary value becomes already internalised when receiving the credits upfront, a loss perspective is more appropriate when interpreting credit use decisions. The study by Nielsen (2004) illustrated the importance of attending to different possible framings, showing larger behavioural changes in a pricing experiment in which participants' driving implied losing money that was given to them at the start compared to an experiment in which driving meant gaining less money at the end of the experiment.

2.3.2 Budgeting and mental accounting

The introduction of a budget to be managed may encourage *mental accounting*. The central assumption in the theory of mental accounting is that money, resources and transactions are psychologically categorised based on their different types of coding and labelling (Thaler, 1999). The concept of mental accounting violates the economic principle of 'fungibility', i.e., that money as a unit is interchangeable, regardless of its resource or label. Mental budgeting, as an aspect of mental accounting, is the process through which people allocate funds to competing consumption categories, keep track of their expenditures, and develop self-control mechanisms (Heath & Soll, 1996; Thaler, 1999; Antonides et al., 2011). A TC budget, although not being a self-imposed and formally restricting budget, may also stimulate budgeting behaviour and facilitate self-control through providing a suggested and shared limit and its explicit reference to bounded car travel capacities for the collective (Capstick & Lewis, 2008).

Based on the theory of mental accounting, it can be assumed that the introduction of TC leads to the creation of a new mental account in people's cognitive decision-making framework to organise car travel. It can also be expected that people show a general hesitance to move beyond their given budget because doing so would imply higher mental costs. Although this process can facilitate credit conservation (i.e., lower car use) in case of credit shortage, it can also stimulate overconsumption (i.e., increased car use) in case of credit surplus because people may want to spend the full amount of resources that they have mentally devoted to car travel. Further, the labelling of income is another important aspect of mental accounting that is of particular relevance in a TC context. For example, Epley et al. (2006) found that an amount of money labelled as bonus income had a higher propensity to be spent than money described as return income, and Arkes et al. (1994) found that windfall gains were spent more readily than other assets. The implication may be that people who fall comfortably within their budget may potentially spend their credits more frivolously and drive even more.

Further, the allocation of (equal) budgets to all participating agents under TC may lead to the shaping of new social norms that emphasise fair and equal credit use based on ideas of cooperation, commitment and responsibility (Fleming, 1997; Bird & Lockwood, 2009). For example, some participants in the study by Harwatt et al. (2011) said that the conviction that others would also change car use when there was a fixed limit on total credit availability made them more prepared to change car use under a TC scheme compared to the fuel increase policy. However, at the same time, TC schemes may 'crowd out' normative motivations through the introduction of marketable credits that could be perceived as a 'right to drive' (Frey & Stutzer, 2008). An interesting observation in this respect was made by Gneezy and Rustichini (2000b), who found that the introduction of a monetary fine for parents who collected their children from day-care centres after closing time significantly increased the number of late arrivals. Parents now perceived they could pay off their duty to be on time.

2.3.3 Decision-making under complexity, uncertainty and over time

Many modelling studies on TC schemes for road transport assume that credit owners have full information about their trips, available alternatives and credit prices. However, in reality, drivers will experience a degree of uncertainty in their TC decision-making that will impact their decision-making.

2.3.3.1 Complexity avoidance

Allowing credit prices to follow the dynamics of supply and demand in a market setting is key for TC schemes to be economically efficient. Although optimal pricing requires variable tariffs, there is evidence that people respond less rationally to fully dynamic price structures in road pricing (Franke & Kaniok, 2013; Link, 2015; Bonsall et al., 2007). In such settings, the pricing mechanism is often perceived too complex, leading to additional 'transaction costs' needed to invest to properly estimate the correct price signal. Research has shown that a higher level of decision-context complexity makes people more likely to employ 'heuristics', i.e., mental short-cuts (rules of thumb) to ease the effort of decision-making, or to prefer the status quo, i.e., to stick to the current situation (Gigerenzer et al., 2011; Swait & Adamowicz, 2001; Tversky & Kahneman, 1974). In a TC context, people might for example only start to consciously take account of their car use as soon as their free credits are about to be exhausted, due to the availability bias (Gaker & Walker, 2011), or choose to buy/sell credits as soon as they reach a certain price in the market, rather than making a complete appreciation of all market information to base their decision on.

2.3.3.2 Endowment effect under uncertainty

Although the endowment effect (see subsection 3.1.2) seems to be absent in trading settings involving exchange goods with fixed prices, experimental research has found a manifestation of the effect in settings where exchange goods were being traded under uncertain prices (van Dijk & van Knippenberg, 1999). In these settings, people cannot simply compute the net gain of the exchange and consequently frame the outcome as a risky prospect, which leads to a larger loss aversion effect (Kahneman & Tversky, 1979). In a TC context, these findings can mean the presence of stronger endowment effects, and therefore an increased tendency to conserve credits can be expected under schemes that operate with flexible prices compared to schemes with fixed prices. Moreover, given that credits would be valid during a multi-day period, uncertainty over future car travel demand could add an extra layer of uncertainty, reinforcing the endowment effect. Interestingly, the interviewees in the study by Harwatt et al. (2011) stated that uncertainty over future prices and credit availability would make them more prone to lower their car use.

2.3.3.3 *Regret aversion*

Studies on choices involving gambling, trading and investing have demonstrated the important role of anticipated regret in decision-making under uncertainty. Formulated as an alternative to expected utility theory and prospect theory, regret theory (Bell, 1982; Loomes & Sugden, 1982) is a powerful and prominent decision theory that not only takes the expected payoff but also the possibility of regretting not choosing the alternative option into account. The application of regret theory in the field of transport has been very modest however, but is receiving increasing attention, for example in the route choice literature (Chorus, 2012; Ben-Elia et al., 2012, see Rasouli & Timmermans, 2014, for an overview). Regret theory assumes that in cases of outcome uncertainty decision-makers anticipate the associated regret (the negative emotion felt when learning that the outcome of the rejected option is more favourable) with each available choice option and postulates that decision-makers are regret averse, i.e., try to avoid options with a larger possibility of regret. As such, regret aversion seems to relate closely to risk aversion. Spending credits now versus later for a possibly more urgent trip, selling/buying credits with a known price now versus later with an uncertain price, and making/cancelling a car trip now versus a potential credit shortage/surplus later are typical TC circumstances in which the concept of regret anticipation could offer a helpful framework of understanding the outcome of such trade-offs.

2.3.3.4 *Immediacy effect*

In behavioural economics and cognitive psychology, *intertemporal choices* have received much attention (Read, 2004; Frederick et al., 2002; Berns et al., 2007). One common finding in terms of time preference is that people generally prefer a reward that arrives sooner to an equal reward that arrives later. Decision-makers tend to place an especially high value on the 'now', which is described as the *immediacy effect* or *temporal discounting* (Keren & Roelofsma, 1995). A classic example of time inconsistency is that most people prefer to receive $100 now rather than $120 one month from now but prefer the latter alternative when the time horizons are redefined to 12 months and 13 months, respectively (Green & Myerson, 2004). Much psychological research has pointed to people's seemingly irrational preparedness to choose immediate gratification over alternatives that are less attractive at present but lead to a better outcome over the longer term, over-emphasising the immediate benefits and acting in states of impulsivity and temptation (Shefrin & Thaler, 1992; Ainslie, 1975; Lynch & Zauberman, 2006). Based on this immediacy effect, in a TC context, people may overspend their credits in the early phase of the budget period, which would contrast with the endowment effect under uncertainty.

2.3.3.5 *Learning effect*

In trading-off travel needs and money over time, TC decision-makers enter a decision cycle in which the payoff of one decision determines that state in which the next decision has to be made. In the case of repeating choices, people learn from past experiences and show adaptive behaviour. Choices that result in satisfying outcomes are more likely to be repeated in the same decision situation, while choices leading to dissatisfying outcomes are less likely to be chosen again (Thorndike, 1898; Ben-Elia & Avineri, 2015). At the same time, the decision-making literature showed that highly uncertain choice contexts hampers learning, i.e., decision-makers seem to move towards random choice when the payoff variability increases (Myers & Sadler, 1960; Busemeyer & Townsend, 1993). Interestingly, the investigation of decision-making in iterative, feedback-based decisions have led to observations that divert from the prospect theoretic accounts of loss aversion and endowment effect, that have typically been formulated on the basis of one-shot, description-based decision tasks (Erev & Barron, 2005). In the empirical TC context, only Aziz et al. (2015) led participants actually trade credits in several rounds in an experiment. They concluded that participants reflected learning behaviour as allocation of credits improved over time. The lack of other research on this topic clearly urges for further investigation of TC decision-making over time.

2.4 Conclusion and future research

This paper contributed in two ways to the recent increase in interest in the concept of tradable credits (TC) in the personal car travel domain. First, we summarised studies that concentrate on the behavioural effects of relevant TC schemes in terms of empirical results and methodologies. Overall, the results indicate that TC schemes can realise significant car use reductions, equal to or even beyond those resulting from pricing measures with equivalent costs. Second, in a critical reflection on the existing empirical studies and to inspire future work, we provided a comprehensive review of behavioural concepts and theories from the fields of behavioural economics and cognitive psychology that we argue are relevant to account for when investigating decision-making under TC schemes.

Based on these reviews, we suggest several main directions for future research. First, to date, most empirical studies have investigated stated behavioural change in response to TC schemes in a rather abstract fashion by situating the choice options in either a fictitious decision context (e.g., based on a hypothetical trip) or an aggregate decision context (e.g., asking for stated reductions in the number of trips made or the total distance driven by car in a full year), both being far from life as it is experienced.

However, it has become evident that travel choice is an adaptive process embedded in the interdependencies between time, money and activity needs and desires (Axhausen & Gärling, 1992; Jones et al., 1990; Gärling et al., 2002). Therefore, placing TC behaviours in the context of people's everyday activity patterns would lead to a better understanding of how decisions are an outcome of actual trade-offs between activity characteristics, TC scheme characteristics, and the travel and activity alternatives accessible in people's everyday contexts. This could for example be achieved by using a set of concrete activities/trips as input for stated choice exercises, or by real-world field trials, that do not suffer from the hypothetical bias.

Second, the option to either gain or lose money under the measure, the need to manage credits over time, and the presence of uncertainty surrounding future credit availability and credit prices are aspects of TC schemes that are largely overlooked in current empirical studies. Ignoring them would lead to biased estimations of TC effects and insights into TC behaviours would be greatly enriched if future empirical studies were able to develop frameworks that can accommodate decision-making under these TC dynamics. In this review we discussed behavioural notions that may shed light on how decision-making mechanisms could be triggered by these dynamics. We presented some initial thoughts about these effects, but at the same time we are aware that people's actual decisions may be more nuanced in reality. For example, people may differ in risk aversion, in the use of reference points (which can be the objectively defined budget limit as well as subjectively defined goals) and in the development of subjective decision heuristics. Additionally, the implication of different behavioural notions discussed in this review can contradict each other; for example, whereas the endowment effect under uncertainty might suggest people to conserve credits for future use, the immediacy effect might imply people to overspend their credits on the short term. Further, empirical research has shown different manifestations of certain effects in different decision contexts; prospect theoretic notions such as risk aversion and the endowment effect that are present in one shot tasks seem to disappear in repeated choice tasks (Erev & Barron, 2005). Therefore, this paper is meant to spur further exploration of TC decision-making research on the presence and working of the reviewed behavioural mechanisms rather than presenting a conclusive evaluation of their effects.

Third, current TC studies predominantly rely on static and closed stated preference techniques, however, these techniques cannot capture the more dynamic and complex attributes of TC systems as these systems force decision-makers to allocate credits over time and in interaction with others through a market. To investigate how TC trade-offs are dependent on time and collective choices, the application of research methodologies that can accommodate dynamic spending preferences, learning effects and market interaction are a necessary next step in TC behaviour research. The use of learning-based models, which has recently been applied to test the effect of travel time information on road choice (Ben-Elia & Shiftan, 2010; Avineri & Prashker, 2006), provide one promising avenue. Additionally, game theory presents a helpful tool for studying the choices of multiple TC decision-makers in a framework in which payoffs are dependent on the choices of others and the market (Levinson, 2005; Hollander & Prashker, 2006). Through bi-level optimisation, drivers' decisions can be integrated with the upper-level attributes and impacts of TC schemes, such as credit allocation by TC operators and traffic flows in the network.

3 Behavioural effects of a tradable driving credit scheme: results of an online stated adaptation experiment in the Netherlands*

Abstract – There is increasing interest in the application of tradable credit schemes in the context of personal travel. To anticipate the effects of a distance-based tradable driving credit (TDC) scheme, an innovative stated adaptation experiment has been conducted. Using an activity-based approach, Dutch participants who frequently commute by car could reschedule their car-based activities and alter the travel pattern they reported in an online travel diary for a full week. This paper presents the results of model estimations that describe the likelihood of changing car use and the number of kilometres driven in response to two TDC scenarios. Reductions were larger for those who experienced losses under the measure compared to those who experienced gains. Participants who worked more hours and who lived in non-urban areas showed lower car use reduction levels, whereas participants with middle incomes and who were 18-25 years old showed higher reduction levels. A car dependency measure was added to the models to assess how these effects are related to the availability of car use alternatives.

3.1 Introduction

Car traffic poses a range of problems in terms of congestion and pollution in many urban areas of the world, leading to major losses in the economic performance of cities and the quality of life of their inhabitants. Without adequate responses, undesirable consequences of growing traffic, such as time losses, social stress and harmful emissions, are expected to worsen given the steady increase in car travel demand and the considerable increase in car ownership in many rapidly developing economies (Pucher et al., 2007; Girod et al., 2013). Various policy responses to curb traffic volume and to influence car travel demand have been proposed at different spatial scales and in different contexts. Many of these initiatives have incorporated pricing mechanisms, as road pricing is believed to be an efficient tool for allocating scarce road

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space and making drivers pay for the negative externalities they impose on others (Pigou, 1920; Vickrey, 1969; Rouwendal & Verhoef, 2006). However, fierce societal and political resistance against pricing measures makes implementing initiatives that could affect car traffic flows at a significant scale difficult (Schade & Schlag, 2003).

The use of tradable driving credits (TDC) has been identified as a promising alternative method of managing the growth of car use in an effective and efficient yet socially feasible way (Viegas, 2001; Goddard, 1997; Verhoef et al., 1997a). In general, TDC refer to market-based instruments that set limits on aggregate car use and distribute credits, representing an individual share of this car use, to participating agents. These credits can be traded so that that credits flow to agents with the highest value of using the resource, while those with the lowest abatement costs are able to sell their excess credits.

Various TDC forms have been theoretically explored in terms of scheme design and functioning (Goddard, 1997; Verhoef et al., 1997a; Viegas, 2001; Raux & Marlot, 2005; Buitelaar et al., 2007). Other studies have approached TDC schemes from a mathematical perspective by modelling traffic flows and times under different credit allocation and traveller assumptions (e.g., Yang & Wang, 2011; Xiao et al., 2013; Nie, 2012; Bao et al., 2014). However, until now, little effort has been made to investigate drivers' responses to TDC schemes at the individual level. Yet, in order to anticipate TDC effects, an empirical approach that relates credit consumption to individual car travel patterns and socio-demographic characteristics is critically needed.

Although some empirical studies have investigated drivers' responses to specific TDC schemes (Kockelman & Kalmanje, 2005; Raux et al., 2015a), or related personal carbon trading schemes, that in addition to travel activities also target other energy consuming actions (Zanni et al., 2013; Capstick & Lewis, 2010; Parag et al., 2007), these studies have generally investigated responses either in fictitious decision contexts or at a highly aggregated level. That is, they either elicited responses to scenarios that were based on hypothetical, non-experienced trips (e.g., Kockelman & Kalmanje, 2005) or presented options in which respondents could change their annual mileage or number of trips without a clear and direct connection to concrete activities and trips (e.g., Raux et al., 2015a, Zanni et al. 2013, Capstick & Lewis, 2010). We argue, however, that placing TDC responses in the context of people's daily activity patterns leads to a more reliable understanding of TDC decision-making as a trade-off between credit availability and real activity and travel needs.

Therefore, this paper discusses the results of an online stated adaptation experiment that has been developed to anticipate responses to a TDC scheme using an activity-based approach (Axhausen & Gärling, 1992; Ettema & Timmermans, 1997). Participants reported their car-based activities for a full week, and they could reorganise this activity/trip pattern in response to two TDC scenarios. Using a sample of 308

Dutch car commuters, this study is the first to use a quantitative stated adaptation method that grounds TDC responses in actual trips and contextual characteristics on a large scale. In this paper, we specifically discuss the extent to which the investigated distance-based TDC scenarios leads to changes in vehicle kilometres travelled and how these changes relate to characteristics of the participants. In doing so, special attention is paid to the effect of facing a loss or a gain under these TDC scenarios, the influence of perceived car dependency and the role of participants' residential location, the latter being an aspect that studies on TDC have largely overlooked until now.

In the next section, we review theoretic and empirical work on TDC instruments. Section 3.3 describes the methodology. Section 3.4 discusses the experiment, the scheme and the sample in more detail. Section 3.5 presents the results, and section 3.6 provides a conclusion and discussion.

3.2 Literature

Tradable credit (TC) programmes offer regulators powerful tools to cope with the problem of the commons by rationing access to a resource and privatising access rights. In *The Problem of Social Costs* (1960), Coase argued that the lack of well-defined property rights causes the existence of externalities. These externalities could be eliminated if resource users could trade delineated private access rights in a market, which would lead to the efficient use of the resource regardless of the initial allocation of rights in situations with zero transaction costs and zero income effects. For a more thorough discussion of the theoretical foundations and practical details (e.g., its basic theorems, the issue of transaction costs, the issue of administration costs), we refer to Montgomery (1972), Baumol and Oates (1988), Hahn and Hester (1989), Hepburn (2006) and Tietenberg (2003). Compared to traditional pricing and taxing, the major advantages of TC programmes are that they provide regulators direct control over the quantity of total consumption and that price setting, which in the case of Pigouvian taxing is often problematic because of the need for *a priori* information about the precise valuation of the true costs of externalities and the demand and costs structures of the market, is left to the market (Verhoef et al., 1997a). TC schemes have found several applications in upstream programmes in contexts such as air pollution control, fisheries, water resource management and land use control (e.g., Sovacool, 2011; Costello et al., 2008), but examples of implementation at the downstream, individual level are still absent.

Various authors, however, have started to conceptually explore the potential of TCs in the personal transport domain. Verhoef et al. (1997a) discussed several TC applications on the vehicle user side, as well as on the vehicle and fuel industries side.

Goddard (1997) proposed replacing the Mexico City non-driving-day vehicle restriction scheme with a more flexible tradable driving-day scheme. Examples of other proposals include mobility rights to drive in specific tolled areas and to ride public transport (Viegas, 2001), tradable fuel credits (Raux & Marlot, 2005; Crals et al., 2003) and, inspired by airport slot-allocation approaches, tradable road access rights (Buitelaar et al., 2007). For an elaborate review on various TC proposals in the transport domain, we refer to Grant-Muller and Xu (2014) and Fan and Jiang (2013). At the same time, a parallel series of studies on the potential of so-called personal carbon trading schemes targeting not only personal transport but all carbon emitting sources used by households has emerged in the environmental literature (e.g., Fawcett, 2010; Starkey, 2012; Capstick & Lewis, 2010). The overall conclusions of these proposals are that TC schemes are theoretically efficient and could feasibly replace current road pricing and rationing initiatives that widely encounter low acceptability rates (Schade & Schlag, 2003; Jaensirisak et al., 2005) and often lead to substantial undesirable side effects (Davis, 2008; Hao et al., 2011).

As a tailored combination of control and pricing measures, TC schemes introduce flexibility and freedom of choice for drivers with respect to credit use within the limits of the cap on aggregate car travel. It is argued that the allocation of free credits to participants and the circulation of money among participants make TC schemes less likely to be perceived as a tax (Wadud, 2011). The opportunity to realise gains under the measure, as a positive incentive, could further enhance its acceptability and function as an additional motivation for drivers to reduce their resource consumption. Moreover, the progressive nature of TC schemes – they will benefit groups with lower car use levels, which are usually lower-income groups – and the possibility for regulators to pursue certain distributional outcomes by means of credit allocation are believed to make a TC scheme more acceptable than a tax, as the distributional consequences seem to be key determinants of the acceptability of pricing measures (Mayeres & Proost, 2004; Bristow et al., 2010). Further, from a more psychological perspective, TC proponents argue that individual TC schemes might realise additional behavioural changes over a tax via the mechanisms of budgeting (i.e., people wishing to remain within the suggested personal limit budget inspired by goal setting), increased individual engagement (i.e., people directly facing the consequences of their behaviour and exercising responsibility for their own credits) and increased collective involvement (i.e., the shaping of new social norms and a sense of collective action) (Capstick & Lewis, 2010; Fawcett & Parag, 2011; Parag et al. 2007).

These conceptual considerations have led researchers to start empirical research on the effects of TC schemes targeting personal transport. For a detailed discussion of this literature, we refer to Dogterom et al. (2017); here, we summarise the most important findings and methodological aspects. Empirical research started by exploring public opinion and general intentions. Kockelman and Kalmanje (2005) investigated attitudes towards and likely reaction to a credit-based congestion pricing scheme in the Austin area (TX, US) by presenting hypothetical situations in which respondents had to imagine travelling for a certain stretch under different credit availability assumptions. In a personal carbon trading (PCT) context, Wallace et al. (2010) and Parag et al. (2011) administered surveys in the UK in which they asked respondents to indicate their willingness to choose several carbon-saving actions. Both studies found higher willingness to choose home-based carbon-saving actions compared to travel-based carbon-saving actions.

Whereas these studies asked respondents to state intentions without relating these intentions to personal travel or carbon consumption patterns, other studies have developed research designs in which reported behaviour serves as input data for customised TC scenarios. Capstick and Lewis (2010) and Zanni et al. (2013), exploring the effects of PCT on all household carbon consumption, used a carbon footprint calculator to estimate participants' annual carbon consumption. Participants were presented with a series of carbon-saving actions via an interactive computer-based simulation that enabled direct feedback on annual personal credit usage. Unfortunately, although both studies included travel-related carbon savings in the presented choice options, the relative impact of car use-specific options remains unclear from these studies.

Raux et al. (2015a), studying a PCT scheme for car travel only, designed a stated preference experiment including trade-offs on various suggested reduction levels, which were presented as a proportion of annual number of trips for different distance categories based on reported travel habits. With regard to duration, they found a higher willingness to reduce the number of shorter trips and, with regard to purpose, commute and shopping trips. A more detailed approach was used by Harwatt et al. (2011) to analyse car use adaptations in response to a PCT measure based on participants' travel patterns collected through a weeklong travel diary. They found the PCT scheme achieving larger reduction levels than a comparable carbon tax, with car trips being especially replaced by the train and bicycle. However, as their study relied on a small sample no firm conclusions can be drawn from this study.

With regard to the effects of socio-demographic characteristics on transport-related TC behaviours, Kockelman and Kalmanje (2005) found that willingness to change car use decreased with age, vehicle ownership and income. A negative income effect was also reported by Zanni et al. (2013), who further found that respondents who were employed and living in larger households showed a higher willingness to change behaviour. An age effect was also reported by Raux et al. (2015a), who found that people between 50 and 65 showed a higher propensity to maintain the status quo in response to a TC scenario than younger people. The authors included residential location in their model but did not find a significant effect. The limited number of studies that model the impact of socio-demographic characteristics on TC behaviours, together with mixed results, clearly indicates a need for further research on possible associations in order to produce more conclusive and robust findings, a goal to which this study will contribute.

To conclude, methodologically, most of the empirical studies on transport-related TC behaviours discussed in this literature review measure car use reduction in a rather abstract manner, i.e., based on either hypothetical trip situations or highly aggregated data (defined in terms of annual distance/trips/carbon consumption). However, as these studies do not relate stated intentions to concrete, experienced trips and activities, it remains unclear how these reductions are to be realised and how they will precisely impact daily car use patterns. However, travel behaviour is intrinsically linked with people's needs, desires and obligations for out-of-home activities, and travel adaptation capacities are highly structured by the space-time constraints of individual's activity patterns and available travel alternatives (Hägerstrand; 1970; Axhausen & Gärling, 1992; Jones, 1983 et al.; Kitamura, 1988; Timmermans, 2005; Dijst, 2009). Taking reported, actual trips and activities as the starting point of the analysis and conceptualising car use reduction as the outcome of dynamic trade-offs between activity needs, TC scheme characteristics and rescheduling opportunities and constraints, this study applies an activity-based approach to the study of TDC responses.

In doing so, we expect to corroborate the age, income and household size effects found in the wider road pricing literature, i.e., the likelihood and the magnitude of change is expected to decrease among older participants, smaller households and higher incomes (e.g., Gehlert et al., 2011; Ubbels & Verhoef, 2005). We will also look into spatial context in this study, and in contrast to the findings from Raux et al. (2015a), who only showed results for the Lyon (France) area, we expect to find a decreasing tendency to change and smaller changes for lower density residential areas, as we collect data from all parts of the Netherlands. This expectation is based on the finding that people in less-dense areas generally report higher levels of car use when measured by mode choice and distance travelled (Dieleman et al., 2002). Another important aim of this study is to assess the relative impact of gaining and losing under TC. Although participants theoretically can receive more credits than needed under a TC scheme, to date, only Zanni et al. (2013) have tried to explicitly capture the behavioural effects of facing a gain. They found that losses have a stronger impact on the decision to change car use than gains, with the probability of reductions increasing with larger losses and decreasing with larger gains. Based on this study and in line with prospect theory (Kahneman & Tversky, 1979; see Dogterom et al., 2017, for a detailed discussion of the potential implication of prospect theory on TC behaviours), we expect to find similar patterns of gains and losses determining the likelihood of changing car use and the magnitude of change.

3.3 Methodology

3.3.1 Stated adaptation experiment

The experiment reported in this paper used a stated adaptation approach to analyse TDC responses. This approach refers to a category of surveys and experiments in which the current behaviour of participants is confronted with a hypothetical and new situation, and participants are asked how they would react to such a situation. Most stated adaptation-based research on the impact of travel demand management instruments on travel behaviour therefore starts with collecting revealed behaviour by means of questionnaires, diaries, interviews or GPS tracking. The measure under examination is then introduced in a customised fashion, and individual reactions are recorded in an interactive simulation interview or experiment (Nijland et al. 2009; Arentze et al., 2004; Faivre D'Arcier et al. 1998; Lee-Gosselin, 1996). The stated adaptation experiment reported in this paper was entirely web based: both revealed car trips and responses to the TDC scenarios, which could be chosen from a pre-defined set of actions, were recorded through an online application that was specifically designed for this purpose.

The experiment's input consisted of participants' car trips over a full week. Although drivers might be given credits for a different period in a real-world TDC setting, we considered a week to be an appropriate experimental period, as a longer period would have burdened the participants too much. Furthermore, as many activities that constitute the core of people's activity participation take place on a weekly basis, we believed that a weeklong experiment is well suited to shedding light on the TDC trade-offs made in the travel episodes that define normal daily life.

In the experiment, we investigated the effects of a distance-based TDC scheme, in which one credit represented one kilometre, irrespective of time and location. For the first scenario, a total reduction goal of 15% was defined in terms of kilometres driven by the sample. For the second scenario, the reduction goal was set at 30% to measure the effect of a smaller budget. Participants received equally sized budgets, implying that some participants were allocated more credits than they needed. In doing so, we could investigate potential differences in responses between participants with credit shortages and those with credit surpluses. Participants were assigned three different price levels: €0.10, €0.15 and €0.20 per credit (i.e., per kilometre). These prices are somewhat higher than the kilometre prices that have previously been used in Dutch kilometre pricing experiments (Ubbels & Verhoef, 2005; van Amelsfort et al., 2008), but we believed the different context of a TDC scheme warranted the use of higher prices because participants would only pay/gain if they exceeded a certain kilometre threshold. Further, because of the low expected short-term elasticity of the price signals (Graham & Claister, 2004; Goodwin et al., 2004), we chose to use prices that

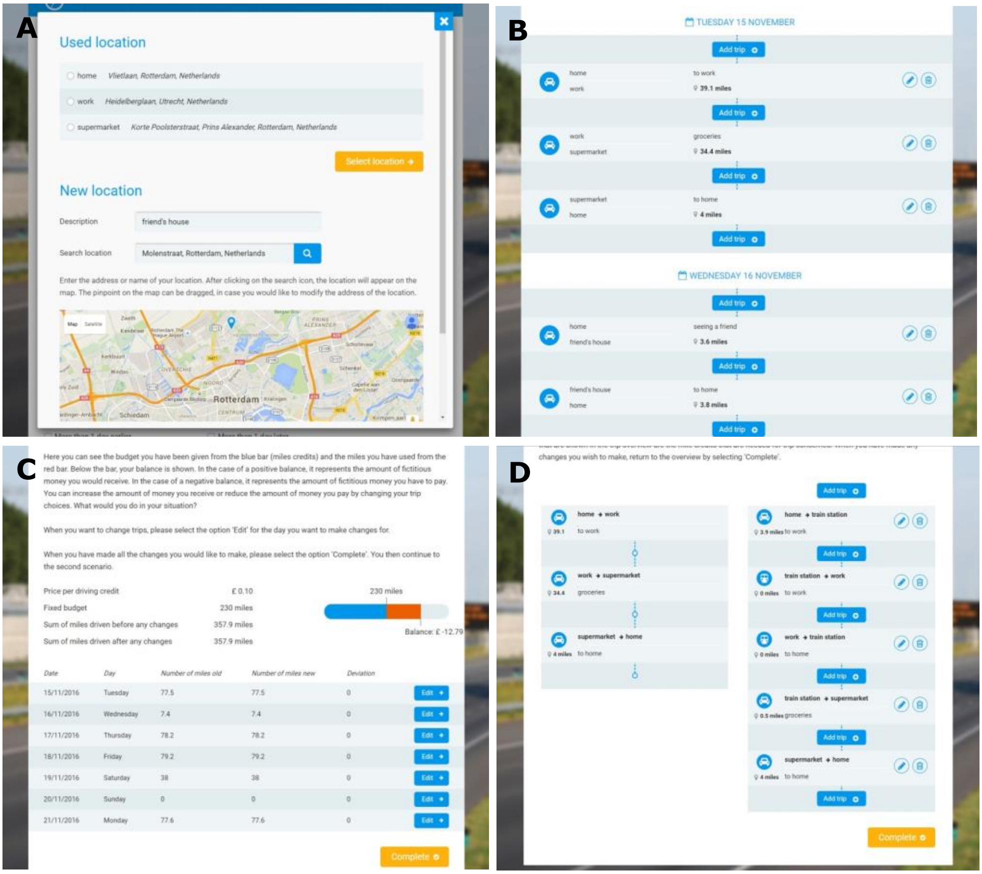

Figure 3.1: Screenshots of the online application (English version) *(a)* When recording a trip in the travel diary, a new location could be entered or a previously used location could be selected. *(b)* A trip overview in the travel diary. *(c)* Presentation of kilometres driven per day, total credit availability and consequent financial balance in the adaptation part. *(d)* An original trip pattern and an adjusted trip pattern for a day in the adaptation part.

would exert sufficient pressure to make participants reconsider their trips, a strategy also adopted by Zanni et al. (2013) in their PCT experiment.

In their travel diaries, participants were required to record each trip they made as a car driver, irrespective of whether the car belonged to them. Each trip they made to complete an activity was defined as an individual trip, so trip chains comprising multiple destinations needed to be recorded as separate trips. Participants were instructed not to record business trips, i.e., trips made for work purposes other than the commute, as these trips are generally the employer's expenses and participants might expect the same to apply in a TDC setting. Trips with a destination abroad were also excluded, as applying these trips to a national TDC scheme might confuse participants.

For each trip, participants needed to record origin and destination locations; activity type; flexibility of the trip/activity in terms of time, location and travel mode; and presence of passengers. Locations could be selected using a Google Maps interface and were saved under a personal description so that they could be easily selected again (Figure 3.1a). Trip distances were calculated by Google Maps on the basis of shortest route by car. Although participants' actual driven route could deviate from this suggested route, it was not possible for them to change the route. This decision was made because changing routes would require too much time and effort from the participants and because we believed routes would differ only slightly in terms of distance.

In the second part of the experiment, participants were presented with the TDC scenarios. After reading the instructions and the description of the adjustments participants could make, they were shown an overview page with information about their credits available, current credit usage and consequential financial balance (Figure 3.1c). In response to the scenarios, participants could cancel trips, add trips and change trips in the same way as they entered trips in the travel diary. An additional option was the choice of a different travel mode: the public transport and slow mode (bike or walk) options did not require credits; the carpool option saved 50% of the original credit amount. The design of the experiment thus enabled participants to reorganise their trip schedule by, for instance, changing activity locations, combining/separating trips, or creating trip chains that use multiple travel modes (Figure 3.1d). Adaptations immediately resulted in updated credit usage rates.

Participants needed to fill out a short questionnaire on socio-demographic characteristics prior to the travel diary. The experiment ended with a set of questions about attitudes towards personal car use and the TDC program.

3.3.2 Sample

This study took place in the Netherlands. Only people who frequently commuted by car were recruited to participate in the experiment because we wanted to explore the TDC measure's impact on the class of drivers that contribute the most to congestion. In addition to commuting at least 3 times per week by car, owning a car and having a fixed work location were defined as additional selection criteria. Having a fixed work location was required to enable the easy detection of a commute trip; owning a car was required because we believed that drivers with a company car might think that the credit costs would be (partly) borne by the employer and might thus take the experiment less seriously.

Participants were recruited by Panelclix/Euroclix, an online fieldwork company that has a nationwide online panel in the Netherlands. The usable sample for this paper includes 308 participants. The characteristics of the sample are given in Table 3.1.

Table 3.1: Sample composition (*N* = 308)

Characteristic	Operationalisation		%
Gender	Male		54.9
	Female		45.1
Age	18-25		8.8
	26-35		26.6
	36-45		27.9
	46-55		26.3
	55-65		10.4
Household	Single	without children	18.5
		with child(ren)	4.9
	Couple	without children	34.4
		with child(ren)	42.2
Educational level	Lower professional or high school		4.9
	Middle professional		32.8
	University/higher professional		63.3
Work	1-19 hours per week		7.1
	20-29 hours per week		15.3
	30-39 hours per week		44.2
	40 hours or more per week		33.4
Income (household disposable income per month)	Less than €2,000		27.9
	€2,000 - €3,500		39.9
	More than €3,500		19.8
	Would rather not say		12.3
Degree of density of municipality of residence	Very strong		18.8
	Strong		37.3
	Moderate		16.6
	Weak, non-urban		25.2

3.3.2 Data collection process

In total, 1,297 persons who were recruited and met the selection criteria received an invitation for the experiment in several waves from October-December 2015. They could access the experiment using a username and password and could start the experiment at their preferred time. After participants recorded their first trip, the 6 subsequent days for which we asked respondents to record their trips appeared in the trip overview. A total of 918 participants started the experiment, of which 567 completed the whole experiment (61.8%). Less-educated participants were relatively overrepresented in the dropout group.

After close examination of the travel diaries before and after adaptation, a significant share of the trip patterns was incomplete (e.g., covering only one day or only one-way trips), inconsistent (e.g., having missing or duplicated trips), or otherwise not useful. Cases with a missing or duplicated trip shorter than 10 kilometres were included in the analysis because we permitted these small and isolated shortcomings to avoid wasting valuable travel and adaptation data. Further, we excluded cases that indicated car use reduction in scenario 1 but not in scenario 2 (25 cases), which very likely demonstrated the non-serious treatment of the second scenario. We also excluded 6 cases with more kilometres in the adapted travel diaries than in the original travel diaries, even in a credit shortage setting, as this behaviour could mean the addition of forgotten trips. Furthermore, these cases pose practical problems in estimating Tobit models. Two outlier cases reported a very high level of kilometres driven and were excluded from the analysis, as they caused the residuals of the dependent variable in the models to be non-normally distributed.

To set realistic, sample-specific budgets for the participants, the budgets were calculated based on the travel data reported in the diaries. For that reason, the adaptation part of the experiment could not be accessed until the budgets had been set based on a collection of travel diaries that showed a stable average distance per driver. Based on this stable distance figure, 15% and 30% reductions in the sample's kilometres driven resulted in individual budgets of 280 and 230 kilometre credits in scenarios 1 and 2, respectively. After data collection and preparation, however, the average number of kilometres per participant was somewhat higher than calculated at the budget-setting stage because incomplete travel diaries, which generally had low reported distances, were excluded after all data had been collected. For the final sample, the budgets in scenarios 1 and 2 represent 17.5% and 32.2% reductions, respectively, of the total distance in kilometres driven by the sample.

3.4 Results

3.4.1 Descriptive analysis

Table 3.2 presents an overview of the average number of kilometres driven and the percentage reduction in car kilometres realised by the participants. Table 3.3 gives an indication of the share of reducers for the overall group and for the subgroups facing losses or gains compared to their situation at the start of the experiment.

The realised reductions of 20.2% and 24.1% in scenarios 1 and 2, respectively, are fairly large; in scenario 1, the total reduction exceeded the goal. Overall, approximately two-thirds of the participants reduced their car use, with the share of reducers in the second scenario being slightly higher than in the first scenario. A total of 99 participants (48.2%) who changed their car use in the first scenario did not make additional reductions in the second scenario. This group might already have deployed their full car use reduction capacities in the first scenario. Although scenario 2 presented a considerably higher reduction to the participants, there was only a slight increase of the total reduction. This finding might be explained by a cost hierarchy present in change options, implying that generally, people first select alternatives that are less costly in terms of money and effort and that additional change is more costly and therefore more difficult to achieve (Loukopoulos et al., 2006). It might also indicate a 'shock effect' in scenario 1, that is, the introduction of the measure has an effect apart from the total credits available (Dogterom et al., 2017). Of course, fatigue could also have played a role, as people might have been less motivated to take scenario 2 seriously because of the complexity and time required for the experiment.

Figure 3.2 shows the percentages of participants that changed their car use and the reduction of kilometres as a proportion of the total kilometres driven grouped by the

Table 3.2: Summary of reported car kilometres in the experiment

	Original	Scenario 1	Scenario 2
Kilometres (credits) in individual budgets	n/a	280	230
Reduction goal	n/a	17.5%	32.2%
Average number of car kilometres	339.2	270.6	257.4
Average realised kilometre reduction	n/a	20.2%	24.1%

Table 3.3: Summary of participants' car use changes

	Scenario 1		Scenario 2	
Percentage of participants that changed car use	62.3%		66.6%	
	Loss	*Gain*	*Loss*	*Gain*
Percentage of participants facing a loss or gain compared to the baseline situation	54.6%	45.4%	64.9%	35.1%
Percentage of participants that changed car use	78.6%	42.9%	78.5%	44.4%

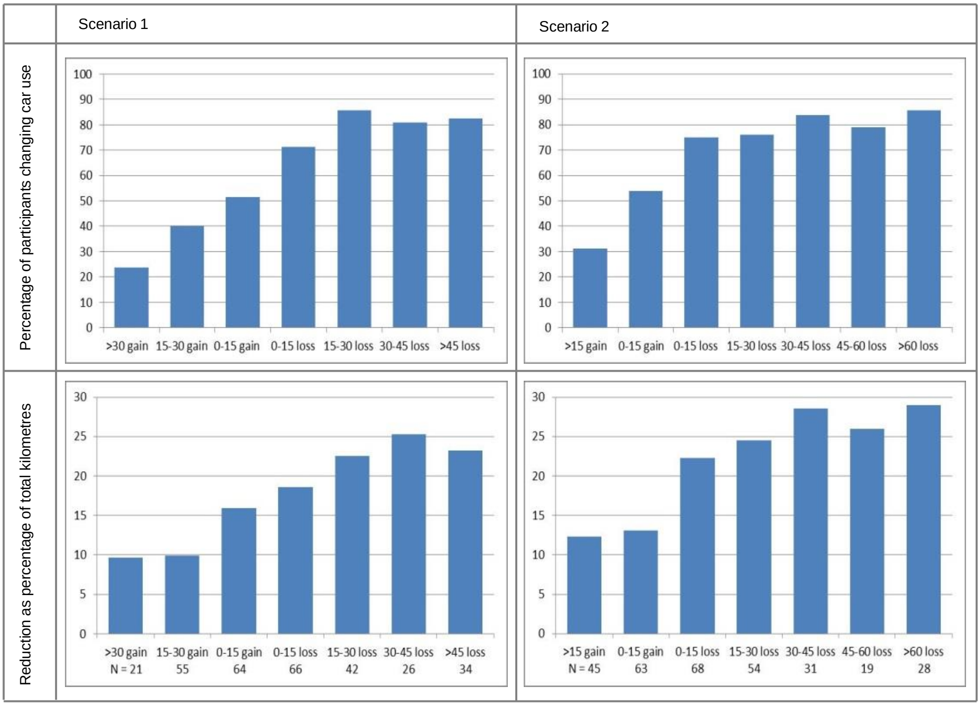

Figure 3.2: Summary of change for different gain and loss groups. Gains and losses are listed in Euros.

gain and loss faced. Both scenarios show higher percentages of participants reducing in loss situations. On the loss side, the likelihood of change increases in the first categories and tends to stabilise as losses become larger. On the gain side, the likelihood of change decreases with larger gains. The same pattern is visible in the figures that show reduction as a proportion of total distance, with a stabilising reduction trend also appearing for those who gain. These patterns might be explained by the 'diminishing sensitivity effect', a robust phenomenon found in behavioural economics that means that the marginal effectiveness of losses or gains decreases with the size of the loss or gain (Kahneman & Tversky, 1979). Concerning the reduction amount, based on several empirical studies in the context of personal carbon trading, Zanni et al. (2013) suggest that there appears to be an overall upper limit of 20% for short-term carbon consumption reduction. The presence of an upper limit, albeit somewhat more than 20%, also seems to appear in our kilometre reduction data.

After these general observations, the following sections provide a more detailed investigation of likelihood of change and the reduction size by modelling these variables in relation to participants' characteristics.

3.4.2 Multivariate analysis

3.4.2.1 Likelihood of changing car use

Because the choice to respond to the presented TDC scheme is binary, logit regression models have been used to estimate the model parameters. Table 3.4 shows the results for the included parameters for both scenario 1 and scenario 2. Separate models have been estimated for total price, which is either a loss or a gain, and marginal price, i.e., the price per credit. Each model was also estimated with a general car dependency measure added, which enables the identification of possible mediation effects of perceived car use flexibility on the association between socio-economic characteristics and car use reduction. Participants' level of car dependency was measured in the final questionnaire by a statement that reads: 'I do not have alternatives for my car use' (completely disagree (1) – completely agree (7)).

Several socio-demographic characteristics have statistically significant impacts on the likelihood of changing car use in response to the TDC measure. In all models, participants aged 26-45 are less likely to change their car use than participants aged 18-25. This is consistent with other road pricing studies that have found that younger people are more likely to adjust their car use (Raux et al., 2015a; Gehlert et al., 2011). Because the effect remains after controlling for car dependency, explanations might lie in younger people having more activity rescheduling options because they might have fewer household responsibilities. In scenario 1, males are more likely to change their car use, but this effect is absent in scenario 2. Explanations for this result are elusive and the literature provides mixed results on gender effects. Polk (2004) found a higher general likelihood of changing car use among women, and Mokhtarian et al. (1997) found the same when specified as a response to congestion. However, Odeck and Bråthen (1997), in the context of Oslo road tolls, reported than men were more inclined to agree with the statement that tolls had made them reduce their car use. In follow up studies, we will analyse activity types, trip attributes and alternatives in more detail, possibly providing more insight into the reasons behind the gender difference we found.

The number of children has a significant, positive effect, meaning that the likelihood of changing car use increases with the number of children living in the household, even when controlling for car dependency. Other studies have also found that the presence of children positively affects the likelihood of adapting car use in response to pricing measures (Ubbels, 2006, Gehlert et al., 2011; Zanni et al., 2013).

One explanation might be that the number of children increases the number and diversity of household activities that require the car, therefore increasing the potential for reduction. Further, tasks can be more easily redistributed within larger households, especially when children are less dependent and can organise their own travel patterns.

Working 40 hours or more per week negatively impacts the likelihood of change at a 10% significance level but only in scenario 1 and without controlling for car dependency. There is an income effect in scenario 2, as those with middle incomes are more likely to change than those in the lowest income group. This finding is somewhat surprising as willingness to adapt car use in response to pricing measures is commonly found to decrease with income (Ubbels & Verhoef, 2005; Kockelman & Kalmanje; Washbrook et al., 2006; Rienstra et al., 1999). A possible explanation is that people in the lower-income group are more constrained in their choices with regard to activity scheduling (Cao & Mokhtarian, 2004).

With regard to residential area, the models show that residing in a weakly or non-urbanised area negatively impacts the likelihood of changing car use compared to living in a highly urbanised area. This effect is more pronounced in the second scenario, where the effect remains significant even after controlling for car dependency. In addition to being more car dependent, those who live in more rural areas might have fewer opportunities for combining trips or choosing alternative activity locations. As expected, the car dependency measure is highly significant in all models and indicates a higher propensity to maintain the *status quo* when fewer car use alternatives are available.

The price per credit has no effect on participants' likelihood of changing car use; rather, the likelihood of change is affected by the total amount of money to be paid or gained – in models with marginal price included the kilometres driven serves as a proxy for total price. Overall, the prospect of a loss has a stronger effect on the likelihood of reducing than does the prospect of a gain, which is consistent with much work on the loss-gain dichotomy in behavioural economics (Kahneman & Tversky, 1979; Kahneman et al., 1991). The direction of the effect is largely intuitive: the likelihood of change increases with larger losses and decreases with larger gains, not only because people facing larger gains might be more easily satisfied with the status quo but also because these people simply have fewer kilometres to reduce.

3.4.2.2 Size of reduction

Another series of models has been estimated to assess the impact of participants' characteristics on the magnitude of car use reduction in response to the presented TDC schemes, as measured by the number of kilometres reduced. Left-censored Tobit models have been estimated because the dependent variable includes many zero

Table 3.4: Estimation results for likelihood to change (logit model)

	Sceanio 1			
	Total price		Marginal price	
	Model 1a	Model 1b	Model 2a	Model 2b
	Coefficient	Coefficient	Coefficient	Coefficient
Constant	2.363**	4.013***	2.544**	4.141***
Male	0.685**	0.598*	0.660**	0.573*
Age 26-35	-1.290**	-1.330**	-1.454**	-1.454**
Age 36-45	-1.497**	-1.262*	-1.582**	-1.323**
Age 46-55	-0.702	-0.638	-0.839	-0.724
Age 56-65	-0.670	-0.279	-0.722	-0.260
Single	-0.125	-0.155	-0.191	-0.186
Number or children	0.346**	0.340**	0.328**	0.343**
Middel education	-0.412	-0.279	-0.271	-0.074
Higher education	-0.047	-0.039	0.175	0.189
Work 20-29 hours	-0.713	-0.688	-0.719	-0.692
Work 30-39 hours	-0.928	-0.848	-0.844	-0.775
Work > 40 hours	-1.190*	-0.965	-1.182*	-0.977
Income €2000-€3500	0.455	0.313	0.438	0.262
Income > €3500	-0.162	-0.402	-0.184	-0.437
Would rather not say income	-0.355	-0.305	-0.377	-0.300
Number of cars in household	0.086	0.334	0.089	0.328
Strongly urbanised municipality	0.069	0.062	-0.096	-0.054
Moderately urbanised municipality	0.172	0.283	0.067	0.221
Weakly/non-urbanised municipality	-0.734*	-0.667	-0.787*	-0.721
No alternative to car use (car dep.)		-0.462***		-0.481***
Total loss	0.015*	0.020**		
Total gain	-0.071***	-0.081***		
Kilometres travelled (loss)			0.001	0.002**
Kilometres travelled (gain)			-0.012***	-0.014***
Credit price is €0.15			-0.224	-0.024
Credit price is €0.20			0.221	0.169
Log-likelihood	-162.905	-149.003	-161.339	-146.967
R^2 (adjusted)	0.202	0.270	0.209	0.280
X^2 (df)	82.22 (21)***	110.03 (22)***	85.35 (23)***	114.10 (24)***

* *p* <0.10; ** *p* <0.05; *** *p* <0.01

Table 3.4: Continued

	Sceanio 2			
	Total price		Marginal price	
	Model 3a	Model 3b	Model 4a	Model 4b
	Coefficient	Coefficient	Coefficient	Coefficient
Constant	3.046**	5.076***	3.231**	5.223***
Male	0.546	0.388	0.490	0.330
Age 26-35	-1.397**	-1.460**	-1.540**	-1.553**
Age 36-45	-1.813***	-1.538**	-1.887***	-1.563**
Age 46-55	-0.965	-0.856	-1.106	-0.928
Age 56-65	-1.237	-0.831	-1.286	-0.805
Single	0.012	-0.016	-0.066	-0.065
Number or children	0.309**	0.309*	0.295*	0.311*
Middel education	-0.630	-0.558	-0.492	-0.386
Higher education	-0.290	-0.345	-0.064	-0.132
Work 20-29 hours	-0.338	-0.065	-0.327	-0.036
Work 30-39 hours	-0.733	-0.476	-0.633	-0.389
Work > 40 hours	-0.752	-0.276	-0.683	-0.242
Income €2000-€3500	0.982**	0.891**	0.958**	0.818**
Income > €3500	0.139	-0.123	0.110	-0.180
Would rather not say income	-0.386	-0.353	-0.416	-0.364
Number of cars in household	-0.160	0.123	-0.175	0.094
Strongly urbanised municipality	-0.144	-0.259	-0.328	-0.394
Moderately urbanised municipality	-0.324	-0.350	-0.424	-0.403
Weakly/non-urbanised municipality	-0.894**	-0.909*	-0.949**	-0.973**
No alternative to car use (car dep.)		-0.559***		-0.575***
Total loss	0.014*	0.020**		
Total gain	-0.101***	-0.123***		
Kilometres travelled (loss)			0.001	0.002**
Kilometres travelled (gain)			-0.017***	-0.020***
Credit price is €0.15			-0.249	-0.037
Credit price is €0.20			0.209	0.166
Log-likelihood	-154.221	-137.273	-153.071	-135.814
R^2 (adjusted)	0.214	0.301	0.220	0.308
X^2 (df)	84.11 (21)***	118.01 (22)***	86.41 (23)***	120.93 (24)***

* *p* <0.10; ** *p* <0.05; *** *p* <0.01

Table 3.5: Estimation results for number of reduced kilometres (Tobit model)

	Sceanio 1			
	Total price		Marginal price	
	Model 1a	Model 1b	Model 2a	Model 2b
	Coefficient	Coefficient	Coefficient	Coefficient
Constant	123.729**	201.872***	146.292**	212.738***
Male	32.492*	21.735	27.049	16.169
Age 26-35	-44.450	-37.872	-45.715	-37.051
Age 36-45	-45.024	-13.855	-41.159	-10.005
Age 46-55	-20.203	-6.262	-19.446	-4.398
Age 56-65	-1.304	24.222	5.366	31.064
Single	-23.081	-26.167	-28.500	-29.773
Number or children	12.519	8.909	10.774	7.791
Middel education	-9.967	-7.911	-11.168	-5.204
Higher education	4.021	3.984	9.018	10.102
Work 20-29 hours	-64.950*	-48.153	-66.683*	-47.414
Work 30-39 hours	-66.841*	-45.445	-61.387*	-38.041
Work > 40 hours	-78.770**	-47.808	-78.936**	-46.272
Income €2000-€3500	15.011	-1.276	14.445	-4.003
Income > €3500	29.645	13.045	21.180	2.694
Would rather not say income	4.063	5.452	-2.325	0.871
Number of cars in household	-12.478	1.399	-15.356	-1.656
Strongly urbanised municipality	11.818	15.959	2.631	10.499
Moderately urbanised municipality	-14.130	-7.120	-14.306	-3.127
Weakly/non-urbanised municipality	-51.352**	-41.133*	-52.142**	-40.385*
No alternative to car use (car dep.)		-28.981***		-29.842***
Total loss	1.896***	2.191***		
Total gain	-4.639***	-4.629***		
Kilometres travelled (loss)			0.257***	0.319***
Kilometres travelled (gain)			-0.768***	-0.740***
Credit price is €0.15			-29.541	-12.786
Credit price is €0.20			2.519	2.840
Log-likelihood	-1269.191	-1247.250	-1266.349	-1243.262
R^2 (adjusted)	0.045	0.061	0.047	0.064
X^2 (df)	119.18 (21)***	163.06 (22)***	124.86 (23)***	171.04 (24)***

* *p* <0.10; ** *p* <0.05; *** *p* <0.01

Table 3.5: Continued

	Sceanio 2			
	Total price		**Marginal price**	
	Model 3a	**Model 3b**	**Model 4a**	**Model 4b**
	Coefficient	**Coefficient**	**Coefficient**	**Coefficient**
Constant	201.500***	285.559***	217.419***	287.070***
Male	26.434	14.264	20.157	8.150
Age 26-35	-87.800***	-80.403***	-90.827***	-81.355***
Age 36-45	-95.142***	-58.204**	-92.022***	-55.201**
Age 46-55	-71.911**	-55.360*	-72.819**	-55.171*
Age 56-65	-66.583*	-36.687	-61.552*	-31.479
Single	-13.827	-17.377	-20.554	-22.007
Number or children	4.879	0.746	3.146	-0.282
Middel education	-12.354	-7.521	-11.618	-2.913
Higher education	-1.600	1.086	7.337	10.843
Work 20-29 hours	-70.331*	-52.189	-74.944**	-52.912
Work 30-39 hours	-77.728**	-54.316*	-72.930**	-47.143
Work > 40 hours	-75.692**	-40.794	-76.403**	-39.416
Income €2000-€3500	49.018**	30.920	49.939**	29.693
Income > €3500	42.325	24.815	34.687	15.305
Would rather not say income	1.679	4.713	-4.092	0.703
Number of cars in household	-22.095	-6.365	-24.728*	-9.431
Strongly urbanised municipality	-13.211	-7.287	-24.246	-14.037
Moderately urbanised municipality	-35.085	-26.615	-36.982	-23.978
Weakly/non-urbanised municipality	-62.980**	-49.716**	-63.985***	-49.317**
No alternative to car use (car dep.)		-32.837***		-33.403***
Total loss	2.036***	2.323***		
Total gain	-6.119***	-6.071***		
Kilometres travelled (loss)			0.268***	0.329***
Kilometres travelled (gain)			-1.048***	-0.983***
Credit price is €0.15			-23.592	-6.245
Credit price is €0.20			21.628	21.728
Log-likelihood	-1344.337	-1313.891	-1342.788	-1311.945
R^2 (adjusted)	0.049	0.070	0.050	0.072
X^2 (df)	137.13 (21)***	198.02 (22)***	140.23 (23)***	201.91 (24)***

* *p* <0.10; ** *p* <0.05; *** *p* <0.01

value observations (approximately one-third did not reduce their car use). Table 3.5 presents the results of the parameter estimations.

The amount of time spent working and the density of the residential area are the only variables that have significant effects in both scenarios. The number of kilometres reduced decreases with the number of hours worked per week. This is a natural outcome, as one might expect working trips to be the least sensitive to road pricing (Ubbels & Verhoef, 2005) and those spending more hours per week on working having a tighter activity-time budget. Indeed, the inability to reduce the number of kilometres driven among those with the most working hours seems to be largely associated with the inability to reduce driving as the effect disappears when controlling for car dependency. Similar to the likelihood of change, living in a weakly or non-urbanised area has also a negative effect on reduction compared to living in a highly urbanised area. The effect remains after controlling for car dependency, although it is somewhat weaker. As mentioned in the previous paragraph, this result indicates that those living in rural areas might face more constraints in terms of trip chaining and the choice of alternative activity locations.

Age and income start to have an impact on reduction size in scenario 2. All participants over 25 years old showed smaller changes than those in the 18-25 age category, indicating that the youngest participants are able to realise larger additional changes with tighter budgets. The effect remains after controlling for car dependency, suggesting that other factors might play a role here. Possible explanations might include younger participants' higher price sensitivity, higher activity and schedule flexibility and greater openness to change. With regard to income, participants with middle incomes report larger reductions compared to those with lower incomes; however, in contrast to the likelihood-to-change models, the effect vanishes after controlling for car dependency. This result suggests that the higher car dependency of participants with disposable monthly incomes up to €2,000 does not impact the decision to change, but it constrains the number of kilometres that they are able to reduce.

As expected, the car dependency measure itself is highly significant, having a negative impact on the reduction size. The variables that indicate total price (total loss/gain, kilometres lost/gained) are highly significant, with the magnitudes of the reductions increasing with greater losses and decreasing with greater gains, which are expected outcomes. Again, marginal price has no effect on reduction. We included a non-linear total price term in the model to test for a 'diminishing sensitivity' effect, but as this term was not significant and did not improve the model, this term has not been included in the model presented here.

3.5 Conclusion and discussion

This paper explored the behavioural effects of a TDC scheme, focusing on its impact on the car use patterns of frequent commuters. An online stated adaptation experiment was designed in which participants could reorganise their activity/trip pattern for a full week in response to two kilometre-based TDC scenarios, simulating reduced credit availability. Such a stated adaptation approach forced participants to reconsider their car use within the experienced framework of concrete trips, activity needs and situational travel alternatives and constraints, which is largely lacking in the existing TDC research. In this paper, we examined the likelihood of change and realised car use reduction, and we related these figures to participants' socio-demographic characteristics, density level of residential area and perceived car dependency.

The results suggest a substantial car use reduction under the TDC measure. Approximately two-thirds of the participants adapted their car use, and total reductions of 20.2% and 24.1% in terms of vehicle kilometres driven by the sample were achieved in scenarios 1 and 2, respectively. Whereas the willingness to change figures are in line with other travel-related tradable credit schemes, the magnitude of change is somewhat larger than what is found in comparable tradable credit studies (Raux et al., 2015a; Zanni et al., 2013, Parag et al., 2011).

At first glance, the reduction levels suggest that a TDC measure potentially competes with other road pricing measures. Other Dutch road pricing studies report lower car change figures, with up to 15% of trips adjusted under a time-differentiated kilometre charge (Tillema, 2007; Ubbels & Verhoef, 2005); however, differences in research design, pricing scheme (charge level, level of differentiation within the scheme) and measurement of change (adjusted kilometres or trips) call for cautious comparison of these figures. Studies that directly compare behavioural change under personal carbon trading schemes and equivalent taxes show mixed results. Whereas Raux et al. (2015a) and Zanni et al. (2013) find no significant differences between the measures, Parag et al. (2011) and Harwatt et al. (2011) report higher mileage reductions under a trading scheme. Further, comparative studies focusing on public perceptions indicate higher levels of support and acceptance for the credit scheme (Bristow at al., 2010; Harwatt et al., 2011; Kockelman & Kalmanje, 2005). To draw firmer conclusions about the effectiveness of TDC relative to other pricing measures, more research that investigates these measures in a comparative research setting is needed. Such research should explicitly address participants' subjective evaluations of these measures, as proponents of TDC commonly refer to its expected competitiveness on the basis of public support and acceptability.

Many road pricing studies to date do not explicitly connect car use changes with people's ability to choose alternatives to their car use. However, by including a car dependency measure in our analysis, we were able to explicitly model the mediating effect of car dependency – measured as a perceived and general car dependency indicator – when we estimated the effects of socio-demographic factors on car use reduction. The effects of working hours and income disappeared (only for reduction size) when controlling for car dependency. However, the effects of gender, age, density and income (only for willingness to change) remained after controlling for car dependency, although somewhat weaker effects were measured, suggesting that factors other than the (in)ability to use other travel modes play a role. Possible explanations might relate to activity rescheduling options – e.g., younger people have more flexible activity schedules, as they often have fewer household responsibilities – or activity locations – e.g., people living in more-urbanised areas having more facility options closer to their homes. Of course, attitudes and preferences could have affected responses as well (Schwanen & Mokhtarian, 2005; Steg, 2005; Jensen 1999). In a next step, our research will analyse car dependency at the trip level and operationalise it in more detail – i.e., measure it relative to various change options – which will enable us to more thoroughly understand car use change as structured by concrete adaptation constraints and capacities. Additionally, we will consider the effect of attitudes towards car use and subjective evaluations of the TDC measure on behavioural change.

Unlike most road pricing studies to date, this study included the density of participants' residential area as an explanatory variable, as level of urbanisation is an important factor in people's mode choices and distances travelled (e.g., Dieleman et al., 2002). Density appeared to have a significant effect, with people living in weakly or non-urbanised areas reporting lower reduction levels. This shows that spatial context is a relevant factor in behavioural change in response to pricing measures that should not be overlooked in the road pricing literature. Indicators of accessibly to facilities and public transport and geographical information about frequently visited locations, such as work locations, might add explanatory power to car use reduction models in future research.

The web application used in this research is a promising tool for further research on understanding travel behaviour adaptations in other contexts. The tool was able to capture multidimensional adaptations by allowing participants to reorganise their complete activity/trip schedule, thus producing more realistic data and enhancing daily car use decision-making understanding, as the majority of quantitative techniques that have been designed to date to measure car use change rely on mutually exclusive change options. However, the application might have been too complex and demanding for some participants, as some who made adaptations in the first scenario did not make many adaptations in the second scenario. Additionally, the dropout rate during the experiment was higher for less-educated participants. At the same time, many people made rather complex adaptations, suggesting that people generally understood the application, were fully engaged with the experiment and felt encouraged to make realistic and feasible decisions.

At the same time, our approach is rather static, using a retrospective perspective together with fixed price levels. As such, the TDC measure in our scenario might have looked very similar to a flat toll, albeit including a kind of 'reverse' toll (i.e., a gain per reduced kilometre), and the experiment might not have been able to account for the more dynamic aspects of TDC schemes. Although the aim and functioning of a TDC measure and its unique features (e.g., the function of credits, their tradability) were explicitly mentioned during the course of the experiment, future research that examines travel behaviour under more dynamic circumstances, preferably by simulating dynamic prices, decision making over time, and the functioning of a market, would further enhance our insights into TDC effects. Interactive simulations and experimental games are promising research avenues in this respect.

4 Activity-travel adaptations in response to a tradable driving credit scheme*

Abstract – Although interest in the concept of tradable driving credits (TDC) has increased in recent years, empirical research into the potential effects of such a measure is scarce. The study reported in this paper employed an activity-based approach to investigate drivers' responses to two distance-based TDC scenarios. Three hundred and six Dutch frequent car commuters participated in an online stated adaptation experiment in which they recorded their car use for 7 days and, in response to the TDC scenarios, had the opportunity to reorganise their car use pattern, if desired. This paper investigates adaptation behaviours at the trip level. The results show that approximately 30% of trips made for maintenance and leisure-oriented activities were subject to change. In cases of change, a travel mode change was the most preferred adaptation strategy. A mixed logit modelling framework is used to test the effect of a variety of activity/trip attributes, TDC scenario attributes, and individual characteristics on the preference for adaptation alternatives.

4.1 Introduction

In the ongoing search for instruments that aim to mitigate the steady growth of car use and associated problems of congestion and emissions in urban areas worldwide, tradable credit schemes have recently received increasing attention. Although the concept of tradable credits (TC) has been developed and applied in the environmental field for decades (Dales, 1968; Baumol & Oates, 1988), the exploration of the potential of 'cap-and-trade' measures in the context of personal transport is relatively new (Verhoef et al., 1997a; Viegas, 2001; Raux & Marlot, 2005; Buitelaar et al., 2007; Yang & Wang, 2011). This interest is part of a broader interest in new travel demand management (TDM) strategies that, as alternatives to the traditional approach of charging for all road use, which has proven highly controversial, propose to manage traffic flows through incentive-based and revenue-neutral approaches, such as the Dutch

* This paper is co-authored with Dick Ettema and Martin Dijst and is, in a slightly modified version, resubmitted to *Transport Policy*.

'peak avoidance' experiment (Knockaert et al., 2012; Ben-Elia & Ettema, 2011) and the FAIR lanes in the US (Fan et al., 2016; DeCorla-Souza, 2005).

In a typical car use-tailored TC scheme, a regulatory body sets a cap on aggregate car use in a defined area and time period (e.g., defined as a total distance or emissions target). Credits representing an individual portion of the rationed quantity (e.g., kilometres, fuel consumption) are distributed to eligible car drivers, who can use these credits, purchase additional credits or sell excess credits in a market. Through this market mechanism, TC schemes can deliver certain goals at minimised social costs, in contrast with traditional 'command-and-control' measures (Verhoef et al., 1997a). Furthermore, the introduction of a freely allocated credit budget and the incorporation of a reward element are important favourable features for motivating behavioural change and public acceptability compared with conventional pricing mechanisms (Viegas, 2001; Kockelman & Kalmanje, 2004; Capstick & Lewis, 2010; Wadud, 2011).

Although several studies have conceptually explored the concept of tradable driving credits (TDC) with regard to design and function (for reviews, see Fan & Jiang, 2013; Grant-Muller & Xu, 2014), empirical research on driver responses is limited. Empirically grounded research is critical to come to understand the potential effects of TDC. As they are largely explorative in nature, current empirical studies only addressed the willingness to change car use under a TDC policy or approached behavioural adaptations under TDC in a generalised manner that did not consider car drivers' actual activity/trip patterns (for an overview, see Dogterom et al., 2017). As such, these studies have not addressed how daily activity/trip scheduling would be affected by such a measure. This is in contrast with the broad consensus among transport researchers that travel and its adaptations in response to TDM measures should be understood in the context of people's actual needs and desires to participate in different activities, the temporal and spatial characteristics of these activities and the complex interdependencies between them (Arentze et al., 2004; Ettema & Timmermans, 1997; Axhausen & Gärling, 1992). An exemption is the work of Harwatt et al. (2011), that used participants' reported one-week car travel as the starting point for analysis of the impact of a TDC scheme. However, this study remained largely descriptive in nature due to the small sample size.

The space-time fixity/flexibility of activities and travel have traditionally been central to a transport geographic approach of travel behaviour; these characteristics and other activity attributes such as the activity type and importance have been used to investigate patterns of activity/travel scheduling and modification (Hägerstrand, 1970; Cullen & Godson, 1975; Jones, 1979; Miller, 2005; Doherty, 2006; Schwanen et al., 2008). The attributes of people's activities, car travel and available alternative travel options determine the framework within which people make their actual adaptation choices based on trade-offs between the costs of car driving under the TDC, the costs of not performing the activity and the costs of organising their travel differently in terms of money, time and effort (Loukopoulos et al., 2006; Gärling et al., 2002). Based on these notions, we designed a stated adaptation experiment to analyse the impact of distance-based TDC scenarios on car drivers' behaviour and identify the role of activity/trip attributes on decisions concerning the types of trips to change and alternatives to choose under the scenarios in cases of change. As such, this paper extends a preceding paper (Dogterom et al., under review a), in which change in car use was analysed on a more aggregate level, focusing on the willingness to change and the size of change. In the current paper, activity/trip attributes such as activity type, geographical context, importance, frequency, spatial and temporal flexibility, and the perceived ability to travel with other modes were used to examine car use adaptation behaviour at the trip level.

In the next section, we discuss our research design and data collection in more detail. Section 4.3 presents a descriptive analysis of behavioural change under the TDC scenarios. Section 4.4 describes the modelling approach and presents the estimation results. A mixed logit choice model is applied to model adaptation choice as a function of participant, scenario and activity/trip characteristics. Section 4.5 presents a conclusion and discussion.

4.2 Experiment and data collection

Detailed information about the design of the experiment, data collection procedure and participant recruitment can be found in Dogterom et al. (under review a). This section summarises the essential details for the analyses presented in this paper.

In the first part of the experiment, participants were asked to fill out a car travel diary for a full week. Each car trip a participant made as a driver to arrive at an activity-location was defined as an individual trip, so trip chains were recorded in the format of separate trips. For each trip, participants entered a start and destination location that could be selected in a Google Maps interface and provided information about the type of activity carried out at the destination, the importance of the activity and the flexibility of the activity and trip (see Table 4.1 for the variables).

Based on the collected travel diaries, fixed individual budgets of 280 and 230 free credits (one credit representing one kilometre) were defined for two scenarios that were presented consecutively. These budgets corresponded to a 17.5% and 32.2% reduction of the total distance driven by the sample. The budgets, which were set directly after collection of the travel diary, were originally defined to represent 15% and 30% reductions, respectively, in total kilometres; the discrepancy was caused by participants with inconsistent data in the original or adapted travel diaries that was removed during post-data collection scrutiny. Setting equal credit budget sizes for all participants meant that some participants received more credits than needed and thus would already earn money in a situation without behavioural change: 45.4% and 35.1% of the participants faced a gain in scenario 1 and 2, respectively. The participants were randomly assigned a price level of 0.10, 0.15 or 0.20 Euros per credit, which had to be paid when buying additional credits or could be earned by selling credits.

After the scenarios were determined, the participants were invited to participate in the second part of the experiment, in which they were presented with the TDC scenarios and could make adaptations in response to the measure, if desired. The participants could reorganise their activity/trip pattern by cancelling, modifying (choosing a different activity location or alternative travel mode) or adding trips in their original trip sequence. Three different categories of alternative travel modes were available to them: the public transport and slow mode (cycling) options did not require any credits and the carpool option saved 50% of the credits relative to an unchanged trip. Figure 3.1 shows screenshots from the different stages of the experiment.

Frequent car commuters were recruited for the experiment and data from 306 respondents was used in this research (see Dogterom et al. [under review a] for a socio-demographic profile of the sample; note that two participants were removed from the original sample because more than half of their trips had missing data on the trip attributes relevant in this paper). The observed data consists of 2,738 trips made to arrive at an activity location, which was the basis for the descriptive analysis. After removing trips with missing observations for several trip-specific attributes, 2,599 trips served as input for the model estimation.

4.3 Descriptive analysis

Table 4.1 summarises several characteristics of the reported trips for 7 different activity categories. In the experiment, 10 different activity categories could be chosen; however, the categories *Work* and *Education, Non-daily shopping* and *Personal services*, and *Social* and *Cultural* were merged due to low frequencies and because the personal descriptions that people attached to their activities showed that people found it sometimes difficult to distinguish between these original activity categories. Table 4.1 includes trip attributes such as distance, the share of trips made with passengers and the share of trips that are part of a larger trip chain, as well as the respondents' subjective evaluations of the need for the trip and the ease with which another location, time or travel mode could be used for the activity. Concerning trip chains (combined activities on

Table 4.1: Summary of trip characteristics for different activity categories

Trip characteristics	Description	Work & Education	Daily shopping	Non-daily shopping & Personal services	Sports, hobby & recreation	Social & Cultural	Pick up/ Drop off	Other
Number of activities		1,306	262	234	222	362	220	132
Passenger present	% of trips made with a passenger(s)	6.8	29.5	39.7	49.1	59.7	63.3	49.2
Part of trip chain	% of trips that are part of a larger trip chain (i.e., a combination of trips)	21.3	39.3	37.2	28.8	34.3	65.9	44.7
Distance	Mean distance in kilometres[1] (standard deviation in parentheses)	27.6 (24.0)	3.2 (3.5)	10.3 (13.8)	16.0 (28.9)	30.6 (39.2)	9.1 (14.4)	14.1 (21.6)
Importance	How important is this trip to you (i.e., the need to make this trip)?[2] (mean)	4.75	3.98	3.79	4.16	4.17	4.45	4.48
Temporal flexibility	How easily could you perform this activity at another time?[3] (mean)	1.88	3.71	3.24	2.49	2.84	1.72	2.25
Spatial flexibility	How easy is it for you to perform this activity at another location?[3] (mean)	1.37	3.23	2.25	1.89	1.48	1.14	1.38
Bike alternative	How easy is it for you to replace the car with a slow mode (bike, etc.) for this trip?[3] (mean)	1.87	2.62	2.30	2.73	2.11	2.09	2.19
Public transport alternative	How easy is it for you to replace the car with public transport for this trip?[3] (mean)	2.09	1.54	1.83	1.63	1.96	1.60	1.64
Carpool alternative	How easy is it for you to travel with somebody else by car for this trip?[3] (mean)	1.59	1.50	1.55	1.74	1.55	1.31	1.53
Frequency reduction capacity	How easy is it for you to reduce the frequency of this activity?[3] (mean)	1.42	2.79	2.64	2.39	2.48	1.73	1.92

[1] Only trips that are not part of a larger trip chain have been included

[2] 1 = Not important; 5 = Very important

[3] 1 = Not possible at all; 5 = Very easy

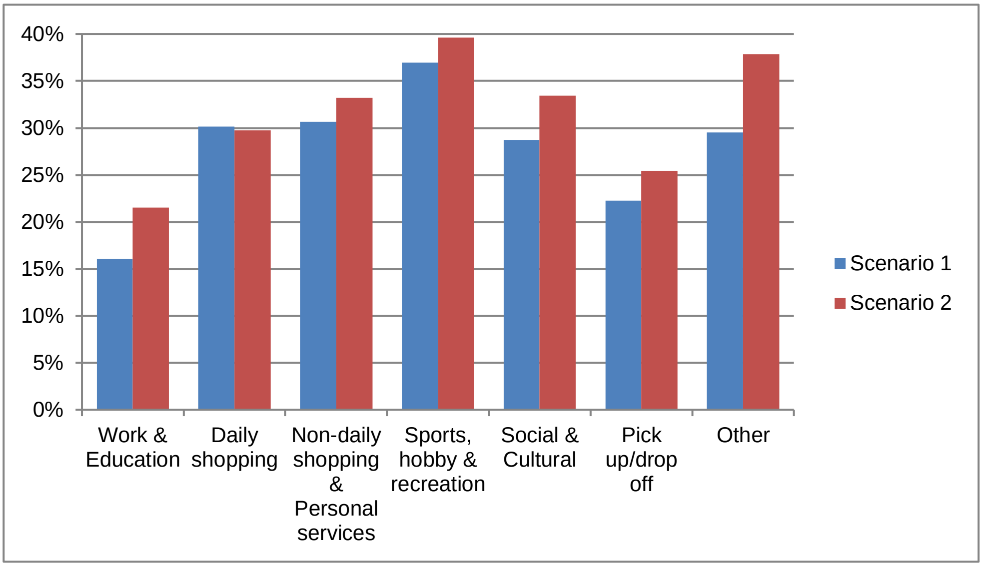

Figure 4.1: Proportion of adapted activities in scenarios 1 and 2

one journey), most trip chains had the home location as the start and end location; however, sometimes other locations such as a partner's home, a second home or a holiday home were used to define journeys when these locations appeared as clear anchor points (e.g., an overnight stay) in the travel schedule and personal descriptions.

Figure 4.1 presents an overview of the number of modified trips as a percentage of the total number of trips in the activity categories for scenario 1 and scenario 2. The figure shows that trips in the *Work & Education* category were modified the least, followed by trips in the *Pick up/drop off* category. This is not surprising, as it follows from Table 4.1 that these activity categories have the lowest scores on most flexibility items and have the highest reported importance along with the *Other* category. In many instances, *Pick up/drop off* trips appeared to be closely tied with work-related trips and involved bringing away/picking up children from school or nurseries on the way to/from work, making these trips relatively difficult to organise differently. The *Sports, hobby & recreation* category had the highest adaptation rate. Together with the *Social & Cultural* category, *Sports, hobby & recreation* activities can be classified as leisure-oriented; however, *Social & Cultural* activities show a lower adaptation rate, probably because these trips are generally longer and more often involve the presence of others, making it more difficult to change these trips. The adaptation rates for *Daily shopping*, *Non-daily shopping & Personal services, Social & Cultural* and *Other* (this category included a wide variety of remaining trip purposes that make this category difficult to describe) are comparable. Although the personal maintenance-oriented trips (*Daily shopping* and *Non-daily shopping & Personal services*) generally show higher flexibility levels, especially in terms of time, location and frequency, these activities may be more firmly embedded in daily structures and routines and therefore less likely to be changed relative to their reported flexibility.

When the amount of free allocated credits is reduced further in the second scenario, drivers generally make additional adaptations in the trip categories that are less flexible, showing that drivers first change the trips that are relatively easy to modify and enact more complex and costlier changes when confronted with greater financial costs (see Loukopoulos et al., 2006).

Participants' adaptations were classified into five distinct choice options for the analysis:

1) *Bike* – includes all trips for which the mode was changed into a slow mode, which we will frame as the use of the bike given its popularity among all slow modes in the Netherlands;
2) *Public transport* – includes all trips that are changed into a trip in which public transport is the sole or the main mode of transport (including trips in which the bike or car is used to get to a train station);
3) *Carpool* – includes all trips that are changed into a trip in which carpooling is the sole or the main mode of transport;
4) *Reschedule and location change* (henceforth *Reschedule*) – includes all trips in which the activity location was changed and all rescheduled trips (i.e., an alternative position in the trip sequence). Although they are two separate change categories, they were merged due to the low frequency of trips in which the change of location is the sole adaptation. Cases with a location change combined with a travel mode change were assigned to the travel mode adaptation category because we consider the desire to use another mode to be the trigger of the location change in these cases.

   Cases of trip chaining (merging two separate activities into one trip) present rather complex situations in terms of defining the change. We do not have information about the time an activity was performed and only know the relative position of the individual activity in the larger trip schedule. Therefore, in some cases of trip chaining, it is not evident which of the trips was changed in time and, hence, is the rescheduled activity. Thus, for cases of trip chaining, both original trips were counted as rescheduled trips. This decision was made also because the attributes of both activities/trips might be relevant to facilitating trip chaining. Only trips that were merged with another trip and in which at least 90% of the distance remained unchanged were not counted as a rescheduled trip. In these cases, for example, people may add purchasing the groceries at a venue close to home to a trip from work to home, in which situation the latter trip has only experienced a very minor change that we do not consider relevant. In cases of adding a separate activity to a larger trip chain, only the activities that directly precede or follow the added activity were counted as rescheduled activities/trips;

5) *Cancel* – includes all cancelled trips. Participants may perform the activity at home, postpone the activity or stop performing the activity in any form.

Figure 4.2 shows the preference for the different adaptation options in the cases of change. Overall, changing travel mode was the most popular adaptation strategy, followed by cancelling the activity/trip. Surprisingly, only approximately 5% of the trips were rescheduled. This might be because rescheduling activities could be a rather complex task for car drivers in daily life. Also, rescheduling activities often resulted in only a marginal credit savings in the experiment; this option is expected to experience increased popularity under a time-differentiated TDC scenario (see Verhoef et al., 1997b). The rather complex manner of handling this option in the experiment might have played a role as well. In cases of a travel mode change, the adaptation option *Bike* was chosen most frequently and was especially preferred for the shorter trips. The average distance of trips switched to bike was 6.3 kilometres, while the distance of all trips that were not part of a trip chain was 21.2 kilometres. The relative popularity of the option *Cancel* showed that there is considerable room for the reported activities to be performed at home, to not be performed at all, or to be postponed beyond the

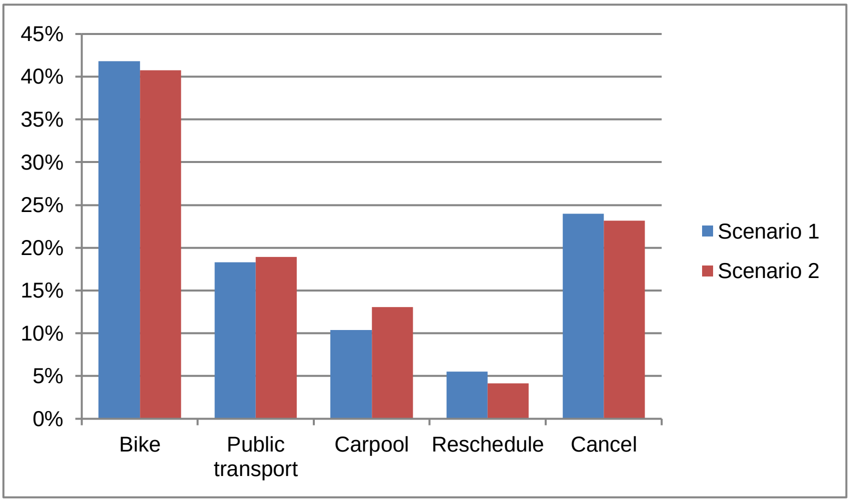

Figure 4.2: Relative preferences for adaptation choices

one-week horizon in the experiment. Unfortunately, we do not have information about the precise reasons for cancelling the activity. Not surprisingly, cancelled activities have a lower reported importance and a higher reported frequency reduction capacity. Finally, it is interesting to note that the relative preference for the adaptation options did not change much between scenarios 1 and 2. The relative preference increases for *Carpool* and – almost negligible – for *Public transport*, which are options that are generally preferred for the longer trips. This thus seems to be in agreement with findings from Loukopoulos et al. (2006) that show that people first choose alternatives that are less costly and opt for more costlier alternatives when they want to make more substantial car use reductions.

Figure 4.3 presents the car use adaptation choices for each activity category and shows how the preferences for the travel alternatives, including the *Car* (no-change) option, differ by trip purpose. This figure and Figure 4.4 only relate to scenario 1 to limit the number of figures. Figure 4.3 shows that the option *Bike* was considerably more popular than the other travel modes for the *Daily shopping*, *Non-daily shopping & Personal services*, *Sports, hobby & recreation* and *Other* activity categories. Although *Bike* was chosen more often, *Public transport* followed closely in the *Work & Education* and *Social & Cultural* categories, which generally had longer distances. The *Sports, hobby & recreation* and *Pick up/drop off* categories had the highest rates for *Cancel*. People can likely more easily skip the activities in the *Sports, hobby & recreation* category, which are more individually-oriented, compared to the other leisure-oriented activities in the *Social & Cultural* category, which might be more frequently performed on a collective basis. Activities in the *Pick up/drop off* category are not likely to be cancelled; rather, people might organise the involved travel differently, e.g., allowing passengers to organise their travel themselves or assigning the task to others. Unfortunately, follow-up questions that would have yielded such information could not be included in the experiment to keep the experiment as simple and short as possible.

To analyse whether trip adaptation patterns are different for participants facing a gain or loss and facing different sizes of the gain/loss, Figure 4.4 shows the adaptation choices for trips made by participants in five price classes that have been created based on an equal number of activities per class. As expected, most alternatives were chosen more frequently when the losses were larger and the preference for the no-change option diminished. One remarkable exemption is the *Bike* option, which shows a rather stable preference rate across the gain/loss classes. This suggests that biking is an alternative that can be implemented at relatively low costs and people are willing to choose when a small incentive is provided. However, there is only potential for the biking option up to a certain level (approximately 10% of the trips), which is not surprising as biking is only a feasible alternative at shorter distances.

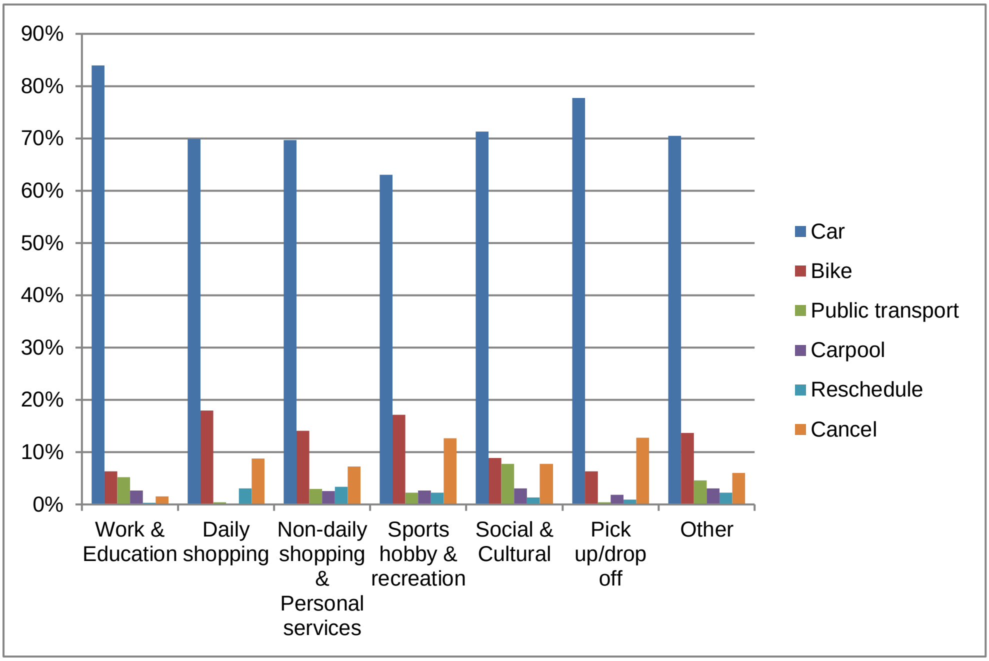

Figure 4.3: Relative preference for adaptation options by activity category

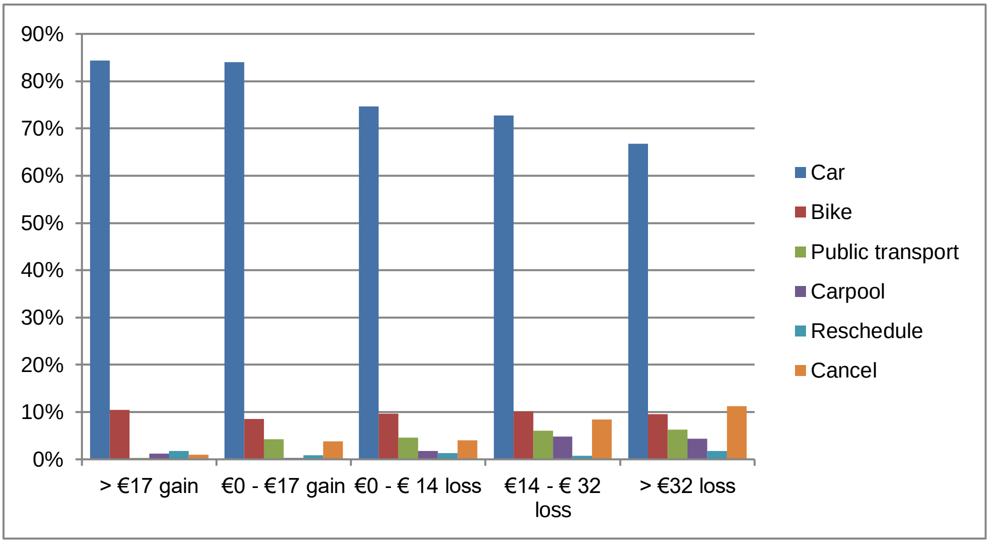

Figure 4.4: Relative preference for adaptation options by gain/loss category

4.4 Multivariate analysis: mixed logit model for adaptation choice

In this section of the paper, we use a discrete choice modelling framework to estimate the effects of various activity/trip attributes and individual characteristics on the probability of choosing the car-use alternatives identified above. Our model is based on participants' adaptations in scenario 1 only. Scenario 1 was defined in a way that represents a realistic TDC setting in which we aimed for the total credit availability to be a reasonable 15% reduction of the total kilometres by car, whereas the second scenario was developed to test the effect of a stricter budget in a situation in which the total credit availability was a less realistic and rather harsh 30% reduction in total car kilometres.

4.4.1 Modelling approach

For each trip, the model describes whether and how the trip is adapted in response to the TDC scenario. The five discrete adaptation options defined above are the choice alternatives and the estimated parameters represent trip-related, scenario and personal explanatory variables. With each participant having multiple trips that must be decided upon under a TDC scheme, the data is structured as panel data in which the trip-specific factors vary across each participants' observations but the individual and scenario-related characteristics are stable. Because participants evaluated multiple choice situations in the experiment, the participant's choices could be correlated due to expected preference heterogeneity among participants, violating the classic assumption of independently and identically distributed error terms (IID) that underlies standard discrete choice models. Mixed logit models can accommodate for these panel effects by allowing for the specification of random parameters that can capture preference heterogeneity among decision-makers (Revelt & Train, 1998; Train, 2009; Hensher & Greene, 2003).

In the mixed logit model, the utility of alternative i out of J alternatives in choice situation t for individual n is denoted by:

$$U_{nit} = \beta'_i x_{nit} + [\,\alpha_{ni} + \varepsilon_{nit}\,] \qquad (1)$$

where x_{nit} is the vector of the non-stochastic observed explanatory variables (socio-demographic characteristics and decision context), β'_i is the vector of the fixed parameters, and where the stochastic portion consists of the error terms α_{ni} which is correlated and heteroscedastic, and ε_{nit} which is an extreme value-type error term that is independently and identically distributed. The distribution for α is denoted by density $f(\alpha|\Omega)$ where Ω is the vector of the parameters of the density function.

For a given α, the conditional choice probability is a standard logit because ε_{nit} is an IID extreme value:

$$L_{ni}(\alpha) = \frac{e(\beta'_i x_{ni} + \alpha_{ni})}{\sum_{j \in J} e(\beta'_j x_{nj} + \alpha_{nj})} \quad (2)$$

Because α is not known, the unconditional choice probability (the mixed logit probability), is obtained by integrating the standard logit formula over all values of α weighted by its density:

$$P_{ni} \int L_{ni}(\alpha) f(\alpha | \Omega) d\alpha \quad (3)$$

The integral has no closed form and therefore the probability is simulated by randomly drawing values from the density function $f(\alpha|\Omega)$.

The normal distribution is assumed for $f(\alpha|\Omega)$, with 0 mean and variance σ. In our panel specification, the normally distributed error terms are perfectly correlated over all the choices for an individual. Halton draws are used for simulation, which were taken for each individual. The software platform 'R' and the 'mlogit' package were used to perform the statistical analysis (R Core Team, 2016; Croissant, 2013).

4.4.2 Results

Table 4.2 presents the model estimation results, with the option *Car* (no change) used as the reference category. Models with 1500 Halton draws or more produced stable results, and therefore the model based on 1500 draws is presented here. The adjusted R^2 of 0.254 indicates a good model fit. The means and the standard deviation of the random alternative-specific constants are significant. This indicates that there is an unobserved preference for certain alternatives among participants that could not be captured by the participant-specific variables alone and that, consequently, a mixed logit framework is an appropriate modelling approach in this context. Overall, the model can identify very few (marginally) significant effects for the *Reschedule* alternative, which likely relates to this option being preferred in a limited number of cases.

To maintain a sufficient number of observations per activity type, the *Daily shopping* and *Non-daily shopping & Personal services* activity categories, that were two separate categories in the descriptive analyses section, were merged into the *Maintenance* category. Note that distance as a factor was not included in the model, because a considerable portion of trips ware part of a larger trip chain and thus it is not possible to determine a useful distance indicator for the individual trips on which the model is based. All other objective activity/trip characteristics (frequency, part of a trip chain, the presence of a passenger, location), reported in Table 4.1, were included in the model. The subjective evaluations regarding the importance and flexibility of the activity/trip have not been included in the model because their effects could mask meaningful effects of the objective measures. Furthermore, the effects of the subjective measures were found to be highly self-evident (e.g., trips with a higher perceived ability to be changed to public transport showing a higher propensity to be changed into a public transport trip). However, in the discussion of several effects of objective attributes, we use these subjective evaluations to try to understand the underlying reasons for the preferences found by the model. In the following, we only discuss the effects that are significant at the 0.05 alpha level.

Activity/trip-specific characteristics

Compared with trips made for work and educational purposes, trips made for all other purposes have a higher chance of being changed into a bike trip, except for trips in the *Pick up/drop off* category, which, in many instances, involve bringing/picking up children to and from school/nursery and are often closely tied to trips to or from work. This pattern might be largely explained by distance, as work trips are usually made over larger distances (see Table 4.1 for the mean distances for non-chain trips). Compared with work and educational trips, trips made for other activity reasons are more likely to be cancelled, which is not surprising given the mandatory nature of work and education-related activities and their high priority and low frequency reduction capacity (see Table 4.1). This is also true for the *Pick up/drop off* trips, which is rather remarkable in light of the relatively high importance and inflexibility attached to trips in this category. However, whereas the activities of people being brought to or picked up might be rather important and inflexible, there might be considerable room for those people to travel differently, e.g., mobilise others or travel by bike or public transport if they are not too young. Further activity effects are only present for *Maintenance*, with trips in this category being less likely to be changed into a public transport or carpool trip, probably because these modes are less efficient for the relatively shorter trips and these activities might involve the movement of goods. Maintenance activities are more likely to be repositioned in the activity pattern than work and education-related activities because these activities are generally less fixed in time (see Table 4.1).

Trips that are part of a trip chain are less likely to be conducted using another travel mode. This is an expected outcome as doing so would generally require significant reorganisation of a travel pattern that might have been formed by participants to be more efficient. The presence of other passengers reduces the probability a trip is cancelled but increases the likelihood of choosing carpool. The latter effect is rather remarkable; one reason might be that participants already travelling together in the original situation simply chose this option in the scenarios as the experiment did not differentiate between different vehicle occupancy rates in determining credit usage in the base situation. The car is less likely to be substituted by public transport if the activity is performed at least once per week. The fact that overall public transport is less time-efficient can explain the preference for the car relative to public transport if the trip involves activities that are a more central part of daily routines and are therefore generally planned more tightly. The preference for cancelling clearly increases if the activity is performed occasionally (less than once per month). Apparently, incidental activities generally less urgent and can be skipped more easily.

The final activity/trip characteristic is the urbanity level of the activity location, measured at a neighbourhood level. We attached a level of urbanity to each activity location, as measured by Statistics Netherlands (CBS) using a 5-point scale. In our model, we used a dummy variable to distinguish between urban (5 = very strongly urbanised, 4 = strongly urbanised, 3 = moderately urbanised) and rural areas (2 = weakly urbanised, 1 = not urbanised). As expected, the bike and public transport are less preferred as alternatives to car use in the rural areas, which was also found in another Dutch road pricing study (Arentze et al., 2004).

Individual-specific characteristics: scenario attributes and socio-demographic characteristics

The Euros to be gained or lost represents the financial base situation faced by the participant in the scenario. When the gain becomes larger, there is a general reduction in the preference to use credit-saving alternatives. This is a natural outcome given the expectation that people who anticipate a higher financial benefit without changing their behaviour are more satisfied with the status quo. Only the rescheduling option had no significant association with the size of gain. If there is room for rescheduling, this strategy can likely be implemented relatively easily without much cost, so participants with higher gains in the base situation consider it worthwhile to reschedule activities. Regarding losses, the size of the loss only has a significant positive association with cancelling, meaning that people are more prepared to cancel activities/trips to lower the loss faced if the loss is larger. For the other kilometre-reducing strategies, it appears that the trip/activity attributes define the likelihood of being chosen rather than the size of the loss, demonstrating that people did not simply tick options but realistically situated their decisions in the context of daily life.

Regarding the socio-demographic characteristics, males systemically more often chose to replace their car trips with biking or public transport than females. Concerning the perceived ability to make the trip by bike or public transport, males indicated they generally find it easier to do do (t-test: *mean difference* = 0.136, $t = 2.61$, $p = 0.009$

Table 4.2: Estimation results for adaptation choice (mixed logit model)

	Bike	Public transport	Carpool	Reschedule	Cancel
Constant	-3.424***	-2.414***	-5.802***	-11.890***	-6.032***
Standard deviation of non-IID residuals	2.008***	1.940***	2.654***	2.920**	-2.156***
Activity/trip characteristics					
Activity (ref = Work & Education)					
Maintenance	2.282***	-1.584***	-2.115**	2.932***	2.848***
Sports, hobby & recreation	1.999***	-0.926	-0.440	1.927	3.473***
Social & Cultural	1.325***	-0.057	-1.030	2.459*	2.347***
Pick up/drop off	0.777	-2.223*	-1.004	2.554	3.068***
Other	1.495***	-0.888	-0.858	2.689	1.863***
Trip part of a chain	-1.376***	-1.678***	-0.873	-0.523	-0.223
Presence passenger(s)	-0.371*	0.046	1.446**	-0.552	-0.706**
Frequency (ref = once per week or more)					
Once per week – once per month	-0.163	1.472***	0.751	0.719	0.528
Less than once per month	-0.544**	1.215***	0.663	-0.074	1.194***
Destination is in a rural neighbourhood	-0.525**	-0.757**	-0.884	-1.756	0.012
Scenario characteristics					
Euros to gain (continuous)	-0.020**	-0.143***	-0.058*	-0.007	-0.126***
Euros to lose (continuous)	-0.001	0.005	-0.0004	-0.011	0.010**
Individual characteristics					
Male	0.805***	0.856**	0.782	0.675	0.334
Age > 45	0.385**	0.089	-0.488	0.400	0.081
Presence of children in household	0.443**	-0.841***	-0.143	1.526	0.729**
Monthly disposable net household income > €2500	-0.286	-0.009	0.821	-2.450	-0.610**
Would rather not state income	0.123	-0.820	1.240	-2.233	-0.659
More than 1 car in household	-0.283	-0.648**	-0.859*	1.661	0.214
Working hours more than 30 hours per week	-0.570**	-0.949**	0.035	2.387	-0.148
Residence is in a rural neighbourhood	-0.413**	-0.096	-1.653**	0.276	-0.141
Log-likelihood (0)	-1939.0				
Log-likelihood (β)	-1702.5				
R^2 (adjusted)	0.254				

* p <0.10; ** p <0.05; *** p <0.01

and *mean difference* = 0.124, t = 2.90, p = 0.004, respectively). It could be that women are more car dependent because they generally are more responsible for household tasks than men, irrespective of their employment status, and therefore, might experience a tighter travel schedule (Hubers et al., 2011; Schwanen et al., 2007). Further, women might already be travelling with alternative modes when possible more often than men, as women are found to cover a smaller share of their travelled distance by car (Matthies et al., 2002), leaving men with a potential larger capacity for mode change. Participants aged 46-65 were more likely to choose the bike as an alternative to their car use than younger participants. As older participants reported a lower average kilometres travelled per trip for non-chain trips (t-test: *mean difference* = 3.879, t = 3.13, p = 0.002), the bike is likely a more viable alternative for older participants because of the shorter distances they generally drive.

The presence of children positively impacts the likelihood to change to the bike but has a negative effect on using public transport. Those with children living at home have a higher reported ability to use biking (t-test: *mean difference* = 0.389, t = 4.88, p = >0.001), possibly related to the significantly shorter average distance they travel for non-chain trips (t-test: *mean difference* = 3.176, t = 2.60, p = 0.009). There was no significant lower perceived ability to travel by public transport for those with children, but participants with children living at home might have a travel schedule that is more constrained by household tasks and the activities of their children, which makes the use of public transport less efficient in terms of time. Participants with children living at home also cancel their activities/trips more often. Those with higher incomes are less inclined to see cancelling as an alternative than those with lower incomes, which is rather difficult to explain given that the overall importance attached to activities and the perceived ability to reduce the frequency of activities does not differ systematically between participants with higher and lower incomes. Participants with lower incomes likely see cancelling the activity as an option more frequently in the trade-off between the meaning of the activity and the money saved by cancelling it due to a higher marginal value of money.

The presence of more than one car in the household negatively impacts the likelihood to change to public transport, which is an expected outcome as car ownership level is an indication of car dependency and hence the ease to switch to alternative travel modes. This only appears to be true for public transport, as the estimation results do not show a statistical difference for biking. Working more than 30 hours per week systematically reduces the preference for biking and public transport as alternatives, as they likely have less time available for a mode change. Finally, with regards to the residential context, those living in a rural neighbourhood show a lower probability to switch to biking or carpooling as alternatives for their car use. The larger distances to be covered in rural areas to reach destinations and the lower geographical proximity of potential co-travellers likely play a role here. We also tested for the personal characteristics of education level and having a partner but, as these characteristics did not affect the selection of car-use alternatives, we excluded them in the final model estimation.

4.6 Conclusion and discussion

In this paper, we analysed the effects of a hypothetical distance-based tradable driving credit (TDC) scheme. In an interactive stated adaptation experiment, frequent car commuters could reorganise their reported one-week travel pattern by choosing from a set of car-travel alternatives in response to two scenarios that used a cap on the sample's total kilometres driven. This stated adaptation experiment was designed based on the assumption that we can only come to a realistic appreciation of the effects of transport policies in a context that uses the wider set of interlinked activities/trips as a starting point for analysis and allows participants fully account for the consequences of the available choices in the context of their concrete daily life. Whereas the value of stated adaptation approaches has been increasingly recognised in travel behaviour research (Arentze et al., 2004; van Bladel et al., 2008; Nijland et al., 2009; Weis et al., 2010), the use of a stated adaptation approach that enables the participant to interactively respond to a scenario and the researcher to perform statistical analysis on the data in the context of TDC is new.

The results show that approximately 30% of the trips made for maintenance-oriented (shopping and personal services) and leisure-oriented activities were subject to change and that, as expected, the change rates for the less flexible trips made for work, education and to pick up/drop off others were considerably lower. Biking was the most preferred alternative and, interestingly, there was a relatively stable adaptation rate of 10% of all trips changed into a bike trip for different loss and gain categories. This indicates that there is seemingly room in people's current travel patterns for a relatively easy change to slow modes that can be actualised when a trigger is provided, which is a relevant finding for other possible incentive-based programmes that seek to reduce car-based travel. When the availability of credits was reduced further in the second scenario, we found that the activities/trips that are generally more difficult to change experienced the largest relative increase in reported adaptation compared with those in scenario 1. This is in agreement with earlier research on adaptations to travel demand measures that suggests that adaptations differ in costliness and effectiveness over trip purposes and alternatives and that, according to a cost-minimisation principle, people only enact adaptations that are costlier in terms of money and effort when they set larger car use-reduction goals for themselves (Loukopoulos et al., 2006;

Gärling et al., 2000). The effects of activity/trip attributes, such as the activity type, presence of a passenger, the frequency and geographical context of the destination, and individual characteristics concerning the preference for various adaptation alternatives, were further investigated using a mixed logit model framework.

In a preceding paper (Dogterom et al., under review a), males and those with children living in the household were found to be more willing to change their car use in response to the TDC scheme. By analysing adaptation patterns at the trip level, this paper showed that males had a higher reported ability to switch to alternative travel modes, suggesting that females generally have a less flexible activity/travel pattern and are more car-dependent (Hubers et al., 2011; Schwanen et al., 2007). Those with children at home showed making more trips that were shorter and generally had lower reported importance, which might explain their higher willingness to switch their trips to biking or to cancel the activity. Participants living in a rural area had a lower preference for biking and carpooling, options for which the attractiveness is normally facilitated by higher densities, possibly explaining these participants' lower willingness to change, as found in Dogterom et al. (under review a).

One major contribution of this paper to TDC research is that it focused on the credit allocation process in the context of concrete activities/trips with an explicit link to the opportunities and constraints in the decision-context regarding reorganising car travel. The stated adaptation experiment used in this study is another contribution to the wider field of travel behaviour research, as it is a promising tool for capturing travel adaptations to TDM measures. The experiment was capable of capturing multidimensional adaptations, which is not the case in many other stated choice and stated adaptation studies. Participants sometimes made rather complex adaptations, showing that accounting for multidimensional choices enhances realism and suggesting that participants were engaged with the experiment.

As this study treated the individual as a rather isolated entity in the experiment, a valuable next step would be to account for the intra-household interaction involved in travel decisions, as it is acknowledged that such interactions play a large role in shaping and constraining opportunities for travel adaptations (Arentze & Timmermans, 2009; Bhat & Pendyala, 2005). Understanding the formation of TDC response strategies at the household level would be especially relevant if more specific assumptions would be made about the precise allocation of credits in a household context. For instance, would the credits be allocated to individuals, to households collectively or to cars? And, if credits would be allocated to individuals, would credits be freely transferable among household members? Assumptions based on these aspects have clearly implications for the extent to which certain actions (e.g., assigning car-based tasks to other household members or tapping the credit resources of other household members) could be considered a feasible response strategy in specific TDC contexts.

We also suggest investigation of the preference for car-use alternatives under different types of TDC schemes. Our results show that the preference for rescheduling activities in time is considerably low, however, it is expected that schemes that differentiate between different times of the day would make people more prone to reschedule their car trips, as shown by studies on congestion pricing (e.g., Verhoef et al., 1997b). The presence of dynamic credit prices that follow the market dynamics of supply and demand for credits in a true credit market could also have a unique impact on drivers' adaptive strategies. Understanding of TDC responses would be greatly enriched if future research included experiments designed to investigate these behavioural strategies in research settings that would facilitate trading between participants.

We acknowledge that the design used in this study inherently poses some limitations concerning a realistic and comprehensive understanding of these adaptations, which could be addressed in future research. First, a switch to another travel mode might involve alternative costs (e.g., tickets to ride public transport), that were not considered in the experiment and therefore might not have been fully appreciated by the participants. Therefore, changing to public transport might have been too attractive in the wish to conserve credits and thus integration with public transport operator's timetables and ticket prices might achieve a higher level of realism, although it would make the experiment more demanding for participants. Second, in the experiment, participants could state to cancel their activity/trip without being prompted to indicate why and how they would do so. Enquiring about the reason for cancelling the activity/trip in its current form (e.g., perform the activity at home, assigning the task to somebody else, postponing the activity, cancelling the activity in any form, etc.) would have provided an opportunity for more detailed analysis. But, again, this would have increased the complexity of the experiment.

5 Willingness to change car use under a tradable driving credits scheme: a comparison between Beijing and the Netherlands *

Abstract – Recent years have seen a surge of interest in the concept of tradable driving credits (TDC) as an alternative to road pricing and driving restriction measures. However, the empirical research into drivers' responses to a TDC measure is limited and even lacking for the Chinese context, where the concept of TDC has attracted considerable attention. This paper reports the results of a survey that was the first to investigate drivers' willingness to change car use under a hypothetical distance-based TDC measure in China (Beijing) and that aimed to compare these results with the results of a comparative Dutch survey. We observed that willingness to change was considerably higher in Beijing than in the Netherlands and that a substantial share of Beijing car owners indicated an increase in car use. In both contexts, higher education and a higher car use intensity had a positive effect on willingness to change, whereas higher income had a negative effect. We found mixed results for household size, respondents' car attitudes and TDC scenario characteristics.

5.1 Introduction

Although many cities around the globe are confronted with the problems of congestion and pollution that are posed by the growing road transport sector, in China, these challenges have manifested themselves at an unprecedented scale. In particular, Chinese megacities, which are the focal points of China's fast economic growth and urbanisation, rank among the most congested and polluted cities in the world and have shown no indications of a projected lowering of car use aspirations among its citizens (Wang & Liu, 2015; Ng et al., 2010). In response, cities such as Shanghai and Beijing have implemented a series of travel demand management measures to address excessive car use. Already in the 1990s, the Shanghai authorities adopted a programme by which it issued only a limited monthly number of license plates through an auction to

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limit the growth of the vehicle population. Beijing started a similar license plate scheme in 2012; however, it chose to issue new license plates by a lottery. In addition, Beijing further rationed car use by implementing a driving restriction measure that does not allow cars to drive on a certain day of the week, based on the last digit of the license plate (Xu et al., 2015; Hao et al., 2011).

Although these measures have slowed new vehicle purchases and reduced traffic congestion and air pollution to some extent (Sun et al., 2014; Hao et al., 2011), researchers commonly agree that these measures – that are appealing to regulators because of their simplicity, quick and visible short-term effects, and implementation at relative low costs – are not sustainable and effective in the long run and have given rise to significant negative side effects. These restrictions do not fundamentally target the intensity of car use (vehicle kilometres travelled, VKT) and therefore can lead to increased car use by those who are allowed to drive. For Beijing, Yang et al. (2014) projected only a 1% decrease in annual fuel consumption by 2020, whereas they expected the total number of vehicles to decrease by 11% with the license plate lottery scheme in place. Further, Beijing's driving restriction has led to compensating responses, such as the temporary substitution of car use, second car purchases, and non-compliance behaviour (Wang et al., 2014). Shanghai's license plate auction scheme, which can make the right to access the roads as expensive as ¥100,000 (almost €15,000) and has resulted in only the wealthy being able to drive, has been heavily criticised for its equity implications (Chen & Zhao, 2013). Nie (2016) laid out a more fundamental criticism of license plate restrictions by mathematically showing that it can never be a first-best nor a guaranteed second-best solution, as it cannot improve the system costs in any configuration.

Making access to roads 'tradable' can offer a solution to these problems, as noted by Nie (2016; see also Verhoef et al., 1997a; Goddard, 1997; Yang & Wang, 2011). Applying a tradable credits approach to managing personal car use, which would lead to situations in which drivers could trade their individual share of a total quantity of road access, could address the welfare loss problems that are associated with the above-discussed measures. Simultaneously, it could provide regulators with more direct control of VKT when, for example, the total quantity is set in units of distance or fuel consumption. Under a tradable credits measure, an economic price that is determined by actual supply and demand would be attached to car use, which, according to transport economists, is crucial to obtain an efficient allocation of scarce road space. At the same time, major objections to conventional road pricing could be addressed by the scheme through the allocation of a minimum amount of 'free' credits – through which authorities could also pursue certain distributional outcomes – and by providing drivers an opportunity to realise financial benefit by selling excess credits.

Recent years have seen a surge of interest in the concept of tradable credits in the transport domain, which has led to many theoretical explorations (for reviews, see Grant-Muller & Xu., 2014; Fan & Jiang, 2013). However, to come to a more comprehensive evaluation of tradable credit-based measures, it is critical to investigate the responses of those who as car owners will be affected by the measure at the micro-level. However, empirical research that seeks to anticipate drivers' responses to tradable credit-based measures is scarce and even missing for the Chinese context, although China is well-represented in theoretical discussions on the concept. The available empirical research, which only relies on data from the USA, the UK, France and the Netherlands, suggests that the measure can mobilise shares of car users to change their behaviour, realise car use change magnitudes, and achieve support levels that are comparable or even larger than more or less equivalent conventional road pricing schemes (for a review, see Dogterom et al., 2017).

The aim of this paper is to contribute to this small body of literature on the behavioural impacts of tradable driving credits (TDC) schemes, specifically by being the first to present results from a Chinese context. It investigates data that were collected by surveys that were conducted in Beijing (China) and the Netherlands, by which car owners' willingness to change and types of behavioural change in response to distance-based TDC scenarios were examined. By relating the Chinese data to the Dutch data, we are able to directly compare car use change behaviour and to investigate the extent to which general patterns and preferences and important differences between an Asian and European context can be found. In doing so, we bear in mind the important geographical, socio-economic and cultural differences that exist between both contexts.

In the next section, we will provide background information about the existing studies on TDC. Next, we will outline our data collection procedure and samples, after which we will present the results. We will end with a conclusion and a discussion.

5.2 Background

The concept of tradable credits originates from the field of environmental economics. Since Dales (1968) proposed marketable pollution rights as a new policy to tackle water pollution, the concept has found numerous applications that attempt to mitigate environmental problems (Tietenberg, 2003; Stavins, 2003). Later, Verhoef et al. (1997a), Goddard (1997), Viegas (2001), Raux (2004), Kockelman and Kalmanje (2005) and Buitelaar et al. (2007) have begun to explore the potential of tradable credits in the domain of urban road transport. Given the ongoing growth of excessive car use demand in many urban contexts and the massive unpopularity of traditional pricing-based measures, together with the present availability of advanced and ubiquitous ICT technologies, the tradable credit approach for managing car mobility has been more vigorously researched in recent years. Yang and Wang's study (2011), which theoretically demonstrated that a tradable credits scheme leads to the most desirable network traffic flows in a revenue-neutral way under an appropriate credits allocation and correct link-specific charges, led to many other studies that analyse traffic patterns and credit price behaviour under different user and market equilibrium assumptions (e.g., Wu et al., 2012; Wang et al., 2012; Ye & Yang, 2013; Nie & Yin, 2013; Xiao et al., 2013; Bao et al., 2014; G. Wang et al., 2014).

The focus of these studies has largely been on macroscopic analysis. Based on this observation, Xu and Grant-Muller (2016a; 2016b) presented a microscopic simulation analysis in which they examined TDC effects on vehicle distance travelled and mode choice based on existing travel data for the cities of Beijing and London. They showed that TDC could effectively affect travellers' mode choice and could be a viable alternative to normal road pricing with regard to car use intensity. Although this disaggregate simulation approach using existing travel data is already an important step in connecting theoretical models to real-world travel patterns, which is inevitably needed to obtain predictions of TDC's effects, these studies still rely on very basic assumptions that do not differentiate between travellers' space-time context and socio-economic status.

Empirical research that has focused on the individual level is very limited. However, such research can provide insight into anticipated travellers' responses to TDC in a more realistic way and can, through statistical analysis, differentiate between groups in regard to behavioural responses. In their proposal for a congestion-based congestion pricing scheme, Kockelman and Kalmanje (2005) surveyed respondents from the Austin area (TX, USA) about their likely reactions to such a scheme. They found that willingness to change current driving behaviour decreased with age, income and vehicle ownership when the respondents were asked how many days they would modify peak-based trips to save credits. In the UK, Zanni et al. (2013) investigated behavioural adaptations in response to a tradable credit scheme that in addition to personal travel, covered all other personal carbon-producing behaviour. Their results showed that people with higher incomes, who are gainfully employed and live in larger households are more likely to change their current carbon-producing behaviour. Raux et al. (2015a), comparing changes in travel behaviour in response to both a tradable credit scheme and an equivalent tax in France, found socio-economic characteristics to only weakly affect car use change, only finding a significant negative effect on willingness to adapt car use for older respondents in the case of the tradable credit scheme.

Dogterom et al. (under review a) designed a stated adaptation experiment in which Dutch frequent car commuters could make modifications in their one-week car travel pattern that was recorded prior to the experiment. The respondents were presented with two TDC scenarios, in which the allocated credits represented a 17.5% and a 32.2% reduction in the total VKT of the sample in a first and a second scenario, respectively. The participants received equal-sized credit budgets, meaning that the credit shortage (loss) or surplus (gain) in the base situation was proportional to their individual VKT. After controlling for the size of financial loss and gain, the results indicate that willingness to make travel adaptations to change the financial outcome increased with the number of children living in the household and decreased with living in a non-urbanised area. Males were more willing to change their car use in the first scenario, meaning that the gender difference disappeared under a stricter budget; however, at the same time, under this narrower budget, the respondents with a middle income were more prepared than the other income groups to make adaptations in their car use.

Only Zanni et al. (2013) and Dogterom et al. (under review a) were able to model behavioural change as a function of the size of the financial gain or loss that is faced by the respondents, as they used an experimental design that was configured to resemble a scheme with an equal-per-capita credit allocation that was applied to drivers with heterogeneous travel demand. Both of the studies found that facing a loss had a larger impact on willingness to change behaviour and that this willingness increased with larger losses and decreased with larger gains.

This paper extends the studies that are discussed above in that it is the first that presents results from a Chinese context, especially from the city of Beijing, which is a context where the problems of excessive car use are particularly pressing and the need for viable travel demand management measures is highly relevant. It is somewhat surprising that the behavioural effects of TDC have not been investigated in China, while a large share of the theoretical studies on TDC has been produced in that country. Additionally, with regard to the road pricing literature in general, individual-based empirical research is very limited in China as compared to western counties. Further, presenting results from China together with results of a similar study from the Netherlands is an important contribution, as this enables a direct comparison of the Chinese findings with findings from a western context. Finally, with regard to the Dutch context, this paper extends the study of Dogterom et al. (under review a) in that it reveals the preferences of the broader group of car owners instead of only the sub-group of frequent car commuters. This paper seeks to determine whether the influencing factors that are identified for more intense car users also play a role for the category of drivers that is a more representative sample of the car-owner population, including non-workers. There may be a greater likelihood of car use change in this group, which on average might be less car-dependent and less forced to drive during peak hours. The data that we present for Beijing will be explorative in essence, as findings cannot be situated in an already-available literature on drivers' responses to pricing initiatives in that context.

At the same time, we believe that several relevant factors should be taken into account when interpreting data from both Beijing and the Netherlands in a comparative analysis. First, there are important geographical and socio-economic factors, as the Dutch data are collected through a national sample, whereas the Chinese data are confined to the city of Beijing alone. Beijing is a megacity that, having more inhabitants than the Netherlands as a whole, considerably differs from the Dutch research context in the structure of the built-up area, the profile of the population and the scale of traffic-related problems. Each location in Beijing is relatively easy to reach by public transport, and its highly dense structure provides many feasible alternative locations for the amenities that are used by its inhabitants, which is different for the less-urbanised areas of the Netherlands. However, in terms of sample profiles, we expect that both samples will be more similar than one might initially expect, as the population of car owners in Beijing largely consists of a relatively homogeneous middle class group, which has more or less western levels of education, income and activity participation. At the same time, there is an important difference in car culture between both contexts. More than in the Netherlands, in Chinese cities the use of travel modes is imbued with psychosocial meaning, and car ownership and use have a strong symbolic appeal for urban residents, marking their entry to the new rising middle class and being a sign of affluence that is eagerly displayed (Williams & Arkaraprasertkul, 2016; Yang et al., 2014). This phenomenon may negatively affect drivers' preparedness to seek alternatives for their car use, even in conditions under which drivers would face increasing operational costs. In the context of the present driving restrictions in Beijing, the implementation of a TDC scheme, in which people can in fact buy road access according to their needs and desires, could potentially mean that higher-income groups and those who find their present travel demand highly suppressed by the existing measures would increase their car use under a TDC scheme. Therefore, to analyse the effects of the psychosocial meaning of car use, we included information about the respondents' car attachment in the analysis.

5.3 Data collection

5.3.1 Survey design

The data were mainly collected through an online survey. Only in Beijing, 10% of the respondents were approached on the streets with a pencil-and-paper version of the survey. The data collection occurred in June (the Netherlands) and July (Beijing) 2016. The respondents were recruited through a panel in both countries. The panel sent an invitation to panel members with a short description of the research. Car ownership was the only criterion for being able to participate in the research. In the Netherlands, the respondents were recruited from all over the country.

In the introduction of the measure, it was stated that the experiment was an academic investigation of the effects of TDC as an alternative measure to combat congestion and that there were no plans for actual implementation. It was communicated that each driver would be allocated a personal budget that contained credits (one credit represented one kilometre) that would allow the driver to drive a certain number of kilometres without additional costs. The driver would be required to buy additional credits when she exceeded her personal credit budget, and she could sell the credits that were left over when she drove less than the amount of credits in the budget. Based on the description and the functioning of the experiment, the respondents had a clear idea of the functioning and implications of a hypothetical TDC scheme in their personal situation.

Although both of the approaches to data collection were similar, there were some differences in the design and procedure of the survey, thus we discuss the details of the data collection separately for the Netherlands and Beijing.

Beijing

First, the respondents were asked to report their car use during the previous 7 days. They were asked to indicate the number of activities and total VKT for 3 different activity groups: 'work and education', 'personal maintenance' and 'leisure'. With regard to VKT, the respondents could choose one of the following classes for each activity category: 'less than 50 km' '50-100 km', '100-150 km', '150-200 km' and 'more than 200 km'. To obtain a rough estimation of the respondents' total VKT, the middle values of these categories were summed (225 km for the 'more than 200 km' category). The respondents were presented with two TDC scenarios. The respondents faced both a credits shortage of 50 credits and a credits surplus of 50 credits. Three different credit values in Chinese Yuan were set (0.5, 0.8 and 1.0), which were randomly assigned to the respondents. The respondents were asked to imagine that their reported car travel was their planned car travel for the upcoming week, for which they had a certain number of credits available. The respondents could indicate whether they wanted to increase or decrease their VKT for the three separate activity groups if the presented scenarios were applicable.

Netherlands

The Dutch survey was slightly more detailed, and it was dynamic in the sense that the amount of available credits was a function of the drivers' reported car use. Dutch respondents were asked to indicate the number of activities performed and the total kilometres driven for 11 activity categories, which were classified into 4 overarching activity groups: 'work and education', 'personal maintenance', 'leisure', and 'other' (including picking up and dropping off people and objects). The kilometres driven could be selected from a list of 19 predefined categories.

In contrast to the Beijing survey, the Dutch respondents faced either a credit shortage or a surplus in the second part of the survey. In these scenarios, the number of available credits was a percentage (15% or 30%) of their reported VKT. One of the four scenarios was randomly assigned to the respondents, together with one of the three credit values in Euros (0.10, 0.15 or 0.20). The respondents were asked whether they would make changes in their VKT in the four separate activity groups if the presented TDC scenario with the total financial gain or loss in a no-change situation were applicable. The respondents could change their VKT by selecting either an increase or reduction percentage from a list (rounded to tens).

Both of the surveys ended with a questionnaire on the respondents' characteristics and their opinions of personal car use and the TDC measure. Three items on car use attachment are included in the analysis of this paper: instrumental (the extent to which a person feels the car is *needed* in daily life), symbolic (the extent to which the car as an object is *meaningful* for the person) and affective car attachment (the extent to which a person derives *pleasure* from using the car) (Steg, 2005). Table 5.1 presents more information on the operationalisation of these items.

5.3.2 Sample

After data preparation, the Dutch sample included 474 respondents, and the Beijing sample included 660 respondents. The socio-demographic characteristics, using the categories that are included in the models, are presented in Table 5.1, together with information about the respondents' VKT and scores on the car attachment items. For the Dutch sample we have additional information on the characteristics age, relational status, work of both the respondent and his or her partner, and the level of urbanity of the residence municipality, which are unavailable for the Beijing sample. Further, with regard to income, only the Dutch survey included the option 'Would rather not say'. Whereas in the Netherlands both relational status and the presence of children were asked, in Beijing the household composition was only measured in terms of household size. We regard the attributes 'presence of children' and 'household size larger than 2' as being more or less comparable, as households in China are normally based on the nuclear family, although a third person could also be another relative instead of a child in the Chinese context.

One of the most remarkable differences in sample composition is the large share of respondents with a university degree in the Beijing sample. This can be explained by the fact that car ownership in Beijing is largely confined to the middle class and

Table 5.1: Sample composition and description of the explanatory variables

	Beijing (*N*=660)		Netherlands (*N*=474)	
Characteristics	**Operationalisation**	**%**	**Operationalisation**	**%**
Socio-demographics				
Gender	Male	48.9	Male	49.8
Disposable household income per month	>¥6,000	54.2	>€2,500 (no income stated)	39.7 (19.8)
Education	University	77.9	Higher professional education and University	38.4
Household	More than 2 persons	80.5	Presence of child(ren)	62.5
Car ownership of household	More than 1 car	8.9	More than 1 car	31.7
Age	n/a	n/a	Age is >45	56.3
Relational status	n/a	n/a	Couple	74.5
Work	n/a	n/a	Paid work	61.8
Work partner	n/a	n/a	Partner has paid work	58.9
Urbanity	n/a	n/a	Residence municipality has urbanity level 1-3 (1= very strongly urbanised; 5 = non-urbanised)	66.5
VKT		*kilometres*		*kilometres*
Average VKT		197.8		339.4
VKT categories	<100 km	30.3	<200 km	37.8
	100-200 km	30.3	200-400 km	28.9
	>200 km	39.4	>400 km	33.3
Car attachment[1]		*mean (s.d.)*		*mean (s.d.)*
Instrumental car use	'How easy could you use other transport modes than the car?[2]'	3.69 (1.73)	'I do not have any alternatives for my car use[3]'	4.22 (1.85)
Symbolic car use	'Do you think your car provides you status and prestige?[3]'	4.10 (1.67)	'My car provides me status and prestige[3]'	2.58 (1.50)
Affective car use	'Do you think driving gives you pleasure?[3]'	4.65 (1.53)	'Driving gives me pleasure[3]'	4.63 (1.55)

[1] Although the Beijing and the Dutch survey used the same car attachment items, the formulation altered somewhat during the translation process. The presented formulation follows the original formulation as closely as possible.

[2] Measured on a 7 point scale: 1 = very easy, 7 = not possible

[3] Measured on a 7 point scale: 1 = fully disagree, 7 = fully agree

elites who are, on average, highly educated in the capital of China, which is the seat of many important (inter)national institutes and companies. Another observation is that the VKT per respondent is generally lower in Beijing, which is not surprising given the megacity structure of Beijing and the polycentric structure of the Netherlands. Because the respondents' VKT could only be roughly estimated and because of the differences in the estimation process in both contexts, we enter VKT as a categorical variable, each group including approximately 30% of the sample, rather than as a continuous factor in the models.

As expected, Beijing car owners have substantially higher scores on symbolic car use and are generally more able to replace their car use with other transport modes. The scores on affective car use are very similar in both contexts.

5.4 Results

5.4.1 Descriptive analysis

This section discusses some general descriptive results for Beijing and the Netherlands. After providing the results for each context separately, the findings will be brought together in a synthesis.

Beijing

Figure 5.1 presents the percentages of the respondents who are willing to change their reported car use with 50 credits less or 50 credits more than they needed. Approximately 60% of the respondents indicated a change, both in the case of a credit shortage and a credit surplus. At the same time, the figure presents the shares of type of change: a reduction or an increase in car use. Of those who would change their car use, 20.5% indicate an increase in kilometres in the credit shortage scenario, while 38.2% do so in the credit surplus scenario. An increase in car use in a situation of credit surplus is understandable: drivers may wish to fully use their given credit budget. However, the finding that one-fifth of the 'changers' report an increase in the case of a credit shortage is somewhat surprising, as this behaviour would imply an increase in operational driving costs in addition to the costs that they already would have to pay in a situation without change. These respondents possibly expect that, considering the current practice under the Beijing driving restrictions, TDC would provide them with the freedom to realise their true travel demand. In addition, people may expect better traffic conditions under the TDC measure as it would set an absolute cap on VKT. For the respondents who state a car use increase, the monetary costs that are involved with driving more under TDC could outweigh the costs of supressed travel

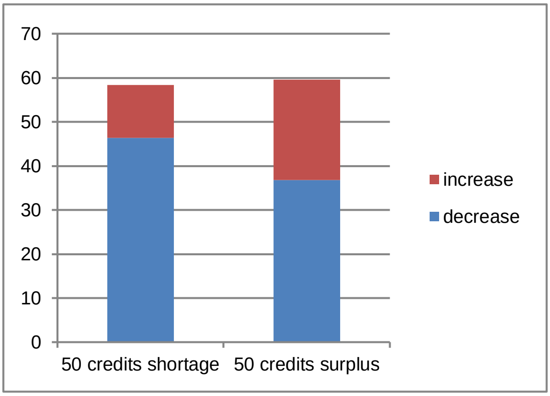


Figure 5.1: Percentages of respondents willing to change car use in Beijing, under two different TDC scenarios

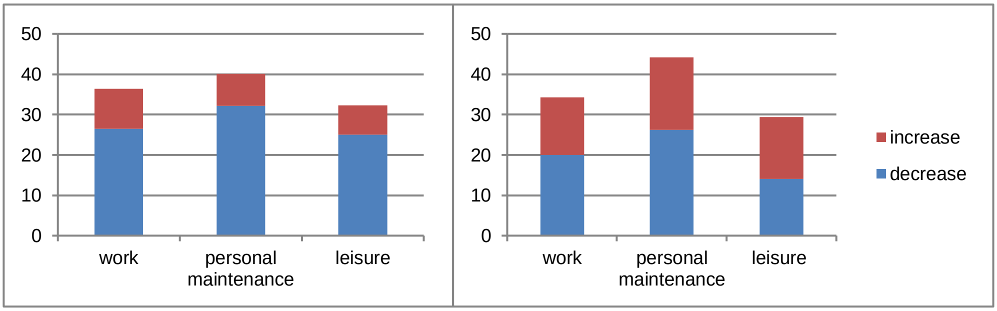
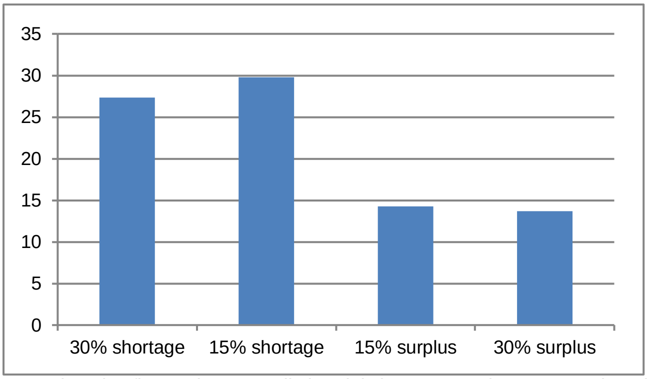


Figure 5.2: Percentages of respondents willing to change car use in Beijing in different activity categories, under a credit shortage scenario (left) and credit surplus scenario (right)

under the current conditions. In Figure 5.2 it can be seen that changing car travel in the domain of 'personal maintenance' is mostly preferred, especially in the case of the credit surplus scenario.

The Netherlands

Figure 5.3 shows the percentages of the respondents who are willing to make adaptations in their car use for the four different scenarios. There is a sharp difference between the 'shortage' and the 'surplus' scenarios, with the willingness to change being twice as great for those who would face a loss compared to those who would face a gain. Only very few Dutch drivers indicated a willingness to increase car kilometres: only 8 out of the 101 respondents who indicated a change in car use (therefore, Figure 5.3 does not distinguish between a decrease and increase of VKT).



Note that the figure does not distinguish between a decrease and an increase in VKT, as only a few Dutch drivers indicated a willingness to increase VKT (8 out of 101 respondents).

Figure 5.3: Percentages of respondents willing to change car use in the Netherlands, under four different TDC scenarios

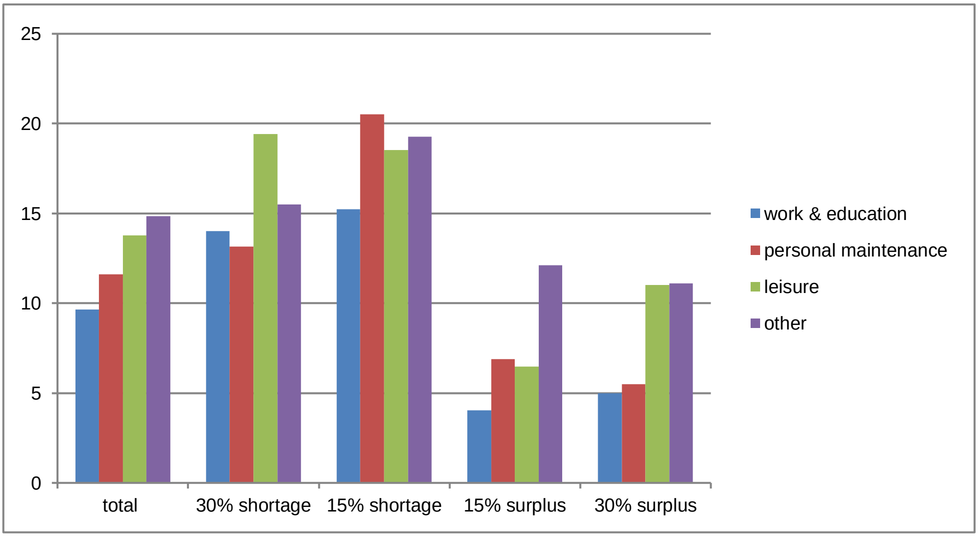


Figure 5.4: Percentages of respondents willing to change car use in the Netherlands for different activity categories, under four different TDC scenarios

Figure 5.4 provides the percentages of the respondents who realise car use changes in the four different activity categories separately. For the entire sample, work and educational activities are changed the least, followed by the activities in the 'personal maintenance', 'leisure' and 'other' category, although the differences in shares are only minor as the change rates range between 9% and 15%. When we consider the willingness to change rates distinguished according to scenario type, these patterns are more diverse across the scenarios. Overall, the rates show the same pattern as is shown in Figure 5.3, with the change rates in the 'surplus' scenarios being approximately half of those in the 'shortage' scenarios. One other more general observation is that the respondents in the 'surplus' scenarios show a relative preference for realising changes in the 'other' category.

Synthesis Beijing – Netherlands

When comparing the willingness to change rates for Beijing and the Netherlands some general conclusions can be drawn. First, the Beijing sample reports a higher willingness to change (approximately 60%) than the Dutch sample (approximately 30% for the scenarios with the highest willingness to change). Second, a remarkable observation is that the clear contrast in willingness to change between the 'shortage' and 'surplus' scenarios that is found for the Netherlands is not present in the Chinese case. Third, when we differentiate between reducing car use and increasing car use as two different responses, the Beijing car owners also show a higher preparedness to change car use in the case of a credit shortage. Still, the willingness to decrease car use is twice as great in Beijing compared to the Netherlands in a surplus situation. In this case, the city environment in which car use can be easily replaced by other forms of travel or activity participation could explain the higher rates of willingness to change in the Beijing context. Fourth, a considerable share of the Beijing car owners' change in car use concerns an increase in car use, even in the case of a credit shortage, whereas in the Netherlands, only a few individuals indicated a willingness to drive more kilometres under the TDC. As noted above, this preference could be explained by the current traffic restriction and conditions in Beijing. Current drivers might see their real travel demand suppressed by the one-day-no-driving restriction and the severe traffic jams, and they may expect to travel more by car if they were allowed to drive without formal restrictions and if they could be assured of improved travel times under an absolute VKT cap, regardless of the extra monetary costs involved. The Dutch car owners might already to a large extent be able to realise their true travel demand under the current conditions.

5.4.2 Statistical analysis

In this section, we present logistic regression models that have been estimated to determine the extent to which willingness to change car use is influenced by personal and TDC scenario characteristics. These characteristics include the respondents' socio-demographic characteristics, kilometres travelled and car use attitudes that are outlined in Table 5.1 as well as scenario attributes (price level, credit shortage/surplus, size of budget).

Table 5.2: Estimation results for car use change for Beijing (multinomial logit model)

	(1) Decrease km				(2) Increase km			
	Model 1		Model 2		Model 1		Model 2	
	Beta	**Sig**	**Beta**	**Sig.**	**Beta**	**Sig.**	**Beta**	**Sig.**
Constant	-1.163	0.000	-1.998	0.000	-3.247	0.000	-5.770	0.000
Male	0.049	0.702	0.125	0.336	-0.286	0.092	-0.078	0.661
Income>¥6,000	-0.471	0.000	-0.464	0.001	-1.004	0.000	-0.981	0.000
University education	0.332	0.031	0.385	0.014	0.995	0.000	0.967	0.000
Household larger than 2 persons	1.019	0.000	1.030	0.000	1.174	0.000	1.175	0.000
More than one car	-0.139	0.529	-0.113	0.618	-0.079	0.788	0.111	0.721
100-200 km	0.264	0.100	0.186	0.255	0.232	0.305	0.087	0.710
>200 km	0.426	0.006	0.329	0.038	0.874	0.000	0.610	0.005
Credit price ¥0.8	0.293	0.054	0.270	0.082	0.715	0.001	0.543	0.012
Credit price ¥1.0	0.358	0.020	0.338	0.030	0.620	0.003	0.553	0.012
50 credits surplus	-0.184	0.142	-0.172	0.176	0.714	0.000	0.763	0.000
Instrumental car use			0.058	0.125			0.034	0.519
Symbolic car use			0.224	0.000			0.446	0.000
Affective car use			-0.063	0.202			0.119	0.113
Log-likelihood		-1276.824		-1230.742				
R^2 (adjusted)		0.065		0.99				
X^2		176.77		268.93				
p-value		0.000		0.000				

Table 5.3: Estimation results for car use change for the Netherlands (binary logit model)

	Model 1		Model 2		Model 3		Model 4	
	Beta	**Sig.**	**Beta**	**Sig.**	**Beta**	**Sig.**	**Beta**	**Sig.**
Constant	-1.079	0.009	-0.553	0.344	-1.354	0.023	-0.688	0.374
Male	-0.332	0.170	-0.464	0.066	0.315	0.224	-0.482	0.076
Income >€2.500	-0.653	0.022	-0.716	0.016	-0.776	0.011	-0.875	0.006
No income stated	-0.080	0.796	-0.177	0.577	-0.172	0.594	-0.293	0.376
HBO and University education	0.590	0.020	0.586	0.026	0.694	0.008	0.731	0.008
Presence of children	0.032	0.898	0.038	0.884	-0.120	0.664	-0.132	0.646
More than one car	0.065	0.802	0.010	0.970	0.009	0.974	-0.089	0.756
200-400 km	0.548	0.060	0.670	0.027	0.578	0.052	0.711	0.021
>400 km	0.552	0.061	0.808	0.010	0.624	0.046	0.863	0.009
Credit price €0.15	-0.200	0.501	-0.133	0.663	-0.177	0.556	-0.112	0.719
Credit price €0.20	-0.011	0.970	0.120	0.681	-0.008	0.977	0.122	0.677
15% credit shortage	0.068	0.817	0.144	0.639	0.069	0.817	0.137	0.658
15% credit surplus	-0.903	0.009	-0.881	0.013	-0.907	0.009	-0.928	0.010
30% credit surplus	-0.936	0.008	-0.912	0.011	-0.944	0.008	-0.947	0.009
Instrumental car use			-0.233	0.001			-0.255	0.000
Symbolic car use			-0.236	0.010			-0.222	0.019
Affective car use			0.192	0.021			0.214	0.012
Age>45					0.142	0.604	0.192	0.515
Couple					0.553	0.115	0.583	0.108
Has paid work					-0.266	0.321	-0.274	0.310
Partner has work					0.107	0.722	0.029	0.925
Lives in urban area					-0.051	0.844	-0.259	0.342
Log-likelihood		-229.393		-218.695		-226.209		-215.091
R^2 (adjusted)		0.066		0.109		0.077		0.122
X^2		32.29		53.68		37.69		59.93
p-value		0.002		0.000		0.004		0.000

Beijing

Because behavioural change consists of two types of change in Beijing, driving more or driving less, we estimated a multinomial logit (MNL) model, which is a much-used discrete choice model. Here, three outcome alternatives are defined: reduce VKT, increase VKT or no change (base outcome). Table 5.2 presents the estimation results of the model. We pooled the data of both the 50 credits shortage and 50 credits surplus to estimate the effect of the credit shortage/surplus (i.e., financial loss/gain) in one model. Two separate models have been estimated, with the second specification adding the three car-use attitudes. By estimating two separate models, we can detect the way in which car attitudes relate to socio-demographic characteristics.

A first observation is that many of the variables that have a significant effect have an effect in the same direction for both alternatives (decrease and increase VKT). Income has a significant effect on both change alternatives and suggests that car owners with higher incomes prefer to stick to the status quo. Those with lower incomes are more likely to decrease their car use, which is an expected outcome as those with lower incomes are widely regarded as being more price-sensitive and having a lower value of time (VoT) (Ubbels & Verhoef, 2005; Rienstra et al., 1999). However, those with lower incomes are also more likely to report an increase in their VKT, which is counterintuitive and difficult to explain. It could be that lower-income groups are more likely to travel by alternative modes at present or that they are less able to bypass the current driving restrictions (by being more flexible, by being more willing to pay fees when breaking the rules, or by relying on other cars), and therefore they are more likely to foresee increased car use under TDC conditions. Another reason could be that the financial (dis)incentive is simply too small to find evidence for lower-income households being are less prone to increase car use under higher costs.

Higher education has a significant and positive effect on both VKT decrease and increase, as has household size. Those with higher education and larger households might have a higher preferred car reliance (e.g., the presence of young children, larger commute distances), which possibly explains their VKT increase. However, at the same time, these groups also report a higher willingness to decrease their VKT. Other unmeasured, underlying characteristics and activity participation patterns (both temporally and spatially defined) might provide an explanation for these seemingly contradictory behaviours. With regard to VKT travelled, the group with the highest reported VKT (200-400 km) is more likely to change car use, again both in terms of VKT reduction and VKT increase. A high VKT might be an indication of a larger car reliance, which leads to a higher preference for increasing VKT under TDC, but at the same time, drivers with VKT generally make more trips, which leads to greater car use reduction potential. Again, other unmeasured factors might play a role in influencing the actual choice outcome.

The results show a price effect in that willingness to decrease VKT is greater for those who face a higher per kilometre price (¥0.8 and ¥1.0). Strikingly, those who are assigned a higher credit price also report being more likely to increase VKT. This appears to be at odds with economic theory, and additional research is needed to determine whether this finding could be corroborated, preferably with higher price levels. When comparing the shortage and surplus scenarios, a higher willingness to increase VKT is found in the case of the surplus scenario, which is not surprising given that increasing car use would not imply additional costs of up to 50 additional kilometres in this scenario. In the surplus scenario, the effect of decreasing VKT is negative; however, this effect is not significant, meaning that there is no systematic difference between the car reduction preferences under the shortage and surplus scenarios.

The inclusion of the car attitude variables leads to only very minor changes in the socio-demographic effects. Whereas males tend to be less likely to increase car use than females (only significant at the 10% level), this effect disappears with the inclusion of car attitudes, suggesting that the small gender difference can be explained by these attitudes. With regard to the attitudes themselves, only symbolic car attachment is found to have an effect on willingness to change. It has both a positive effect on decreasing and increasing VKT, although the effect is larger for increasing VKT. Whereas increasing VKT might be explained by those with higher symbolic car attachment being more eager to use their cars if possible, these people might also be those with higher levels of not strictly necessary car use, which creates opportunities for car use reduction. Of course, all of the possible explanations for the observed stated behaviours are only put forward in a tentative way and clearly call for further research to shed light on the relevant underlying explanatory mechanisms and preferences.

Netherlands

For the Dutch data, we estimated a binary logit regression model because the low frequency of cases of reported car use increase (8 out of 101 cases of change) prevents the estimation of an MNL model, as we did in the Beijing case. The choice alternatives for the Dutch data are therefore change (i.e., reduce VKT in most cases) and no change (base outcome). Table 5.3 presents the estimation results of four different models. The first two models include the variables for which we also have information in the Beijing context and that hence enable direct comparison. The third and the fourth models include the personal characteristics for which we only have information from the Dutch respondents.

Having a higher income has a negative effect on willingness to change, whereas a higher education positively affects the likelihood of changing car use. As mentioned above in the Beijing case, people with higher incomes are generally believed to have a lower marginal utility of money and therefore to have a lower preparedness to change behaviour to circumvent losses or increase gains. The higher willingness to change among higher educated people might relate to such people often working in larger cities, where alternative travel modes are better provided, and generally being more flexible in choosing their working time and location.

Driving more kilometres leads to a higher preparedness to change car use, which is an effect that is stronger when car attitudes have been controlled for. Note that in the Dutch case, VKT acts as a proxy for total financial loss or gain in the scenario, as the credit budget is a function of VKT, and thus people who drive more kilometres not only have more car reduction potential but also face larger losses or gains. At the same time, the size of the financial outcome is also determined by the respondent being assigned either a 15% or a 30% credit shortage/surplus rule; however, there is no significant difference between these two credit availability percentages in both the shortage and surplus scenarios. As expected, whether the scenario implies a loss or a gain does have an effect, as the surplus scenarios significantly differ from the 30% shortage scenario. Marginal price (credit price level) does not have an effect, which is similar to the findings of Dogterom et al. (under review a), using the same price levels.

In contrast to the Beijing results, the car attitudes all have a significant effect. Those with a higher instrumental car attachment are less likely to adapt their car travel, as are those with a higher symbolic car attachment, both of which are expected results. However, those who derive more pleasure from driving are more willing to change. It could be that these people make more leisure- and/or recreational trips, which are trips that could potentially be changed more easily when confronted with a road pricing measure. Controlling for car attitudes does result in the gender variable gaining a significant effect, with males being more likely to prefer the no-change option, and leads to stronger effects for VKT. Overall, the inclusion of car attitudes does not change the level of significance nor the sign of the coefficients of the variables that have an effect in model 1. Further, the inclusion of the additional personal characteristics in models 3 and 4 does not alter the effects. None of these characteristics are found to have a significant effect on willingness to change and together lead only to a small increase in model fit.

Synthesis Beijing - Netherlands

When we compare the statistical results from Beijing and the Netherlands, a first observation is that the explanatory power of the models, which is indicated by the adjusted R^2, is very similar for both contexts. Although the explanatory power is very modest, the similar magnitudes suggest a 'general' relative importance of the included socio-demographic and attitudinal characteristics in explaining car users' willingness to change under TDC in both contexts.

In terms of the personal characteristics that are found to influence willingness to change, we found a similar income, education and car-use intensity effect. The car owners with a higher education and higher reported VKT tend to change car use more often, whereas those with a higher income are less likely to adapt their car use in response to the measure. The income effect can be well explained by the lower marginal value of money of higher income households that therefore are less sensitive to an increase in loss or gain that is faced under the measure. This income effect is also found in the wider road pricing literature (Kockelman & Kalmanje, 2005; Ubbels & Verhoef, 2005; Washbrook et al., 2006; Rienstra et al., 1999). However, when Dogterom et al. (under review a), using three income levels, found an income effect, they only found middle income households to report a significantly higher willingness to change. The education effect is an effect that has not previously been reported in the very limited strand of literature on TDC behaviours. A positive impact of the presence of children on willingness to change that is reported by Dogterom et al. (under review a) and other studies on road pricing (Ubbels, 2006; Gehlert et al., 2011; Zanni et al., 2013) could only be found for the Beijing case (where we interpreted children to be present in households that are larger than 2 persons).

With regard to the TDC scenario characteristics we found some differences between Beijing and the Netherlands. The Dutch respondents indicated a significantly stronger preference for changing car use under a credit shortage situation compared to a surplus situation, which was also reported by Dogterom et al. (under review a) and Zanni et al. (2013). In the Beijing context, a stronger preference for reducing car use in the shortage scenario could not be found, but instead there was a stronger preference for increasing car use in the surplus scenario. Credit price had an effect in Beijing, where each participant received the same amount of credits, with a higher credit price leading to larger preparedness to change; however in the Netherlands, where financial outcome was a function of both credit price and VKT, an effect of credit price *per se* could not be found. The differences in the way in which credit budgets and financial outcome were defined might have played a role in these different outcomes.

In addition, regarding car attitudes, we found some contrasting results. Whereas the respondents' subjective evaluation of their instrumental, symbolic and affective car use all had an effect for the Dutch respondents, only symbolic car use had an effect in Beijing. Additionally, whereas a higher symbolic car use had a negative effect on willingness to change in the Netherlands, in Beijing it had a positive effect, which is in contrast with our expectations given the high symbolic meaning of car ownership and use in contemporary China; although, at the same time, the effect of symbolic car attachment was larger for an increase of car use than for a reduction of car use.

A striking result is that the factors that were found to affect willingness to change for Beijing car owners do have an effect of the same direction on both reported VKT decrease and increase. This is difficult to explain in some cases and we attempted to provide some possible explanations in the subsection on the Beijing results; however, further and more detailed research on these identified preferences is clearly needed.

5.5 Conclusion and discussion

At present, there is a lively strand of literature that theoretically explores the potential of tradable driving credits (TDC) and that considers it to be a promising alternative to road pricing and driving restrictions, which generally face significant public aversion and have demonstrated the production of considerable negative side effects. However, individual-based empirical research into drivers' responses to the measure is scarce and even lacking for the Chinese context. In this paper, we therefore investigated car owners' willingness to change under a hypothetical TDC measure in Beijing (China) and the Netherlands. By means of a direct comparison between both contexts, this research addressed the research questions of how drivers in these different contexts respond to the measure and to what extent preferences of drivers in an Asian megacity are similar or different to what has been found in a European context.

We found substantial differences in the percentages of car owners who are willing to adapt their car use if a distance-based TDC scenario, in which people would receive credits below or above their reported travel demand by distance (km), would apply. Nearly 60% of the Beijing car owners indicated a willingness to change, whereas in the Netherlands this was slightly more than 20%. For the Dutch data, the indicated willingness to change substantially differs from the rate that were found by Dogterom et al. (under review a) based on other Dutch data. They found also a willingness of approximately 60%; however, in their experiment more of the respondents faced a loss, and only frequent car commuters, who potentially have more options for changing travel patterns, participated.

The ease with which car travel can be substituted in Beijing, which has good public transport facilities, might provide an explanation for the large difference in the likelihood of adapting car use between Beijing and the Netherlands. However, at the same time, a substantial part of the Beijing car owners reported an increased car use rather than a car use reduction (21% and 38% of those who would change in the credit shortage and surplus scenarios, respectively), whereas in the Netherlands only a few car owners stated a willingness to increase their car use under TDC. It is possible that Beijing drivers would expect TDC to replace the current one-day-no-driving restriction and expect better traffic conditions due to the absolute cap on traffic and therefore foresee their demand for car travel – currently suppressed – to increase despite the additional credit costs involved.

As such, the results show that TDC, especially in the context of Beijing, would not necessarily lead to a net reduction in congestion if a TDC scheme would work on the basis of fixed credit prices. Such a scheme would basically resemble a tax programme, with the distinction that people who drive below a threshold can face a 'reversed tax', i.e., receive a monetary reward. The participants would then 'trade' with the regulator that has chosen to use predetermined prices to keep the scheme simple and understandable. In such a setting the regulators would require *a priori* information about the demand functions of the credits to guarantee a certain total VKT outcome, which is difficult in real life. However, in a true tradable credit scheme as it is typically understood in the literature, the regulator would set a cap on the total VKT and would let a dynamic market determine the credit price. As such, a TDC scheme is able to guarantee a certain outcome and therefore effectively reduce congestion, based on the VKT cap that is defined.

We therefore suggest that future research investigate car use preferences in such a dynamic setting. Investigating driver's responses in such a setting would not only be needed to obtain a more realistic appreciation of credit use and trading patterns, but it would also be needed to evaluate the impacts of credit price on different groups of drivers from an equity perspective. This is relevant, as many of the Beijing respondents, when they could leave a personal remark at the end of the experiment, expressed a concern that higher income drivers would simply buy all of the credits, which would drive up the credit price.

We used multinomial logit (MNL) (Beijing) and binary logit (Netherlands) regression models to estimate the effect of respondent and scenario characteristics on willingness to change. A limitation is that we had to rely on two different types of models to address the type of data that was available for both contexts. In contrast to the Dutch case, we pooled the data for the Beijing case to estimate the unique effect of either facing a shortage or a surplus scenario. Because the Beijing respondents were presented with both scenarios, the Beijing data are structured as repeated observations, which is a limitation because it might violate the assumptions that underlie MNL.

The modelling results showed that in both Beijing and the Netherlands willingness to change car use under TDC is higher for those with higher education and car use intensity, but lower for those with higher income. With regard to scenario effects and car attitudes our results are mixed, which might be partly explained by the differences in scenario design. The inclusion of the car attitudes did not fundamentally change the effects of the socio-demographic characteristics and did not much improve the model results. It could be that attitudes towards the TDC measure itself, attitudes towards car travel alternatives, or a measure of a more concrete car use flexibility in relation to the trips that were reported in the experiment, could have functioned as more important explanatory factors for willingness to change under TDC.

For Beijing, a remarkable observation is that many variables that have a significant effect on willingness to decrease car use also have a same-direction effect on willingness to increase car use. Whereas this indicates that some groups prefer the status quo, it is sometimes difficult to provide reasons why the same groups would show both more car use reduction and intensification behaviours. We provided some initial thoughts on possible explanations; however, this result clearly calls for further research. This future research on TDC responses in China should include a richer set of respondent characteristics, as our data omitted important characteristics such as age, type of work and residential and work location. Further, it should seek to explicitly link behavioural responses to more detailed activity/trip patterns and access to competitive travel modes, as explanations might be found in these domains. A valuable next step would also be to appreciate the type of behavioural change in more detail, considering the size of change in kilometres and choice of travel alternatives.

6 Acceptability of a tradable driving credit scheme in the Netherlands and China*

Abstract – There is increasing interest in the concept of tradable driving credits (TDC) as an alternative road pricing measure. To a considerable extent, this interest is inspired by the belief that TDC will address some major equity-related concerns, which are often raised in the case of traditional road pricing, because the measure is revenue-neutral, offers an opportunity for individuals to gain and guarantees a minimum amount of 'free' travel through the allocation of personal credit allowances. This study investigates the acceptability of a proposed kilometre-based TDC scheme for personal car use. By analysing data from the Netherlands and China (Beijing), opinions towards TDC and its determinants are studied in two different cultural, societal and institutional contexts. Acceptability was much higher in Beijing: 67% compared to 22% in the Netherlands. We relate this difference to higher congestion levels in Beijing and the city's current license plate-based driving restriction policy, compared to which TDC is evaluated to be more effective and fair by a majority of the participants. Having a higher income was positively related with acceptability in both countries, as were expected effectiveness and fairness. The effect of perceived fairness was particularly strong in Beijing.

6.1 Introduction

Considering the high external costs of congestion and pollution posed by the ongoing growth of car mobility, academics studying transport have long been convinced of the power of pricing solutions to internalise these costs and deliver a more efficient use of scarce road space (Pigou, 1920; Vickrey, 1963; Small & Verhoef, 2007). However, the small number of successful implementations following a multitude of road pricing proposals from all over the world to date demonstrates the massive unpopularity of charging for car use from societal and political sides. This trend has led to a recent growth in research that recognises the lack of public acceptance associated with road pricing measures and investigates its causes and variations (Harrington et al., 2001;

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Schade & Schlag, 2003; Jaensirisak et al., 2005; Ubbels & Verhoef, 2006; Gärling & Schuitema, 2007; Gaunt et al., 2007; Schuitema & Steg, 2008). These studies highlight that major contributors to people's opposition of pricing initiatives are the disbelief that road pricing will solve their problems, fear that the measure will treat them or others unfairly, and scepticism regarding the way revenues will benefit them or the transport domain as a whole.

Based on these observations, transport researchers have increasingly shown interest in the concept of tradable driving credits (TDC) as an alternative pricing measure that can potentially address these obstacles (Verhoef et al., 1997a; Viegas, 2001; Raux & Marlot, 2005; for reviews, see Fan & Jiang, 2013; Grant-Muller & Xu, 2014; Dogterom et al., 2017). As is commonly understood, a TDC scheme would allocate individual proportions of car use to drivers based on an aggregate target (formulated in, for example, units of distance or fuel consumption) that can be used and traded according to personal aspirations and prevailing market prices. Theoretically, TDC is effective in reaching a predefined car use reduction goal through cap setting, whereas in the case of conventional road pricing, *a priori* knowledge is needed regarding the precise elasticity figures to arrive at the desired reduction levels. Additionally, the goal can be reached in a cost-efficient way through the market. Furthermore, TDC could address issues of equity related to conventional road pricing by the distribution of free credit allowances to participants, by offering the opportunity to get financial gains out of the scheme, and by providing regulators with a tool to pursue certain distributional outcomes by configuring the initial credit allocation. Finally, TDC is revenue-neutral, leading to money circulating between participants rather than flowing to government funds.

Although TDC can be an appealing concept in theory, its feasibility is ultimately a matter of public opinion. At present, however, despite a rapidly increasing volume of theoretical explorations of TDC, very little attention has been devoted to public attitudes and perceptions of acceptability to potential TDC schemes in an empirical context (but see Kockelman and Kalmanje (2005) and Harwatt et al. (2011) for initial explorations on this theme). Public opinions have been more widely researched in the context of personal carbon trading (PCT), a comparable tradable credit scheme that covers other personal carbon producing sources in addition to car use (Bird et al., 2009; Bristow et al., 2010; Wallace et al., 2010; Andersson et al., 2011). These studies find a common preference for the trading scheme when compared to an equivalent carbon tax. However, these studies are largely UK-based and rely on qualitative interviews or questionnaires that are very general in design and do not present respondents with experiments in which their present behaviour is confronted with hypothetical scenarios, which could influence attitude formation. Moreover, although studies on acceptability in the context of PCT may yield valuable insights into the level and determinants of public acceptability of tradable schemes in general, they are of limited value when it comes to a more direct evaluation of TDC's acceptability relative to other travel demand management measures, which is important from a policy perspective. Finally, current studies are largely confined to the Western context, although interest in the concept of TDC is also coming from other contexts, especially from Asian countries, that might differ in cultural values when it comes to car use and public opinions towards travel demand management measures.

The aim of this paper is to address these shortcomings in the literature regarding public attitudes towards TDC by reporting the results of two studies, conducted in the Netherlands and China (Beijing). In these studies, the perceptions of and attitudes towards TDC were investigated as part of a larger experiment, in which participants had their car use confronted with hypothetical TDC scenarios and could make car use adaptations in response (see Dogterom et al., under review b). An important contribution of this paper is that, because of the nature and scale of the experiments, it is the first study that is able to quantify and analyse TDC's acceptability in relation to a wide variety of relevant mediating factors, such as socio-demographic characteristics, car use dependency, problem perception and expected outcome. A second contribution of this paper is that, by presenting results from a Dutch and Chinese context, it aims to identify whether there are differences in the acceptability of TDC and the factors contributing to it between settings in Europe and Asia. Not only is empirical research in the field of road pricing in China scarce, also the major cultural and institutional differences between both contexts make a comparison highly valuable.

This paper starts with a review of the current literature on the acceptability of road pricing in general and on TDC in particular. The third section discusses the data collection procedure. The fourth section first presents a descriptive analysis of the attitudes, opinions and TDC acceptability and then investigates the effects of attitudes, opinions and socio-demographic characteristics on TDC acceptability by using multivariate regression analysis. The paper ends with a conclusion and a discussion.

6.2 Literature review

This section first summarises the literature on the acceptability of road pricing in general, followed by a review of studies that have addressed acceptably of tradable credit schemes, both in the domain of personal travel and in the more general domain of personal energy consumption.

6.2.1 Acceptability of road pricing

An investigation into the acceptability of urban road pricing in eight European cities found an average acceptability of less than 30% (PRIMA, 2000). Based on a review of several road pricing studies, Jaensirisak et al. (2005) reported an average acceptability of 35% in cases without explicit mentioning of revenue use and of 55% in cases where revenue hypothecation was specified. The acceptability of road pricing[1] is found to vary with a range of factors.

Regarding the design of pricing schemes, the use of revenues is an important factor. Generally, schemes that lead to revenues flowing to general public funds are least acceptable. Re-allocation of revenues within the transport system, for example by investing it in public transport or lowering taxation on fuel consumption and car ownership, could lead to increased acceptability (Schade & Schlag, 2003; Ubbels & Verhoef, 2006; Schuitema & Steg, 2008; Verhoef et al., 1997b).

Studies have also identified the effects of socio-demographic characteristics on the acceptability of road pricing. Income is typically regarded as an important determinant, with acceptability assumed to be higher for higher-income groups because road pricing, in the absence of revenue redistribution, would favour those with a lower marginal utility of money and a higher value of time (Arnott et al., 1994; Evans, 1992). However, whereas Verhoef et al. (1997b) and Golob (2001) could confirm a positive relationship between income and acceptability, Odeck and Bråthen (1997), Rienstra et al., (1999) and Jaensirisak et al. (2005) did not find a significant relationship, and, surprisingly, Harrington et al. (2005) even reported a negative association. Regarding age, Odeck and Bråthen (1997) and Jaensirisak et al. (2005) found that younger people accepted road pricing more readily, whereas Rienstra et al. (1999) found more support among older people. Of the studies that have identified a significant effect for education, Ubbels and Verhoef (2006), Odeck and Bråthen (1997) and Rienstra et al. (1999) reported more support among higher educated people, whereas Harrington et al. (2005) found a negative relationship between education and support. Another relevant factor is intensity of car use, which Gaunt et al. (2007) and Odeck and Bråthen (1997) found to negatively affect acceptability. The location of residence has not often been analysed as a distinctive factor. Rienstra et al. (1999) found lower acceptability levels for people living in villages compared to those living in larger cities and Gaunt et al. (2007), analysing the voting outcome of the Edinburgh road pricing referendum, found greater opposition among people living in the suburbs. Arguably, the effect of place of residence could be related to car use intensity, as those living in less populated areas often experience a higher car dependency.

[1] Here, road pricing refers to different types of charging for the use of public roads, including congestion-based, cordon-based and distance-based pricing.

In summary, studies have demonstrated mixed results regarding the effect of important socio-demographic factors. At the same time, studies that have also incorporated attitudinal factors and subjective perceptions in their analyses widely agree that attitudes have a much greater predictive power than socio-demographic factors in determining acceptability (Schade & Schlag, 2003; Jaensirisak et al., 2005; Gärling et al., 2008). Problem perception, fairness, infringement on freedom, expected effectiveness and expected personal outcome have been identified as important dimensions in the evaluation of road pricing's acceptability. Rienstra et al. (1999), Verhoef et al. (1997b) and Harrington et al. (2005) found that problem awareness has a positive effect on acceptability, although Bartley (1995) concluded that problem awareness is only very loosely related to acceptability and Schade and Schlag (2003) even reported the absence of a significant effect. Rather, it is expected effectiveness, i.e., the conviction that a measure can solve the problem, that seems to have a stronger impact on acceptability (Bamberg & Rölle, 2003; Schade & Schlag, 2003; Rienstra et al., 1999).

Another well-established finding is that the evaluation of a pricing measure as limiting a person's freedom and as being unfair leads to reduced acceptability levels (Bamberg & Rölle, 2003; Jakobsson et al., 2000; Eriksson et al., 2006; Golob, 2001). Bamberg and Rölle (2003) showed that these two concepts are related: the more the measure is perceived as an infringement on freedom, the less fair the measure is assessed. Fairness is not only a concept that is confined to the individual outcome, but evidently also relates to evaluations of equity, which refers to the distribution of costs and benefits of the measure on the aggregate level, which links to the concept of justice (Ittner et al., 2003).

Of course, socio-demographic characteristics might exert an effect through attitudes. Jakobsson et al. (2000) found that income had an indirect negative effect on the acceptability of road pricing through perceived fairness and infringement on freedom. In addition, Schade and Schlag (2003) concluded that higher-income groups were more likely to expect benefits from road pricing and therefore might support the measure through perceived outcome.

6.2.2 Acceptability of tradable credit schemes

Kockelman and Kalmanje (2005) proposed a credit-based congestion pricing scheme, in which drivers would receive a monthly free allowance of travel credits and would pay only when they exceeded their allowance, and investigated its potential compared to a regular congestion pricing scheme. They asked respondents in Austin (TX, US) for their responses to and support for the measure. The authors found that 24.9% of the respondents clearly supported the measure, which was considered a substantial figure given the respondents' unfamiliarity with the measure, and concluded the measure to be a viable and competitive alternative. Harwatt et al. (2011) interviewed 60 persons in the UK about their reactions to and opinions of a personal car use-oriented tradable carbon permit scheme and an equivalent fuel price increase. They found that the trading scheme scored significantly higher than road pricing on personal and social acceptability as well as on fairness, expected effectiveness and the evaluated balance of costs and benefits. The interviews highlighted that the respondents believed that the trading scheme was fairer than road pricing, which led to the more positive attitude towards the trading scheme. Also, they believed that only the trading scheme was able to lower aggregate car use because of the limited availability of credits, which was an important contributing factor in their evaluation.

Other studies on the acceptability of personal trading schemes have been carried out in the context of schemes that cover all other personal/household energy usage and not only personal car use. Wallace et al. (2010), Bristow et al. (2010) and von Knobelsdorff (2008) found remarkably similar support levels, with 42%, 43% and 44% of the respondents, respectively, supporting a personal carbon trading scheme in the UK, and also reported an overall preference for the trading scheme in comparison with a carbon tax. In contrast, in a Swedish context, Andersson et al. (2011) found that 36% of the respondents supported a personal carbon trading scheme, significantly lower than the support for increasing carbon taxes, although it should be noted that a carbon tax had already been introduced in Sweden and could have had a negative effect on the support for an additional, different type of scheme. Their study showed perceived fairness to be a main determinant of support. However, they also controlled for the perceived complexity of the trading scheme and found this variable to have a larger impact on the scheme's acceptability, with lower support for higher perceived complexity. In contrast to the above-mentioned studies that evaluated attitudes to a fixed tradable scheme design, Bristow et al. (2010) investigated the impact of design aspects on the acceptability of both a personal carbon trading scheme and a carbon tax. Although no unique preference could be attributed to the trading scheme over the tax, their results indicate that the actual design has a critical influence on acceptability, with higher support ratings for the trading scheme based on credit allocation strategies that were regarded as being fairer.

Because TDC essentially is a pricing measure, that despite its unique distributional characteristics, still might be perceived as a measure meant to ration and price the otherwise (to some extent) free road access, we assume the factors and their effects identified in the road pricing literature as important determinants of acceptability to be largely the same in a TDC context. At the same time, we expect TDC to be evaluated more positively relative to conventional road pricing on expected effectiveness and fairness. Because of the strict cap on aggregate car use as a distinctive feature, and supported by the initial conclusions of the qualitative study of Harwatt et al. (2011), we expect people to have a stronger believe in TDC's ability to reduce car use relative to alternative measures. We also hypothesise that TDC will be evaluated more positively on fairness, because of the free distribution of free credit allowances, the ability to make money out of the scheme, and the placing of additional costs solely on above-allowance drivers. At the same time, there could still be a positive association between income and TDC acceptability because a TDC scheme, using an equal per-capita credit allocation, can still be expected to be regressive beyond the allowance, because it is not necessarily lower-income drivers that have the lowest car use intensities, and because higher-income drivers may have a higher willingness to pay for additional credits. Also, several studies found lower-income groups to be less able to change their car use in response to pricing measures (Washbrook et al., 2006; Clay & Mokhtarian, 2004), which can potentially reinforce a possible resistance to accepting TDC. Finally, we expect TDC to be more acceptable in Beijing than in the Netherlands given the higher levels of congestion and car-based pollution and the relative unpopularity of the present license plate-based driving restrictions in Beijing.

6.3 Data collection

6.3.1 Experiments

Data on attitudes towards the TDC measure were collected through a questionnaire that was included in a larger experiment on behavioural responses towards the measure. The online experiments conducted in the Netherlands and Beijing varied in design, procedure and participants to some extent. However, the same hypothetical TDC scheme was presented to the participants and the same questionnaire on TDC attitudes was used, apart from some minor modifications in the Chinese version, providing common ground necessary for comparison.

In both experiments, participants were first asked to report the car trips they made during the 7 previous days and to estimate the number of kilometres they drove during these days. Next, a distance-based TDC scheme, in which one credit was set to represent one kilometre of car driving, was introduced. Then, participants were presented with a series of scenarios in which they were given a certain number of free credits to use in the recorded week and in which they could state whether and how they would make changes to their trips in retrospect. In the Dutch experiment, the levels of credit availability and shortage were defined as a percentage of the reported car kilometres travelled. These levels and a value per credit (0.10, 0.15 or 0.20 Euro) were randomly assigned to the participants. Participants were asked to indicate the percentage of change in number of kilometres for the different activity categories if they wanted to change their car use in response to the scenario.

In Beijing, every participant was presented with the same scenarios, in which the credit surplus and shortage levels were set at a fixed amount for everyone, irrespective of the number of kilometres driven. One of three different credit values (0.5, 0.8 or 1.0 Yuan) were randomly assigned to the participants. Both experiments thus used multiple scenarios with different credit surplus and shortage levels. Consequently, participants could not easily detect from the experiment how such a scheme would possibly affect their personal situation on the basis of their car use intensity relative to that of others.

6.3.2 Sample and context

In both contexts, car owners were recruited to participate in the experiment. Data collection took place in June (Netherlands) and July (Beijing) 2016. For details about the recruitment procedures and sample compositions the reader is referred to Dogterom et al. (under review b).

There are important geographical, cultural and institutional differences between the Netherlands and Beijing that must be considered when interpreting the findings. First, the sample in the Netherlands covers the nation as a whole, whereas the Chinese data collection is limited to the city of Beijing only. In a city context, exposure to travel-related problems might be more severe, while at the same time, car use alternatives are generally more abundantly available. Especially in Beijing, problems of congestion and pollution caused by car travel manifest themselves at a massive scale. Second, the socio-cultural position of the car is a context-specific factor, with car ownership and use having a much stronger appeal as a status symbol in China than in the Netherlands, especially among the rapidly growing wealthy and self-conscious Chinese urban middle class (Williams & Arkaraprasertkul, 2016; Yang et al., 2014; Belgiawan et al., 2014). Third, both contexts have their own unique historical trajectories with regard to car use management policy. Plans for a nationwide kilometre-based road pricing scheme were proposed and heavily debated in the Netherlands in the 90s, but were rejected because of very limited social and political support (Ardıç et al., 2013; Smaal, 2012). In Beijing, citizens have faced some rigorous and very restricting measures in recent years that aimed to curb congestion, such as the lottery for the issuing of new license plates and the license plate-based one-day-a-week non-driving restriction (Xu et al., 2015; Yang et al., 2014; L. Wang et al., 2014.). These settings form a relevant backdrop for interpreting TDC attitudes.

6.3.3 Questionnaire

Table 6.1 lists the items that measured the participants' attitudes towards the TDC measure and their car use. All attitudes were measured with a 7-point scale. Following

Table 6.1: Measured attitudes and operationalisation

Attitudes
Problem perception congestion (societal)
To what extent do you think congestion in general is a problem in [the Netherlands/Beijing]? [a]
Problem perception congestion (personal)
To what extent do you experience congestion as a problem in your personal car use? [a]
Problem perception environment
To what extent do you think that car use in general is a problem for the environment? [a]
Expected effectiveness congestion
Do you think that the implementation of Tradable Driving Credits would reduce congestion? [b]
Expected effectiveness environment
Do you think that the implementation of Tradable Driving Credits would reduce the impact of car use on the environment? [b]
Personal outcome
Netherlands – Do you think that in general you would be better or worse off if a Tradable Driving Credits scheme were implemented? [c]
Beijing – Do you think in general you will be worse off if a Tradable Driving Credits scheme were implemented? [b]
Instrumental car attachment
Netherlands – I do not have any alternatives for my car use [d]
Beijing – How easy could you in general choose other transport modes than the car? [e]
Symbolic car attachment
Netherlands – My car gives me status and prestige [d]
Beijing – Does the car provide you with status and prestige? [d]
Affective car attachment
Netherlands – Driving gives me pleasure [d]
Beijing – Does driving give you pleasure? [d]
Infringement on freedom
Netherlands – I view Tradable Driving Credits as an infringement on my personal mobility freedom [d]
Beijing – Do you perceive Tradable Driving Credits as an infringement on your personal mobility freedom? [d]
Unfairness
Netherlands – I view Tradable Driving Credits as unfair [d]
Beijing – Do you think Tradable Driving Credits is fair? [d]
Relative effectiveness
Netherlands – Compared to a “per-kilometre charge”, i.e., a scheme in which everybody pays a fee for each kilometre, I think Tradable Driving Credits is a better way to deal with congestion [d]
Beijing – Do you think Tradable Driving Credits can perform better in reducing congestion than the license plate-based driving restriction policy? [b]
Relative fairness
Netherlands – Compared to a “per kilometre charge”, I think Tradable Driving Credits is fairer [d]
Beijing – Do you think Tradable Driving Credits is fairer than the license plate-based driving restriction policy? [b]
Acceptability
Netherlands – How acceptable is Tradable Driving Credits overall to you? [f]
Beijing – In general, do you think Tradable Driving Credits is acceptable to you? [d]

[a] 1 = not a problem at all; 7 = very severe problem
[b] 1 = very unlikely; 7 = very likely
[c] 1 = much worse; 7 = much better
[d] 1 = fully disagree; 7 = fully agree
[e] 1 = very hard; 7 = very easy
[f] 1= highly unacceptable; 7 = highly acceptable

Schade and Schlag (2003), regarding problem perception, a distinction was made between perceived travel problems related to congestion and environmental impact. This was also relevant because we framed the TDC measure from the perspective of congestion in the introduction of the experiment. With regard to congestion, a further distinction was made between congestion as a personal and a social problem, because people might perceive congestion as a harmful phenomenon for society, without being personally affected by it (cf., Rienstra et al., 1999).

In contrast with most of the studies on the acceptability of road pricing, the questionnaire included the concept of car attachment, measured in three dimensions: instrumental, affective and symbolic (Steg, 2005). We did so because positive car attitude is found to be negatively associated with the acceptance of road pricing (Steg, 2003), and because we expected meaningful differences between the two samples in the domain of car attachment. As already indicated, we expect important differences between symbolic car attachment between the Dutch and Chinese samples because of the car's strong role as a status symbol in a Chinese context (e.g., as a means to display wealth and financial reliability).

At the end of the questionnaire, two questions were formulated to inquire about participants' evaluation of the TDC measure compared to the recently debated per-kilometre fee (Netherlands) or the implemented license plate-based driving restrictions (Beijing) to address the relative attractiveness of TDC. The relative attractiveness was measured in terms of expected effectiveness and fairness, as the two issues have been identified as the most important objections to these respective policies.

Note that the translation process resulted in a somewhat different formulation of questions/statements between the Netherlands and Beijing. Whereas in the Netherlands most questions were formulated using the statement format, the Beijing questionnaire relied solely on the question format. Further, note that the items personal outcome, instrumental car attachment and fairness used opposite measurements. Although we acknowledge that this is not an ideal situation, we reversed the scores for Beijing on these items for the purposes of analysis.

6.4 Results

6.4.1 Descriptive results

The means and standard deviations for the measured items are presented in Table 6.2, as well as the results of the t-tests on the means. The results show that there are major statistical differences between the two samples on multiple items. First, car owners from Beijing report a considerable higher problem awareness, both in terms of congestion and car-related pollution, which is not surprising given the scale and intensity

Table 6.2: Means and standard deviations of the measured attitudes

	Netherlands		Beijing		t-test[a]
	M	S.D.	M	S.D.	
Problem perception congestion (societal)	4.98	1.27	6.00	1.24	-13.46**
Problem perception congestion (personal)	3.27	1.53	5.55	1.29	-26.37**
Problem perception environmental	4.17	1.43	5.59	1.44	-16.33**
Expected effectiveness congestion	3.38	1.52	4.55	1.76	-11.98**
Expected effectiveness environment	3.44	1.47	4.58	1.75	-11.89**
Personal outcome	3.60	1.45	3.51	1.76	0.92
Instrumental car attachment	4.22	1.85	3.69	1.73	4.85**
Symbolic car attachment	2.58	1.50	4.10	1.67	-16.00**
Affective car attachment	4.63	1.55	4.65	1.53	-0.21
Infringement freedom	4.64	1.70	4.44	1.78	1.88
Unfairness	4.26	1.64	3.17	1.62	11.06**
Relative effectiveness	3.75	1.41	4.64	1.80	-9.27**
Relative fairness	3.84	1.42	4.82	1.76	-10.36**
Acceptability	3.46	1.51	4.85	1.67	-14.68**

[a] Welch's test for unequal variances

** $p < 0.05$

of these problems in Beijing. At the same time, likely influenced by problem awareness, they report a higher perceived ability for TDC to effectively curb congestion and car-related pollution than car owners in the Netherlands. Regarding the Dutch sample, one remarkable observation is that the mean score for perceiving congestion as a societal problem is substantially higher than the mean score for viewing congestion as a personal problem, whereas this gap is smaller in Beijing.

Beijing car owners report a lower instrumental dependence on car use but a higher symbolic value of car use than car owners in the Netherlands. This is in line with our expectations based on the reasons outlined in the previous section: better access to alternative modes of transport and the framing of the car as status symbol in Beijing. There are no statistical differences between the samples on infringement on mobility freedom. However, there is a difference with regard to unfairness, with the Beijing participants believing the measure is fairer on average than those in the Netherlands. As the literature on road pricing indicates that infringement on freedom is usually closely related to perceptions of fairness, the differences between the mean values of both items for Beijing are rather remarkable. However, in contrast to infringement on freedom, an evaluation of perceived unfairness could transcend the personal domain and include equity aspects related to the larger community. Therefore, Beijing car

Table 6.3: Shares of participants with different scores on the attitudes relative effectiveness, relative fairness and acceptability (in %)

		Netherlands			Beijing		
Value		Relative effective-ness	Relative fairness	Accepta-bility	Relative effective-ness	Relative fairness	Accepta-bility
Low	1	10.4	10.2	15.7	10.5	9.9	6.8
	2	8.7	6.4	11.7	5.0	3.3	5.5
	3	12.7	13.1	15.0	8.0	6.5	5.6
	4	42.6	43.2	36.0	14.6	13.2	15.2
	5	17.4	17.0	15.0	22.9	23.5	26.2
	6	5.5	7.2	3.8	26.8	29.9	26.2
High	7	2.8	3.0	2.8	12.3	13.8	14.6
Low	1-3	31.8	29.7	42.4	23.5	19.7	17.9
	4	42.6	43.2	36.0	14.6	13.2	15.2
High	5-7	25.6	27.1	21.6	62.0	67.1	67.0

owners, although perceiving the measure as restricting their own mobility, could still believe the measure is just considering the wider distribution of costs and benefits for the city and the entire group of car drivers, to which the more collectivistic-oriented culture of China might contribute (Zhao et al., 2015; Sun et al., 2004). Also, Beijing participants' experiences with existing travel demand management measures, which are widely viewed as unfair, could contribute to a lower score on perceived unfairness, which a related item considers in more detail.

Beijing car owners indicate a higher expected effectiveness and fairness of TDC relative to the alternative measure taken as a reference. However, a comparison between the Netherlands and Beijing is less meaningful here because of the very different, context-specific alternative measures that TDC is compared with. Still, the evaluation of expected effectiveness and fairness of TDC relative to the kilometre-based road pricing and the license plate-based driving restriction as proposed/implemented in the Netherlands and Beijing, respectively is highly relevant in their own case. Therefore, Table 6.3 provides additional details on these items. Approximately 25% of the Dutch car owners believe TDC is more effective and fairer than kilometre pricing and more than 40% of the respondents have a neutral stance. In Beijing, 62% of the respondents think TDC is more effective than the license plate-based driving restriction, and more than two-thirds believe the measure to be fairer. This indicates a high level of dissatisfaction with the current car travel policy in Beijing and suggests that TDC can possibly be a viable alternative when it comes to public support. This is further supported by a similar acceptance rate (67%) for TDC for Beijing. In the Netherlands, the acceptance level of TDC is much lower, with only 21.6% of the participants believing the measure is acceptable, while about twice as many think the measure is unacceptable. This might be caused by a lower perception of congestion as an urgent problem and a lower level of acceptance of government intervention in their personal car use in a culture where the influence of the government in people's daily life is limited compared to the Chinese context. However, again, a relatively large proportion, 36% of the respondents, take a neutral stance, suggesting there might be room for acceptance levels to increase with scheme adjustments or by providing more information.

6.4.2 Multivariate analysis of TDC acceptability

6.4.2.1 Approach

In the following section, regression models will be presented to investigate the factors contributing to the acceptance of TDC. These factors include the attitude items as discussed above as well as the socio-demographic characteristics of the participants.

It should be noted that in our aim to identify factors that contribute to the acceptance of TDC we present our results as two different case studies rather than as a direct comparison of the Dutch and Beijing cases. This is not only because some attitudes have not been measured equally in both contexts, but also because of the presence of some dissimilarities regarding data on the socio-demographic characteristics of the two samples. For example, while the Dutch dataset includes information about participants' relational status and the presence of children in the household, in the Beijing dataset only information about the number of people in the household is available. Further, relevant information on the age and residential context of the participants is only available in the Dutch dataset. Additionally, one should bear in mind that the income categories are not fully comparable. First, an appropriate reference income level, such as average income, is difficult to define in the Beijing context where car owners have categorically higher incomes than the average income for all Beijing inhabitants. Secondly, the income categories used in both experiments (number of categories and number of participants in the respective categories) differed considerably. Therefore, the three income categories in the respective models have been defined based on the availability of the data and are not directly comparable between the samples.

Ordinary least squares (OLS) regression models were estimated with the level of acceptability as the dependent variable. For both samples, two models were estimated: one to test the effects of socio-demographic characteristics only, and one to test the combined effects of socio-demographic characteristics and attitudes. In each of the models, the maximum variance inflation factor did not have a value higher than 5, indicating the absence of multi-collinearity among the variables and suggesting OLS was an acceptable approach to estimate the coefficients. The regression on the Beijing data failed the Breusch-Pagan test, implying the presence of heteroscedasticity. Therefore, a regression with robust standard errors was performed for the Beijing case.

6.4.2.2 Results

Tables 6.4 and 6.5 present the estimation results for the Dutch and Beijing case, respectively. Consistent with previous research (Schade & Schlag, 2003; Jaensirisak et al., 2005; Gärling et al., 2008), the impact of socio-demographic characteristics on the level of acceptability is very limited, as demonstrated by the low fit of the models with the socio-demographic characteristics only.

For both the Dutch and Beijing sample, the results of Model 1 reveal an income effect. In the Netherlands, those in the highest income category view TDC more acceptable than those in the lowest income category. In Beijing, both the middle and higher income groups consider TDC more acceptable, with the strongest effect for the middle-income group, as shown by its larger coefficient. This income effect casts doubt on the assertion that TDC could lead to more equal rates of support among different income groups because elements of the scheme would be more beneficial to lower-income groups than conventional road pricing. This assertion is often linked to the distribution of free credits and the belief that lower-income groups generally drive fewer kilometres and thus would be better able to sell excess credits.

Whereas the income effect is the only socio-demographic effect in the Dutch model, in Beijing, acceptability is also influenced by household size, as those living in household with more than two persons find TDC significantly more acceptable. It is possible that these households are more car-reliant and are more severely affected by congestion and the license plate-based driving restriction measure, especially if younger children are present, may make them more prone to evaluate TDC positively.

Clearly, the attitudes are better predictors of acceptability, as the total explained variance by the model increases to 68% and 69.1% in the full models for the Dutch and Beijing samples, respectively. Most of the socio-demographic effects disappear, only a marginally significant income effect remains in the Dutch full model, showing that socio-demographic effects are largely mediated through the attitudes. Our results show that for both samples, problem perception has no significant effect on acceptability, but that expected effectiveness does have an effect, although there is only a marginally significant effect for the Dutch sample. The effects in this study are not different from what has been found in the literature on conventional road pricing, It is rather the belief that the measure could help solve the problem rather than the perception of the problem itself that explains acceptability of the measure (Schade & Schlag, 2003; Bamberg & Rölle, 2003). Further, as expected, perceived unfairness, another important predictor of acceptability found in the literature (Jakobsson et al., 2000; Fujii et al., 2004; Eriksson et al., 2006), impacts acceptability. The effect of perceived unfairness is particularly strong for the Beijing sample, as revealed by the size of the coefficients, which might be explained by concerns that TDC will favour richer car drivers in the city, which faces extreme competition for road access and has large income differences. In the Beijing experiment, participants were given the opportunity to leave a personal remark and a considerable share of them expressed concerns about wealthier drivers simply buying all the credits needed to satisfy their car travel aspirations under TDC, hence driving up credit prices.

The importance of expected effectiveness and fairness as predictors of acceptability is further evidenced by the significant effects of these items when they are measured as a relative evaluation of TDC compared to kilometre-pricing/license plate-based driving restriction. Here, however, the effect of relative effectiveness and fairness on acceptability is larger in the Netherlands than in Beijing, as indicated by the larger coefficients. The effect of relative fairness in Beijing is only significant at the 0.1 alpha level. This might be due to the higher correlation between perceived unfairness and perceived relative fairness in Beijing as compared to the Netherlands (-0.59 and -0.29, respectively). The large effect size for perceived unfairness implies that in Beijing, TDC acceptability is largely affected by the more fundamental evaluation of how fair the expected distribution of benefits and costs under TDC is for participants themselves and others, rather than by a relative evaluation of the measure compared to the existing license plate-based driving restriction, which is subject of a common disapproval, as shown in the previous subsection. In contrast, in the Netherlands, where participants had a more neutral stance towards the expected performance of TDC compared to a hypothetical per-kilometre road pricing measure, the expected relative effectiveness and fairness appeared to be more important as determinants of TDC acceptability.

Infringement on freedom does not influence acceptability for either sample. As found in the literature, this could be because infringement on freedom is closely related to fairness and personal outcome. A striking difference between the Dutch and Beijing case is the presence of an effect of personal outcome in the Netherlands, whereas such effect is absent in Beijing. Potentially, Dutch participants view personal outcome more as an evaluation of expected personal financial benefit or loss, making the item a clearly distinct category relative to the other items, whereas Beijingers might evaluate personal outcome more in relation to other items such as fairness and freedom of mobility. Contextual factors can also play a role here, with Beijingers, living in

Table 6.4: Estimation results for TDC acceptability for the Netherlands (OLS regression model)

	Model 1		Model 2	
	Beta	**Sig.**	**Beta**	**Sig.**
Constant	3.497	0.000	0.900	0.006
Socio-demographic characteristics				
Male	-0.096	0.502	0.040	0.632
Age 30-45	-0.207	0.344	-0.050	0.700
Age >45	-0.302	0.141	-0.110	0.377
Single	0.108	0.550	0.009	0.929
Children in household	0.122	0.460	0.024	0.809
Higher education (university and higher professional)	-0.126	0.420	-0.052	0.575
Disposable monthly household income €2000-3500	0.226	0.240	0.054	0.638
Disposable monthly household income >€3500	0.616	0.011	0.279	0.054
No income stated	-0.015	0.946	0.145	0.262
More than 1 car in household	-0.088	0.590	-0.022	0.822
Residence in non-urban municipality	-0.001	0.996	0.113	0.206
Attitudes				
Problem perception congestion (general)			-0.019	0.615
Problem perception congestion (personal)			0.017	0.582
Problem perception environmental			0.014	0.707
Expected effectiveness congestion			0.086	0.056
Expected effectiveness environment			0.015	0.743
Personal outcome			0.171	0.000
Instrumental car attachment			0.005	0.843
Symbolic car attachment			0.052	0.109
Affective car attachment			0.019	0.520
Infringement freedom			-0.059	0.108
Unfairness			-0.176	0.000
Relative effectiveness			0.224	0.000
Relative fairness			0.375	0.000
R^2		0.023		0.680

Table 6.5: Estimation results for TDC acceptability for Beijing (OLS regression model)

	Model 1		Model 2	
	Beta	**Sig.**	**Beta**	**Sig.**
Constant	4.103	0.000	5.201	0.000
Socio-demographic characteristics				
Male	-0.089	0.495	-0.013	0.863
Disposable monthly household income ¥4000-6000	0.693	0.009	-0.112	0.478
Disposable monthly household income >¥6000	0.545	0.039	-0.057	0.708
University degree	-0.048	0.741	-0.111	0.193
More than 2 persons in household	0.378	0.026	0.058	0.547
More than 1 car in household	-0.379	0.174	-0.093	0.541
Attitudes				
Problem perception congestion (general)			0.011	0.791
Problem perception congestion (personal)			0.033	0.497
Problem perception environmental			-0.030	0.483
Expected effectiveness congestion			0.120	0.014
Expected effectiveness environment			0.031	0.512
Personal outcome			0.006	0.887
Instrumental car attachment			-0.007	0.750
Symbolic car attachment			0.031	0.393
Affective car attachment			0.001	0.973
Infringement freedom			-0.057	0.209
Unfairness			-0.586	0.000
Relative effectiveness			0.117	0.025
Relative fairness			0.093	0.094
R^2		0.023		0.691

a very congested and economically unequal city and in a country with a more collectivistic orientation, possibly attaching more importance to evaluations of TDC in relation to broader themes of congestion and equity than to evaluations based on a purely individually-oriented monetary cost-benefit analysis when it comes to accepting TDC.

6.5 Conclusion and discussion

Road pricing is a theoretically attractive mechanism to solve urgent congestion problems. However, the widespread lack of public acceptability is a major obstacle for its implementation. The tradable driving credits (TDC) measure presents an innovative concept that seeks to address some key aspects of this lack of social support: it would guarantee a certain minimum level of car use without additional credit costs to drivers, offer the opportunity to financially gain from the system by selling credits, ensure effectiveness through a fixed cap on total car travel, and present a revenue-neutral pricing system. In this paper, we investigated the levels of TDC acceptability and its evaluation in reference to alternative travel demand management (TDM) measures, and analysed the factors that affect TDC acceptability. By analysing data from the Netherlands and from Beijing, we presented two case studies that illuminate opinions concerning TDC and its determinants from both a European and an Asian context.

In the Netherlands, 21.6% of the car owners view TDC as acceptable to various degrees, and slightly more than 25% of the respondents think that TDC is more effective in reducing congestion and is fairer than a conventional road pricing scenario with a per-kilometre price. This level of acceptability is lower than the acceptability rates of about 30-35% that other (urban) road pricing proposals have gained according to the literature. Also, it is lower than other studies on tradable credit-based policies have found in other Western European countries, but as these studies discuss (carbon-trading) policies with a rather different scope and scale, a comparison with these acceptability rates can only be made with caution. However, the acceptability rate is comparable with the support level that Kockleman and Kalmanje (2005) found in the US in the context of a more similar credit-based congestion pricing policy (24.9%). They concluded that the measure is a promising alternative to conventional road pricing given the little knowledge their respondents had about the measure. They argued that making people more familiar with the measure through information and experience might lead to increased support levels. The same might apply in interpreting our results. Additionally, as 35% of the Dutch participants have a neutral opinion, and thus are not clearly opposed to the measure, it can be concluded that there is certainly potential for TDC, especially since in the Netherlands congestion is steadily rising again in a period of renewed economic growth, which is accompanied by an increasing recognition that price-based TDM measures seems to be unavoidable in the future.

As for Beijing, a much higher share of 67% of the participants view the TDC measure as acceptable. Reasons for this high level of support are likely to be found in the city's massive problems of congestion and car-related pollution, and widespread dissatisfaction with the current driving restrictions. More than 60% of the respondents believe that TDC is more effective and fairer than the current license plate-based driving restriction, which was taken as a reference TDM measure. Academic studies have criticised these license plate-based driving restriction measures in Chinese cities repeatedly by empirically demonstrating its evident negative side effects and by theoretically showing its inability to deliver an efficient and sustainable solution in the long term, and have suggested a tradable credit approach to deal with the urgent car traffic problem as a better alternative (e.g., L. Wang et al., 2014; Nie, 2016; 2017). In addition to these studies, this present research shows that from a social acceptability perspective, TDC is certainly worth considering further in the context of cities such as Beijing.

Regression analysis revealed that in both the Netherlands and Beijing, people with higher incomes find TDC more acceptable, and that people living in larger households do so in Beijing only. These effects correlate with attitudes because the socio-demographic effects largely disappear when other attitudes towards TDC are included. Attitudes of expected effectiveness to reduce congestion and perceived fairness, which have been identified in the literature as the most important factors in explaining acceptability of road pricing, also dominate as predictors of TDC acceptability. In the Netherlands, people who report that they expect a better personal outcome under TDC and have a higher symbolic car attachment, which seems to correlate with income, rate TDC as more acceptable.

The income effect that has been found is interesting because in the wider road pricing literature some studies find a similar income effect whereas others do not. It is also interesting because TDC is often framed as an alternative that is potentially less harmful to lower-income households compared to conventional road pricing, which is often regressive in nature. Yet, the alternative concept of TDC does not lead to lower-income groups viewing the measure equally as acceptable as higher-income groups. Lower-income groups might be more worried about the 'marketisation' of road access and might expect that higher-income groups' higher willingness to pay to maintain their travel will drive up credit prices to levels that make buying additional credits less affordable to them. This might especially be the case in a highly competitive context like Beijing. A considerable share of the Beijing participants' personal remarks hinted at the presence of such worries. Also, perceived fairness appeared a stronger determinant of TDC acceptability in Beijing than in the Netherlands.

Due to the lack of space – the questionnaire on attitudes was part of a larger experiment – some determinants of TDC acceptability need more detailed investigation to come to a better understanding of their precise role in TDC acceptability and meaning in their own unique socio-cultural context. For example, personal outcome could be defined in terms of accessibility improvement or merely by financial gain/loss, and fairness could be approached more specifically from a consumer and a citizen perspective (Eliasson, 2016; see also Levinson (2010) for different dimensions of equity). Psychological factors such as social norms and trust in government, that have not been covered in this research, have also been identified as important influencing factors of road pricing acceptability (Schade & Schlag, 2003; Eriksson et al., 2006; Kim et al., 2013), and should be addressed in future (cross-cultural) TDC research.

Further, as Bristow et al. (2010) showed in the context of personal carbon trading, acceptability of tradable credit-based policies greatly depends on the features of the scheme. Much differentiation is possible in terms of credit allocation (e.g., definition of eligible credit receivers, differentiation according to needs), credit price and trading (e.g., introduction of maximum price, setup of the market), and credit usage (e.g., only during congestion, attached to fuel instead of distance). It is likely that TDC acceptability levels will vary substantially under different TDC designs and can potentially increase after some design fine-tuning. Future research is needed to determine possible design effects: qualitative research that is able to identify critical design features and to clarify the particular social strengths and weaknesses of TDC in relation to other TDM measures, as well as quantitative research that is able to systematically test design effects and to assess what would constitute an optimal TDC scheme when it comes to social support.

7 Conclusion and discussion

Road pricing has been a much-researched topic in the academic transport community. This finds its basis in the intriguing relationship between the efficiency and acceptability of road pricing measures, with the most efficient pricing measures often being the least popular (Verhoef et al., 1997a). Road pricing has also rapidly gained (again) a central position in public debate recently, at least in the Netherlands, where this thesis was written. Here, the negative effects of congestion and accompanying public frustration are becoming increasingly manifest in a time of renewed economic growth. The growth of car use has quickly outstripped the provision of new road space, opening up new room for pricing-based measures as a potentially more effective alternative for combating congestion and other car-related problems.

This thesis has looked into the potential of tradable driving credits (TDC) as an alternative road pricing measure. The concept of TDC has received increasing academic attention in recent years, and many proponents have claimed benefits of the measure over conventional road pricing in terms of effectiveness, acceptability and social involvement. Although the measure might be theoretically attractive, its effects are still empirically under-researched. Therefore, the aim of this thesis was to explore the behavioural effects of and attitudes towards TDC in an empirical setting. The results of this exploration will be discussed in this chapter, as well as some theoretical, methodological and policy reflections.

7.1 Findings of the study

Specifically, the research question is the following:

What behavioural changes and attitudes towards the measure can be expected under TDC?

The research that was carried out to address this research question dealt with four themes, each revolving around a different research sub-question.

7.1.1 Current insights

After the introduction of the TDC concept in Chapter 1, Chapter 2 provided a systematic literature review of existing TDC research based on the following research question:

1. *What are the current insights into possible behavioural effects related to TDC?*

Three features of TDC make the policy clearly distinct from conventional road pricing. Under TDC, drivers would face 1) the opportunity to realise both gains and losses, 2) the presence of a budget with credits that needs to be managed, and 3) the trading mechanism, presenting challenges in terms of decision-making over time and under uncertainty. Current empirical studies on tradable credit schemes, either focusing on personal car use alone or defined as a broader personal carbon trading scheme, have generally looked into these schemes' effects on the willingness to change and the magnitude of change as compared with the effects of a conventional taxing scheme. They commonly find that tradable credit schemes can achieve levels of behavioural change that are comparable to or beyond levels under a conventional tax policy with equivalent prices. Most studies thus far have taken a very general and static approach, and have made little effort to test particular effects that can be related to the three TDC dimensions mentioned. Nevertheless, there is some initial evidence that the desire to avoid a loss under a credit shortage is more powerful in realising behaviour change than the desire to increase a gain in a credit surplus situation. Further, some results indicate that a declining credit budget over time tends to lead to an intensification of credit-saving behaviour, independent of financial signals, suggesting some budgeting effects. However, these effects have been tested in only a very limited number of studies, that, at the same time, do not specifically focus on the personal car travel context as an exclusive research setting. Further, additional research is needed in order to understand decision-making processes of credit allocation and trading patterns in a dynamic TDC market environment, which has been largely lacking until now.

Insights from the fields of behavioural economics and cognitive psychology are highly relevant in understanding decision-making processes in relation to the three central TDC features identified. For example, studies from these fields have addressed budgeting behaviour and the concept of mental accounting, on the basis of which one can expect credits not to be perfectly interchangeable with money but to function as a separate resource devoted to car travel that can stimulate credit conservation in cases of credit shortage or instead stimulate driving when people want to fully deplete their credits they may have framed as a 'right to drive'. Further, these fields have much to say about decision-making under uncertainty and over time, showing, for example, how different time horizons affect the propensity of credit spending over time and how risk and complexity aversion in the trading environment often lead to people acting less rational. Current empirical TDC research only occasionally hints at such decision-making mechanisms at work under TDC, however, future research should more thoroughly attend to these mechanisms and their behavioural consequences in order to more realistically appreciate the effects of the features that make TDC radically different from other road pricing initiatives.

Another gap in the current empirical literature on TDC effects is related to the methodologies used. By using hypothetical base situations or by measuring change at an aggregate level (e.g., in amount of kilometres travelled or trips per year), most current studies do not present participants with decision contexts in which they can state behavioural change in the context of their actual and concrete travel patterns. As such, the estimation of TDC effects will be biased, because it is not based on realistic simulation experiments that seek to relate credit allocation to everyday car use as dependent on drivers' need for activity participation, as embedded in social, spatial and temporal constraints, and as structured by the availability of travel alternatives. Therefore, an activity-based approach (Axhausen & Gärling, 1992; Timmermans et al., 2002) to understanding TDC decision-making is needed to come to a more realistic appreciation of the effects of TDC policy on travel behaviour.

7.1.2 Behavioural change

One of the main aims of this research was to address this lack of activity-based research in investigating individuals' allocation of credits over their activity/travel patterns under TDC. To fill this gap, the following research question was formulated:

2. *To what extent are car drivers' willingness to change behaviour and size of change under TDC affected by credit availability, credit price, socio-demographic characteristics, residential characteristics and car dependency?*

Chapter 3 demonstrated that a TDC scheme with a kilometre cap can mobilise a significant change in car use. Two-thirds of the participants reported one or more occasions of change in their car use in a TDC scenario. Reduction levels in total number of kilometres collectively driven by the sample were 20.2% and 24.1% when the amount of free credits available for the sample represented a 17.5% and 32.2% reduction goal in kilometres travelled in two successive scenarios, respectively. As expected, in the case of TDC, avoiding a loss (a case of credit shortage) proved a stronger motivation for behavioural change than the desire to increase a gain (a case of credit surplus). Further, the size of the (dis)incentive matters, with people facing a larger loss being more prepared to change car use and people having a larger credit surplus being less prepared to do so. At the same time, we expected that people facing a higher price per credit would be more willing to change behaviour. However, no systematic differences between the distinguished price levels could be found, a finding that is corroborated by results from the Dutch version of experiment II, reported in Chapter 5.

Important socio-demographic characteristics that affected behavioural change under TDC are age, household size and gender. Explanations of these effects can be found in the activity-trip pattern of these categories of respondents, of which we, in contrast to many pricing studies, have detailed information, which is analysed in more detail in Chapter 4. Younger respondents and males are more flexible overall, and those living in households with more children on average show activity-trip patterns that are more diversified and have shorter distances, opening up more opportunities for organizing the activity-trip pattern differently. Further, as hypothesized, geographical background played a role in behavioural change, as those living in non-urban areas were less likely to change behaviour.

Behavioural change was lower for people reporting a higher perceived car dependency (degree to which there are no alternatives for car use), but at the same time, car dependency was not strongly associated with socio-demographical characteristics. Overall, the power of socio-demographic characteristics was rather limited in explaining behavioural change, especially when it came to the magnitude of change. This supports our conviction that capacity for change is likely to be more rooted in people's actual travel patterns rather than related to socio-demographics *per se*, and that attending to people's travel patterns is crucial to better grasp the determinants of responses towards pricing measures.

In Chapter 5, the results of a different experiment were presented. This was a less elaborate experiment undertaken to facilitate a comparison between the Netherlands and China. Its aim was not to test the effect of a cap on kilometres for the participants as a collective, like experiment I; rather scenarios with credit shortages and credit surpluses were equally distributed among participants. Participants only indicated whether they would change car use in response to the scenarios instead of stating the type of change for each individual trip they reported. Furthermore, whereas experiment I only focused on frequent car commuters, experiment II focused on the group of car owners in general (for more details, see Section 1.5).

Compared to experiment I, willingness to change was significantly lower in the Netherlands: approximately 30% and 15% of the participants indicated a change in a situation of credit shortage and credit surplus, respectively. Explanations might be related to differences in experimental design and participant groups (for a reflection, see Section 7.2.2). On the other hand, willingness to change was high in Beijing, where approximately 60% of the participants reported a change in both a situation of credit shortage and of credit surplus. Geographical context might function as an explanation here, with the environment of a dense megacity providing more options for travel pattern change through more alternative travel modes and activity locations within people's reach. Beijing drivers' greater exposure to car use-related problems and a relatively favourable attitude towards TDC as compared to present TDM measures (as evidenced in Chapter 6), as well as a higher cost-sensitivity in China due to differences in wealth, might provide additional explanations.

Another important difference between the results from the Netherlands and China is the finding that a considerable share of the Beijing participants indicated an *increase* in car use in response to TDC, even in a situation of credit shortage. It is hypothesized that this might be due to many Beijing car drivers finding their current car use aspirations constrained by the presence of high congestion levels and the restrictive license plate-based driving restrictions and being willing to rather intensify car use when TDC guarantees better traffic conditions and provides the ability to buy credits according to their true travel demand.

Accounting for different dimensions of car attachment, which is rarely done by other studies, yielded interesting results. First, as hypothesized, the results stress the importance of the symbolic position of the car in China, as only symbolic car attachment appeared to be associated with TDC responses. Overall, symbolic car attachment is much higher in Beijing than in the Netherlands (see Chapter 6). Second, people with a higher symbolic car use appeared to be more eager to increase car use under TDC, although it also had a positive but smaller effect on car use reduction, possibly because those with higher symbolic car use make more unnecessary trips. In contrast, in the Netherlands, instrumental car use appeared to be as important as symbolic car use in explaining willingness to change, both having a negative association.

Despite these differences, similar effects of income, education and car use intensity were found for the Netherlands and Beijing. Willingness to change was higher for those with a lower income, higher educational level and more kilometres driven. These results are in line with the broader literature on road pricing. The fact that Chapter 3 did not find these effects might be because experiment I only focused on frequent car drivers, representing a different and potentially more homogeneous type of car travellers.

7.1.3 Adaptation choice

The type of change and its determinants in response to TDC was studied based on the following research question:

3. *Which adaptations do car drivers make under TDC, and how are these adaptations affected by credit availability, socio-demographic characteristics, residential characteristics, and activity/trip characteristics?*

In Chapter 4, an analysis of adaptation patterns on the activity/trip level made by participants in experiment I was presented. As expected, and in line with the cost-minimisation principle (Loukopoulos et al., 2004; 2006), participants were more prepared to make changes in activity categories that had lower overall importance and fixity levels. Trips related to sports, hobby and recreation activities were adapted the most frequently, whereas trips for work and education purposes were changed the least. Overall, changing the travel mode was the most popular adaptation strategy in case of change, with the bike being twice as popular as public transport. Rather surprisingly, nearly 25% of the trip changes involved cancellation of the trip, which is a substantial share. Unfortunately, the experiment did not allow us to conclude in these cases whether people would perform the activity at home, cancel the activity altogether, transfer the activity to other household members, or postpone the activity to a week with less credit consumption. Only approximately 5% of the trips were rescheduled, a rather limited share. This can be explained by the fact that this option delivered only a marginal credit saving in many occasions, as in this scenario, the TDC scheme was not time-differentiated. Also, the rather complex way of handling this option in the experiment might have played a role.

Several important effects of personal characteristics on adaptation choice were present. The modelling results showed a larger preference for a change of travel mode for males and for those with less working hours per week. The nature of the activity/trip patterns might explain this, as they appeared to be more rigid for females, probably because they have more complex household agendas, and for those with more working hours, likely because of more time pressure. Further, the presence of children, which was already defined as an important factor in the willingness to change, appeared to play a prominent role in adaptation choice. People living in a household with children reported lower average activity importance and shorter trips, making them more prone to switch to the bike or to cancel the trip, but they were also less likely to change to public transport. In short, a key implication of Chapter 5 is that attending to activity/trip patterns is crucial to better estimate car use change effects and to gain a better understanding of the underlying reasons for observed behavioural change.

Furthermore, the type of activity plays an important role in adaptation choice. The options bike and cancelling were more often chosen when the trip was a non-work trip. There was also a significantly lower preference for public transport and carpooling, together with a higher preference for the rescheduling option, when the trip was related to a personal maintenance activity. In addition, the relative position of an activity to other activities and the frequency of occurrence appeared to be highly relevant factors. When an activity was connected to other activities in a trip chain, a switch in travel mode was less likely to occur. At the same time, activities that were performed less often, which turned out to be generally perceived as less important, were more likely to be cancelled and to be switched to public transport, probably because these activities are normally performed when time pressure is less of an issue. Again, Chapter 4 showed the relevance of accounting for the geographical contexts of car use when understanding adaptation choice. In line with our expectations, both the perceived ability to switch to another travel mode and the act of doing so were lower when the participants' home and the destination were in a non-urban area.

7.1.4 Acceptability

The research question formulated for the investigation of TDC acceptability is as follows:

4. *To what extent do car drivers evaluate the TDC measure as acceptable, and how is TDC acceptability affected by socio-demographic characteristics, residential characteristics and attitudes towards car use and TDC aspects?*

This research question was addressed in Chapter 6, which, based on the data gathered through experiment II, provided a Netherlands-China comparison. As expected, Chapter 6 showed a considerable difference in acceptability levels between the Netherlands and China. Whereas in the Netherlands, 21.6% of the participants viewed TDC as acceptable, 67.0% did so in Beijing. Two reasons may explain this difference. First, on average, Beijing participants regard congestion as a more pressing issue both for society and in their personal daily life, possibly making them more convinced of the urgency to address this issue and, hence, readier to accept TDC. Second, Beijingers are already familiar with rather stringent vehicle use policies, particularly the license plate-based driving restriction. Because 62.0% and 67.1% of the Beijing participants assessed TDC to be more effective and fair, the relative dissatisfaction with this restriction may have contributed to a positive attitude towards TDC. In contrast, in the Netherlands, where participants were asked to evaluate TDC in reference to a recently debated conventional per-kilometre charge, only 25.6% and 27.1% assessed TDC as more effective and fair, respectively.

Participants with higher incomes viewed TDC as more acceptable in both the Netherlands and China. This is an interesting finding as TDC is often argued to be more beneficial for lower-income households compared to conventional road pricing because the latter generally drive fewer car kilometres and because of a certain number of 'free' credits (see Yang & Wang, 2011). However, TDC, at least the scheme investigated in this thesis, apparently does not eliminate the 'traditional' difference in acceptability among income groups that is often observed in the case of conventional road pricing.

A reason might be that lower-income households are more constrained in their choices when it comes to travel mode, activity and scheduling choices (see Cao & Mokhtarian, 2004), and therefore more readily oppose any measure perceived as an attempt to urge them to make car use changes. Furthermore, under TDC, lower-income groups might be more worried about the possible trend that higher-income groups would simply buy additional credits to fulfil their travel needs, causing credit prices to rise in the market and, hence, making credits less affordable for less-wealthy drivers. This situation might be especially relevant in the Beijing context, where large differences in income between resident groups and a strong competition for scarce road space are present. This can explain the finding that perceived fairness of TDC is a much more powerful determinant of TDC acceptability in Beijing than in the Netherlands, although fairness plays an important role in the Netherlands as well. Besides perceived fairness, perceived effectiveness appears to be another important determinant of TDC acceptability in both contexts, which confirms earlier research on road pricing acceptability and its determinants. Also, in line with this wider body of research, our results show that the predictive power of subjective evaluations of the policy is far greater than that of socio-demographic characteristics.

7.2 Reflections

7.2.1 Theoretical reflections

The empirical research reported in this thesis has sought to understand people's responses to TDC based on an explicit link to their everyday car use and activity participation patterns. This is in stark contrast to empirical studies on TDC that so far largely remain very general (Raux et al., 2015a; Parag et al., 2011; Wallace et al., 2010), rely on abstract decision contexts (Raux et al., 2015b; Aziz et al., 2015; Kockelman & Kalmanje, 2005), or are only linked to concrete car use patterns in a qualitative way (Harwatt et al., 2011). By applying an activity-based approach, this thesis builds on a tradition that finds its roots in Hägerstrand (1970) and his time-geography, Chapin (1974) and his interest in the relationship between individuals' motivations for activity engagement and the environmental characteristics enabling these activities, and Cullen and Godson (1975) in their emphasis on activity attributes and their meaning in the structure of activity participation patterns (see also Ettema & Timmermans, 1997; McNally, 2000; Algers et al., 2005; Dijst, 2009). Attempts to assess the impact of any travel demand management measure without connecting to people's daily travel patterns will result in non-realistic and biased estimations of effects. Moreover, attending to important activity/trip pattern attributes, such as the presence of others, trip chaining patterns, and the flexibility/fixity of locations, times and modes, is critically needed to gain insights into the working of these structuring elements in the process of turning certain car use change goals into concrete adaptation actions (Loukopoulos et al., 2006; Gärling et al., 2000).

One major contribution of this thesis is that, compared to most empirical TDC research to date, it focused on the credit allocation process, by allowing people to allocate credits over a set of activities. It did so under the conditions of fixed credit prices and known trips, in which participants were asked for their optimal credit spending retrospectively. As such, this thesis explicitly zoomed into the effects of measured attributes of the activities/trips and the interlinkages between those activities/trips. A valuable next step would be to simulate circumstances of uncertainty, both about credit price as a function of dynamic aggregate credit demand and about future car use needs, by using a more prospective approach with a clear focus on the activity/car use scheduling process. As argued in Chapter 2, such research would benefit from drawing on the insights from behavioural economics and cognitive psychology to better grasp decision-making under the dynamics of trading, uncertainty and varying time horizons. As outlined, risk aversion, complexity aversion and time discounting present fruitful concepts when it comes to understanding such behaviour, as important strands of literature suggest that decision-making under uncertainty and over time may deviate from assumptions based on utility-maximizing theories. Such an approach to TDC decision-making would resonate with a current increasing interest in behavioural concepts in the wider travel behaviour literature (e.g., Avineri, 2012; Metcalfe & Dolan, 2012; Ben-Elia & Avineri, 2015).

Another direction for future research on credit allocation would be to not solely focus on the individual, as this thesis did, but to expand the investigation of travel (adaptation) decisions under TDC to the household, a decision-making entity that shares resources such as income, cars and certain activity needs. To a large extent, activity participation, car use and time allocation are joint decisions that are made within the household. As a result, the activity agendas of household members shape the opportunities and constraints for each other's adaptation options. Understanding household decision-making mechanisms would be especially relevant if more precise rules and regulations were formulated that govern credit distribution and transferability in the TDC scenarios (e.g., Would household members be able to freely transfer credits to each other? Would credits be distributed to cars or households rather than individuals?). Currently, there is increasing interest in methods for surveying and modelling complex intra-household interactions (see Arentze & Timmermans, 2009; Bhat & Pendyala, 2005), from which future TDC research should benefit.

Additionally, it might be of added value to incorporate non-car-based activity patterns in future efforts to assess drivers' responses to TDC. For example, information about people's current bike and public transport use and about online activity patterns performed at home, such as e-shopping, might function as a valuable backdrop against which people's adaptations can be understood more thoroughly. For example, a frequent bike user might have a lower preference barrier against bike use, making her more likely to choose this mode in other situations, or a frequent bike user might already have switched to the bike whenever possible in her daily routines, making a choice of the bike as a substitute for her car less likely. Furthermore, as this thesis only focused on short-term adaptation, it is worthwhile to also look into medium- and long-term adaptations, such as the decisions to buy an e-bike, to take out a public transport subscription, to work closer to home, or even to relocate (see Tillema et al., 2010; Arentze & Timmermans, 2007).

Another behavioural mechanism that has an important place in this thesis is decision-making under an incentive versus a disincentive. A consistent finding of this thesis is that avoiding a loss (in case of credit shortage) is a stronger motivation for behavioural change than the ability to earn (in case of credit surplus). Through this finding, this thesis contributes to the literature on the effects of rewarding as a travel demand management strategy, which has received increasing attention recently, among the most prominent examples being the Spitsmijden (peak avoidance) project in the Netherlands (Knockaert et al., 2012; Ben-Elia & Ettema, 2011). This interest is motivated by the strategy of rewarding being more readily accepted as a travel demand management policy by car users, and it is inspired by the claimed effectiveness of rewards to reinforce behavioural changes in psychological research on learning and motivation (e.g., Berridge, 2001; Geller, 1989). However, to date, the effects of incentives and disincentives on travel behaviour have been studied in isolated cases, which does not facilitate a direct comparison of their relative effects (Tillema et al., 2013). The conclusion of this thesis is that although positive monetary incentives are effective, and are certainly worth considering because they enjoy higher public popularity, they are not as effective as equivalent disincentives and, hence, cannot be viewed as a full alternative to negative pricing when the realisation of car use change is the main aim.

Further, based on an important strand of research that has demonstrated the meaningful function of attitudes in travel behaviour choices (e.g., Van Acker et al., 2010; Beirão & Cabral, 2007; Clifton & Handy, 2001; Jensen, 1999; Verplanken et al., 1994), this thesis has given attitudes towards car use and TDC a prominent role in understanding TDC responses. Whereas the incorporation of attitudes is widespread in the psychology-oriented literature on the acceptability of road pricing (Schuitema et al., 2010; Eriksson et al., 2006; Jakobsson et al., 2000), the inclusion of attitudes in the more economics-oriented studies on road pricing effects is less common. However, car use and, hence, reactions to policies that seek to change car use are recognised as being structured to a large extent by motivations, preferences and worldviews, that do not necessarily concur with socio-demographic characteristics (Steg, 2005; Anable, 2005). This thesis particularly considered the role of car attachment in TDC responses and clearly demonstrated that subjective car dependency, not only instrumentally but also symbolically and affectively, represents a valuable layer of explanation in the case of TDC responses. This becomes especially relevant when understanding differences in TDC responses between a Dutch and a Chinese context with their own unique car cultures. Future research that acknowledges the embeddedness of travel policy responses in underlying attitude and preferences will contribute to meaningful progress in understanding the fundamentals of travel behaviour responses. Such research can, for example, help to draft better tailored policy designs for specific types of drivers. In the context of this thesis, the functioning of social norms, the readiness to accept government interventions, and the evaluation of the performance of travel alternatives are examples of psychological constructs and perceptions that have not been covered but that might be of additional relevance in understanding responses to TDC in future research (cf. Raux et al., 2015b; Cools et al., 2011; Eriksson et al., 2006).

In addition to attitudes towards car use and TDC, which represent psychological constructs, participants in experiment I were also asked for evaluations of the perceived importance and flexibility with regard to place, time and travel mode of the activity/trip. In Chapter 4, these subjective evaluations were not included as separate variables in the model on adaptation choice because doing so would have led to self-evident conclusions (e.g., a trip being perceived as easily replaced by bike having a higher likelihood of being changed to a bike trip) and would have masked important effects of objective activity/trip attributes and socio-demographic characteristics. Yet, these subjective evaluations proved to be of great value in order to come to possible explanations of certain adaptation behaviours of different participant groups, showing the relevance of attending to such subjective evaluations of individual trips.

By investigating responses to TDC in both the Netherlands and Beijing, this thesis addressed the need for an enrichment of the road pricing literature with insights from a non-Western context, particularly from a Chinese context. Current insights into behavioural responses and attitudes towards road pricing policies have largely relied on Western situations, although a number of studies from China have appeared very recently (e.g., Jia et al., 2017; Sun et al., 2016). Yet, these are often isolated case studies that provide little reflection on how local and unique social, cultural and institutional elements shape responses. Such reflection is, however, needed to adapt policies to local contexts and cultures. Wang (2010), for example, warned of not simply copying transport policies that are successful in Western countries in Chinese situations because of differences in city structures and societal values. Meaningful differences in responses between a Western and Chinese context can only be detected and understood in direct cross-cultural comparisons that account for contextual elements (see Fujii et al., 2004, for a scarce example). This thesis sought to do so by interpreting the results in connection with local traffic conditions, travel policy context and car cultures. With regard to the already mentioned attitudes related to social norms, government intervention and car use alternatives, important differences could be expected that potentially have to do with the more collectivistic culture of China and the Chinese people potentially having another conception of personal freedom and the role of the government in daily life (Zhao et al., 2015; Sun, 2004).

An intriguing difference between the Netherlands and Beijing was, for example, found with regard to the role of fairness and personal outcome as determinants of TDC acceptability. The effect of perceived fairness turned out to be significantly larger for Beijing than for the Netherlands, while at the same time, the effect of expected personal outcome was absent in Beijing. As already mentioned, the license plate-based driving restriction, functioning as a reference point, and the large differences in income between groups of drivers in Beijing might function as an explanation here. However, the reasons might as well be related to perceptions of fairness and personal outcome as concepts. For example, in a recent paper, Eliasson (2016) distinguished between consumer and citizen perspectives on fairness, showing that ideas of winning and losing under road pricing depend on a whole range of different senses of fairness pertaining to self-interest, equity, procedural fairness and ideas of what is socially desirable. It is highly recommended that future research seek to provide more detailed insights into the role of different ideas of fairness in the context of road pricing in China and other non-Western cultures and how these are culturally shaped, using more elaborate questionnaires with a more varied set of psychological constructs.

Geographical context also appeared to be a relevant factor at a more detailed level in the Netherlands, the only country for which we had information about the location of the participants' residence and trip destinations. There was a lower propensity to change car use and a lower likelihood to choose a mode change as an adaptation strategy when these locations were in a non-urban area. These results are as expected but are important in two ways. First, the results show that locational factors cannot be neglected in understanding travel behaviour changes to transport policies, which is of course a common conviction in transport geographical research (cf. Schwanen, 2003; Dieleman et al., 2002) but it seems not to resonate widely yet in the more economics-oriented literature on road pricing effects. Nevertheless, car use is geographical by definition. Second, geographical context only appears to be a relevant factor in the results of experiment I. People may not always be aware of locational factors, and they may represent a constraint when people proceed from a more general formulation of a car reduction goal to the formation of concrete actions. If true, this would be another reason why the adoption of an approach that situates people's travel behaviour changes within their concrete lives is highly preferred when appreciating the effects of travel policy measures.

7.2.2 Methodological reflections

The stated adaptation experiment as used in this thesis represents a relatively new approach to analysing changes in travel behaviour that are induced by alterations in the travel conditions. In the early days of activity-based research, researchers started to develop qualitative techniques to investigate adaptive behaviours in response to changes in the travel context. Jones (1979), Lee-Gosselin (1996) and Faivre D'Arcier et al. (1998), for example, designed specific games in which individuals could state in a personal interview how they would adjust their activity/trip patterns to a new travel situation. Such games have largely served descriptive purposes. However, the Internet has made possible online stated adaptation experiments that rely on online travel data collection, include personalised scenarios, present interactive interfaces that automatically update the consequences of choices, and, not least important, facilitate data collection on a larger scale. Examples of quantitative-oriented internet-based stated adaptation studies are Weis et al. (2013), Nijland et al. (2009) and Arentze et al. (2004). Compared to traditional stated choice techniques, stated adaptation experiments make it easier to take different choice facets and a wider set of activities into account and therefore connect well with the activity-based approach. Yet, there are several methodological issues worth reflecting on.

In particular, experiment I was developed to function as a valuable contribution to the discussion on stated adaptation experiments. The online application was able to capture multidimensional adaptations, which is not always the case in other stated adaptation experiments. To limit the burden for the participants, the adaptation options were defined rather generally. This led to a situation in which we could not, for example, identify the precise reason for cancelling the activity/trip (e.g., perform the activity at home, postpone the activity, cancel the activity altogether), could not differentiate between various types of public transport, or could not account for possible household interactions (e.g., transfer the activity to someone else in the household). However, in the context of the present flexibility of the transport system (e.g., sharing initiatives, Mobility-as-a-Service approach; see Mulley (2017), Jittrapirom et al. (2017), Hietanan (2014)), individual travel patterns can be rather varied and subtle, and their diverse and individual-specific forms might be difficult to capture through approaches that seek to quantify adaptations in a more generalising way. The ambitions to arrive at quantifiable results, to enhance realism, and to achieve information richness pose tough dilemmas. It has, for example, led other researchers to bring choice options together under a single category at the expense of information loss (e.g., Roorda & Andre, 2007; Andrey et al., 2004). However, in our experiment participants often made rather complex adaptations with the options available. Participants, for example, selected a location change and a travel mode change for the same activity or changed an original car trip into a combined bike-train-bus trip (sometimes, public transport modes could be discerned by the locations and the personal descriptions attached to the trips). This not only shows that the approach used in this thesis was able to detect varied and complex adaptation strategies that other experiments do not always allow but also that participants generally understood the application, were engaged with the experiment and sought to make changes feasible in their own personal context.

Further, the option to reschedule the activity, i.e., give it another position in the activity/trip pattern without a mode change, was selected at a rather low rate. One reason might be that this option resulted in only a marginal credit saving in most of the cases because the scheme was not time-differentiated, which might be desirable when it comes to a practical implementation (see Section 7.3.3). That this option required some effort in the experiment (cancelling the old activity and creating a new activity in the activity/trip pattern) might also explain this finding. The infrequent selection of this option might have contributed to the model in Chapter 6 not being able to identify certain statistical associations related to this adaptation alternative that might be present in reality.

As already stated in Section 7.1.2, the large differences in willingness to change under experiments I and II in the Netherlands might be explained by the differences in experimental design. First, in experiment I, a larger share of the respondents faced a scenario with a credit shortage. However, when distinguishing between gains and losses, willingness to change was still considerably higher in experiment I. Second, frequent car commuters might face more options for car use change in daily life, although this seems to be unlikely, as frequent car commuters did not report a higher number of car-based activities and did report a higher instrumental car dependency. Third, because experiment I was relatively complex and the drop-out rate substantial (see Section 1.5.3), people being sceptical of the TDC concept and their own ability to change car use might be overrepresented in the drop-out group, potentially leading to a bias towards more change-minded participants. At the same time, there seems to be no ground to believe that the sample of experiment I was biased towards a more positive evaluation of TDC, as initial results of an analysis of TDC attitudes of participants in experiment I – that is not reported in this thesis – shows no statistical difference between the groups in terms of TDC acceptability. Finally, the detailed and personalised design of experiment I may have fostered a greater personal involvement and awareness of potential for car use change, resulting in participants being more motivated to change their car use, even if it would involve only a small change. There is evidence from the literature on energy-saving behaviour that providing detailed information about choice options and feedback after choices have been made has a positive effect on readiness to change behaviour (Fischer, 2008; Darby, 2006). This can help explain the higher change rates in experiment I and should stimulate regulators to develop personalised and tailored approaches in transport policies.

We are aware that the use of self-reported recall travel dairies to gather the input information for the TDC scenarios in experiment I was a rather time-consuming strategy and may have led to the data collected deviating from actual behaviour, which is a common problem in traditional travel diary research (see Bohte & Maat, 2009). Currently, GPS tracking methods are increasingly used to map people's car travel patterns, which are generally less intrusive, less time-consuming and more accurate (Prelipcean et al., 2017; Shen & Stopher, 2014; Bierlaire et al., 2013; Stopher et al., 2008). However, such methods were evaluated as less useful for our research, as GPS tracking methods would still have needed significant trip detection and validation processes before a useful trip pattern could be presented to the participants. In a situation in which the TDC scenarios had to quickly follow the travel data collection and in which we wished to attach a series of questions about (subjective) trip attributes to the individual trips, a traditional online travel diary method was preferred. GPS tracking methods, on the other hand, are very helpful for travel data collection prior to a personal interview about the effects of TDC and other measures, as such a research procedure allows more flexible time planning and room for personal discussion with the participants (as is done in, e.g., Hanson & Hildebrand, 2011).

A more qualitative approach is recommended in order to come to a more detailed and nuanced understanding of underlying motivations for TDC behaviours and attitudes towards various aspects of the measure. Such an approach, in which Harwatt et al. (2010) have made a promising first step, would provide a valuable complement to more quantitative estimations of TDC effects.

Further, the hypothetical bias might be present in our results: saying one will change a trip is not necessarily the same as doing so. However, the same is true for all other stated preference approaches that nonetheless are frequently applied in road pricing studies (see Li & Hensher, 2012). The realism of TDC experiments can be enhanced by setting up field trials in the real world that preferably make use of real money, if available of course. Participants, for example, could be given a sum of money prior to the field trial that they can increase or decrease by their credit spending behaviour, a strategy similar to that which has been employed in the AKTA road pricing experiment in Copenhagen (Nielsen, 2004).

Field trials also present good opportunities to investigate credit allocation with a prospective focus, e.g., looking into activity scheduling processes under anticipated travel demand and market circumstances. When studying the effects of market dynamics on individual choices, as well as the negotiation and bargaining processes in the case of credit trading, game theory and serious gaming (Klein & Ben-Elia, 2016; Hollander & Prashker, 2006; Levinson, 2005) and interactive agency choice experiments (Brewer & Hensher, 2000) can present fruitful approaches.

7.2.3 Societal and policy reflections

There is a clear societal value in studying drivers' potential responses to TDC. This is because policymakers are confronted with increasing car volumes that in many places around the world exceed the road capacity and pose problems in terms of congestion and car-based pollution. They therefore continue to look for tools that can manage the steady growth of car use in an effective yet socially feasible way. Furthermore, in the specific cases of the Netherlands and Beijing, there is considerable dissatisfaction with the way some transport policies function at present, making it worthwhile to consider potential alternative policies. In the Netherlands, the traditional pricing regimes that levy taxes on car ownership rather than on actual car use intensity (e.g., Motorrijtuigenbelasting (MRB) and Belasting voor personenauto's en motorrijwielen (BPM)) are increasingly considered unfair and unsustainable (ANWB, 2014; Platform Anders Betalen Voor Mobiliteit, 2005). In Beijing, the license plate-based driving restriction, together with the license plate lottery for vehicle ownership, is frequently criticised for being unfair, leading to significant welfare losses and having many negative consequences such as the purchase of second cars and non-compliance behaviour (Nie, 2016; L. Wang et al., 2014; Hao et al., 2011). Can TDC function as a viable alternative?

For the Netherlands, the results suggest that a TDC scheme like the one investigated in this thesis has the potential to be at least as effective as the nation-wide road pricing schemes that have recently been discussed. Unfortunately, no direct comparison with equivalent road pricing studies can be made, because the available road pricing studies differ in experimental design and price levels used. For road pricing schemes using a 3, 6 or 12 Eurocents per-kilometre price, combined with various types of tax reforms, Ubbels and Verhoef (2005) found an average trip adjustment rate of 9.7% and a slightly lower percentage of kilometre reduction, although a precise figure for kilometre reduction is not given. CPB and PBL (2016) report an expected kilometre reduction of 10-15% under a pricing scheme based on a flat kilometre price of 7 Eurocents. Of course, this thesis used higher kilometre prices (10, 15 and 20 Eurocents). However, given that we could not find a statistical difference in change behaviour between groups with different credit price levels, it could be tentatively concluded that a higher motivation for change under TDC as compared to conventional road pricing cannot be solely attributed to the higher per-kilometre prices used. This assertion is supported by the majority of studies that have directly compared a tradable credit scheme with a tax scheme on the basis of equivalent prices, either in the context of personal travel or in the context of more general carbon consumption. These studies indeed found a higher willingness to change and a larger size of change under the credit scheme (Raux et al., 2015a, Zanni et al., 2013; Harwatt et al., 2010; Parag et al., 2011; see Chapter 2).

Of course, in contrast to the scheme investigated in this thesis, which used fixed credit price levels and in which credits were seemingly 'unlimitedly' available, a TDC as typically understood would lead to a car reduction level that equals the cap set by the regulator through the market mechanism. Such a scheme would be effective in essence, necessarily delivering the cap. However, what this thesis shows is that a TDC scheme with fixed prices can already mobilise a level of behavioural change that is comparable to or beyond that of conventional road pricing. Therefore, attributes of the TDC concept other than the price signal alone are argued to serve as motivators for additional behaviour change. These can be the presence of a positive incentive, the personal budget referring to road access as a scarce resource and stimulating a sense of 'collective action', and the scheme's ability to achieve a clear reduction in car kilometres by its definitive kilometre cap, as interviews in Harwatt et al. (2010) hint at. These are the elements that make the TDC concept attractive and worth discussing more thoroughly in the scientific, political and societal arenas.

In light of the many failed road pricing proposals worldwide due to public resistance, it is public opinion towards the measure rather than its effectiveness that is the key to evaluating the desirability of TDC. In Beijing, the 67% of participants viewing TDC as acceptable indicates an important level of support for the measure. We argue that the dissatisfaction with current car management policies is a major contributor to this favourable attitude, as the majority of the respondents favour TDC over the current license plate-based driving restriction in terms of perceived effectiveness and fairness. At the same time, this thesis has shown that a share of drivers tend to be eager to increase their car use under TDC if it will replace the license plate-based driving restriction. This could have significant implications for the availability of credits in the city's context of strong competition for scarce road space, driving up credit prices to high levels. Because perceived fairness is found to the key determinant of TDC acceptability, equity-related concerns should be considered with special attention in future research and debates on potential TDC implementation in Beijing. This would also involve the issue of speculation, which might occur under large credit price differences. As a first step, limiting the window of validity of the credits so that they expire at a certain time may discourage speculation behaviour (Wu et al., 2012; Keppens, 2006; Raux & Marlot, 2005).

In the Netherlands, the acceptability rate of TDC is much lower, with 21.6% viewing the measure as acceptable. This is somewhat lower than what is generally found in the literature on conventional road pricing. At first, this seems to be a rather low figure. However, the relative unfamiliarity with the measure as compared to conventional road pricing, which has received much media attention in recent years, might play a role. The support rate for a tradable credit scheme in the study by Kockelman and Kalmanje (2005) in the US was only a slightly higher 24.9%, which they interpreted as a promising level, given the complexity of the policy and the fact that participants had only 15 minutes of experience with the policy in their experiment. The same conclusion might apply for the results on the acceptability of experiment II reported in Chapter 6. Furthermore, 36% of the Dutch participants showed a neutral stance towards TDC, which indicates that a large share of the participants did not clearly oppose the measure and might even show a more favourable attitude to TDC after some scheme adjustments. It is highly likely that support for TDC will vary for different TDC specifications, as Bristow et al. (2010) demonstrated that the acceptability of personal carbon trading schemes could be substantial under the 'right' scheme design. It is therefore critical that transport researchers and policymakers systematically evaluate the impact of a range of scheme attributes (see Box 1.1) on TDC acceptability to identify the 'best' scheme, which is not necessarily the scheme studied in this thesis.

Several more general issues related to the potential implementation of TDC are worth reflecting on. First, the complexity of a TDC scheme is an issue, not only for regulators, because of the need to set up, monitor and enforce the scheme, but also for participants, especially if they have to manage their budget, find trading partners and negotiate in a fully dynamic market context. This may lead to significant transaction costs. It can, however, be expected that services and technologies would soon help smoothen transactions and make decision-making easier to some extent. Brokers can help in providing information and facilitating transactions (Grant-Muller & Xu, 2014; Nie, 2012). Also, integrated systems for credit management and trip planning might become available to participants through online apps that facilitate information provision and decision-making, similar to apps developed in the context of Mobility-as-a-Service initiatives that seek to integrate different mobility options and an interoperable payment system in a single interface (Jittrapirom et al., 2017).

There is not only the complexity of the scheme itself; also varying credit price levels under dynamic market forces might add a layer of complexity. Reviewing empirical research on responses towards tariffs in transport and telecommunications, Bonsall et al. (2007) conclude that there is a tension between a theoretical desirability of highly flexible price structures and the ability of consumers to respond to them in an effective way. Also, Franke and Kaniok (2003) conclude that people generally have a strong preference for simple price structures. Therefore, potential regulators may want to consider a less efficient but potentially simpler and, hence, more socially viable TDC design. Regulators can, for example, set up a system in which drivers can directly buy and sell credits against fixed prices with a central authority, in which a dynamic trading mechanism underlying the cap-and-trade measure would in fact be absent. Alternatively, regulators might design a TDC scheme with a price ceiling and price floor, in which the regulator would commit itself to sell credits at a ceiling price and buy them at a floor price to ensure the price is kept within acceptable bounds. Such 'safety values' would limit the full forces of the market from imposing excessive costs, which should also discourage speculation (Hepburn, 2006; Santos et al., 2010). Such designs would not only address the complexity issue but might also powerfully address equity-related concerns that stem from the potential fear that only those with greater purchasing power would be able to afford expensive credits under circumstances of strong competition.

Furthermore, the integration with other (transport) policies has to be carefully examined when considering TDC implementation. The TDC measure, as most frequently discussed in the literature, would be a revenue-neutral measure, implying that money flows back to participants rather than to government funds. In the discussion on replacing the current vehicle ownership taxes by a pricing regime in which people pay for their car use, as it is currently taking place in the Netherlands, it might be difficult to consider TDC as an alternative for current taxes, as it would deprive the government of revenues. TDC would be more feasible as a complementary measure to existing taxes if the public were convinced of the measure's ability to effectively solve the congestion problems they experience on a daily basis. The steadily rising levels of congestion in the Netherlands, Beijing and many other countries and cities could therefore increasingly open up room for the TDC measure. It might therefore also be more promising to start implementing TDC in regions that experience the worst congestion, instead of attempting a nation-wide implementation. Nevertheless, one should be aware of negative side effects in the border regions when implementing pricing schemes at smaller geographical scales. Alternatively, in another type of TDC scheme, credits could be sold in an auction rather than through grandfathering. In this way, revenues could be raised that could be used to lower other taxes. Car drivers would be required to acquire all their needed credits in a competitive bidding process (Nie, 2012; Santos et al., 2010).

This thesis has looked into the effects of just one type of TDC scheme among many others that are conceivable. Stevens and Verhoef (2013), for example, have proposed a TDC scheme that applies to peak hour traffic only, which could be more socially feasible because it would introduce a time-differentiation on the basis of which drivers have the means to circumvent paying credits to drive. A promising avenue for a first step application could be to introduce TDC to firms that can experiment with TDC, potentially applying it to other travel modes as well, on a voluntary basis, similar to the concept of the 'mobility budget' (Zijlstra et al., 2014). Of course, as with all other measures, all versions of TDC would have their challenges when it comes to an actual implementation. However, the concept clearly has many attractive points, among which are its ability to realise a clear decrease in car use through the introduction of a definite cap, the incorporation of a reward element, and the measure offering participants the freedom to choose how to use their credits. These benefits make it highly worthwhile to discuss and investigate the concept further.

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Samenvatting in het Nederlands

Achtergrond

Prijsbeleid voor weggebruik staat opnieuw volop in de belangstelling in Nederland. Na jaren van relatieve 'rust' op de Nederlandse wegen neemt de filegroei, ondanks de vele nieuwe aangelegde wegen en opgeloste knelpunten in de afgelopen jaren, weer fors toe met het aantrekken van de economie. Er is daarom een groeiende overtuiging onder wetenschappers, mobiliteitsorganisaties en verschillende politieke partijen dat de invoering van nieuw prijsbeleid – een andere manier om automobilisten te laten betalen voor hun weggebruik – onontkoombaar is om de fileproblematiek, en andere problemen die het groeiend autogebruik met zich meebrengt, op een effectieve en duurzame wijze aan te pakken.

Voorstellen voor andere vormen van betalen naar autogebruik – kilometerheffing, rekeningrijden, congestieheffing, etc. – zijn in het verleden veelal gestrand vanwege een gebrek aan publieke en politieke steun. Dergelijke maatregelen worden door het publiek vaak opgevat als een verhoging van de kosten voor hun autogebruik, terwijl dat netto niet altijd zo hoeft te zijn wanneer deze vergezeld gaan met een andere inrichting van de autobelastingen. Daarom is het cruciaal op zoek te blijven naar prijsmaatregelen die zowel effectief, d.w.z. congestie op een doeltreffende en duurzame manier weten aan te pakken, als sociaal geaccepteerd zijn, d.w.z. op steun van autogebruikers kunnen rekenen.

Vanuit dit perspectief is de afgelopen jaren in wetenschappelijke kringen steeds meer interesse in het concept van *tradable credits* (verhandelbare rechten) ontstaan. Toegepast in het domein van autogebruik wordt met deze maatregel, zoals die meestal in de literatuur wordt voorgesteld, een maximum gesteld aan het totale autogebruik in een bepaalde regio en tijdspanne. Dit maximum kan worden vastgesteld in bijvoorbeeld eenheden van kilometers, passages of brandstofconsumptie. Vervolgens ontvangen autogebruikers een budget met rechten die staan voor een individueel deel van het totale toegestane volume autogebruik. Deze rechten zijn verhandelbaar. Wanneer een individu een hoger autogebruik wenst te realiseren dan waarin voorzien wordt door de hem toebedeelde rechten, dient hij extra rechten in te kopen. Wanneer een individu rechten overhoudt kan hij dit overschot aan rechten verkopen. De markt zorgt voor afstemming van vraag en aanbod van deze rechten.

De maatregel is in theorie effectief. Een aantrekkelijk kenmerk van de maatregel is dat door de uitgifte van een beperkt aantal rechten, die dus corresponderen met eenheden autogebruik, een vooraf gesteld doel in reductie van het totale autogebruik altijd gehaald zal worden. Dit is anders in het geval van een conventionele (vaste) heffing, waarbij de uitkomst altijd onzeker blijft. Vanuit economisch perspectief is het aantrekkelijk dat de maatregel daarnaast ook efficiënt is: het vooraf gestelde doel zal tegen de laagste sociale kosten gehaald worden, omdat door het marktmechanisme de rechten zich zullen bewegen van degenen die het makkelijkst hun autogebruik kunnen verminderen naar degenen die de hoogste waarde toekennen aan hun autogebruik.

De maatregel leidt mogelijk ook tot een hogere sociale acceptatie. Allereerst is de maatregel budgetneutraal en zal daarom waarschijnlijk minder als een belasting worden opgevat: in plaats van directe geldstromen richting de overheid tot stand te brengen zal de maatregel voornamelijk leiden tot geldstromen tussen autogebruikers onderling. Ten tweede is er een positieve prikkel aanwezig in de maatregel: zij die rechten overhouden kunnen een financiële beloning tegemoet zien. Ten derde is een belangrijk kenmerk van de maatregel dat de uitkomst altijd economisch efficiënt is, ongeacht de oorspronkelijke verdeling van de rechten. Daarmee kan een autoriteit eenvoudig differentiatie aanbrengen bij het toekennen van rechten, al naar gelang verschillen in mobiliteitsbehoeften van autogebruikers en politieke wensen, zonder dat het systeem als geheel aan efficiëntie inboet.

In de afgelopen decennia zijn verschillende voorstellen voor toepassing van het concept van *tradable credits* in het domein van persoonlijk autogebruik gedaan in de wetenschappelijke literatuur. Recentelijk is het aantal studies dat op een theoretische, mathematische manier het functioneren van hypothetische *tradable credit* programma's onderzoekt sterk gegroeid. Empirisch onderzoek naar de mogelijk effecten van dergelijke programma's op het gedrag van individuele autogebruikers is echter schaars. Dergelijk onderzoek is echter onontbeerlijk om de effecten van de maatregel en zijn potentie voor een mogelijke implementatie op waarde te schatten. Dit proefschrift heeft als doel de effecten van en attitudes jegens een mogelijke *tradable credits* variant te onderzoeken. Het betreft een op kilometrage gebaseerde variant, die in dit onderzoek in de Nederlandse vertaling *verhandelbare kilometerrechten* is genoemd. Naast Nederland heeft het empirisch onderzoek ook in Beijing (China) plaatsgevonden; twee hoofdstukken uit het proefschrift presenteren resultaten uit zowel Nederland als China. Er zijn verschillende onderzoeksthema's gedefinieerd en de resultaten van elk van deze thema's zullen in de volgende secties achtereenvolgens beschreven worden.

Huidige stand van zaken in de literatuur

Allereerst is in hoofdstuk 2 een systematische literatuurstudie uitgevoerd naar de huidige inzichten op het gebied van de effecten van verschillende *tradable credit* programma's op individueel autogebruik. Er zijn een aantal studies beschikbaar die op vergelijkende wijze de effecten van een *tradable credit* programma en de effecten van een heffing met equivalente prijzen hebben onderzocht in een empirische setting, zowel gericht op alleen persoonlijk autogebruik als gericht op meer alomvattend huishoudelijk energieverbruik. Op basis van deze studies kan geconcludeerd worden dat de mate van gedragsverandering die een *tradable credit* programma kan verwezenlijken even groot dan niet groter is als die een vergelijkbare heffing kan realiseren.

Een aantal studies geeft aan dat er in het gedrag van mensen onder een *tradable credit* programma mogelijk gedragsmechanismen in het spel zijn die een effect hebben bovenop het gewone prijseffect. Deze effecten worden vaak gekoppeld aan kenmerken van het *tradable credit* concept die de maatregel uniek maken ten opzichte van conventionele heffingen. Echter, een systematische bespreking van dergelijke effecten op basis van relevante wetenschappelijke literatuur ontbreekt. Daarom zijn in het tweede deel van de literatuurstudie een drietal unieke kenmerken van het *tradable credit* concept genoemd en zijn potentiële gedragseffecten die aan deze kenmerken gekoppeld kunnen worden besproken. Deze kenmerken zijn 1) de mogelijkheid om zowel financieel verlies als winst te kunnen realiseren onder de maatregel , 2) de aanwezigheid van een budget met rechten dat beheert dient te worden, en 3) de aanwezigheid van een markt en de uitdaging die deze biedt voor het beheren en inzetten van rechten over een langere tijdsperiode en onder omstandigheden van onzekerheid.

In de literatuur uit de gedragseconomie en de psychologie zijn veel inzichten te vinden die kunnen helpen om potentiële gedragseffecten van *tradable credits* te verkennen. Zo kan bijvoorbeeld op basis van de invloedrijke *prospect theorie* gesteld worden dat het voorkomen van verlies in een geval van een tekort aan rechten een sterkere motivatie voor gedragsverandering is dan de mogelijkheid tot het vermeerderen van winst in het geval van een overschot aan rechten. Ook kan bijvoorbeeld verwacht worden dat de rechten als een aparte munteenheid gaan fungeren voor deelnemers, een betaalmiddel die zij cognitief aan autogebruik koppelen en niet een op een met geld is in te wisselen, zodat het overschrijden van hun budget als een psychologische barrière zou kunnen werken. Aan de andere kant zou dit er ook voor kunnen zorgen dat mensen juist intensiever hun auto gaan gebruiken, vooral wanneer zij de rechten als hun eigen persoonlijke 'recht op autogebruik' hebben *geframed*. Ook geven studies aan dat mensen lang niet altijd op een rationele manier onzekerheid of toekomstige behoeften verdisconteren, waardoor het inzetten van rechten op de langere termijn sterk zal worden bepaald door het rekening kunnen houden met toekomstige behoeften en een persoonlijke mate van aversie tegenover risico's en complexiteit. Mensen met een hogere mate van dergelijke aversies zullen bijvoorbeeld sneller geneigd zijn om bepaalde *heuristics* (zogenaamde vuistregels voor beslissingen) in te zetten om sneller beslissingen te kunnen nemen, bijvoorbeeld om rechten te verkopen zodra deze een bepaald prijsniveau hebben bereikt.

Een eerste implicatie van de literatuurstudie is dat in toekomstig onderzoek naar de effecten van *tradable credits* op autogebruik de potentiële aanwezigheid van dergelijke gedragseffecten een prominentere plaats moet innemen. Een tweede implicatie is methodologisch van aard. Het meeste bestaande empirische onderzoek is gebaseerd op een onderzoeksopzet waarbij niet wordt aangesloten bij de dagelijkse realiteit van respondenten. Er is bijvoorbeeld enkel gevraagd hoeveel kilometers of ritten respondenten zouden willen reduceren op geaggregeerd niveau als reactie op een *tradable credit* scenario. Of er werd aan respondenten gevraagd beslissingen te maken op basis van hypothetische ritten. Dit proefschrift beargumenteert dat het cruciaal is om gebruik te maken van realistische scenario's, waarin respondenten in de context van hun ervaren reisgedrag wordt gevraagd om een afweging, waarbij zij dus rekening dienen te houden met hun alledaagse behoeften voor het participeren in activiteiten, hun sociale omgeving, en de reisalternatieven die in deze specifieke gevallen voorhanden zijn. Het doel van dit proefschrift is vooral om, vanuit deze tweede implicatie, de effecten van de verhandelbare kilometerrechten (VKR) maatregel op individueel autogebruik na te gaan aan de hand van de zogenaamde *activity-based* benadering, een benadering die reisgedrag niet als iets abstracts ziet maar als ingebed in concrete activiteiten met hun eigen beperkingen en onderlinge relaties.

Onderzoeksopzet

Er zijn twee typen experimenten opgezet. Experiment I was gericht op frequente forenzen en is alleen in Nederland uitgevoerd (308 participanten), terwijl experiment II was gericht op autobezitters in het algemeen en naast Nederland ook in Beijing is uitgevoerd (respectievelijk 474 en 660 participanten). In experiment I hebben participanten gedurende 7 achtereenvolgende dagen hun afzonderlijke autoritten bijgehouden, waarbij zij gedetailleerde informatie over ritten en activiteiten hebben gegeven. Vervolgens is hun in een tweetal scenario's een aantal verhandelbare kilometerrechten voor de betreffende week toegekend, waarbij het aantal toebedeelde rechten voor elke participant hetzelfde was. In reactie op de scenario's, waarin participanten op basis van hun gereden kilometers ofwel een tekort of overschot aan rechten hadden, konden participanten aangeven of zij hun autogebruik zouden hebben aangepast wanneer het scenario voor de betreffende week zou gelden. Aan de hand van verschillende opties konden zij hun ritten/activiteitenpatroon anders inrichten om een verandering in het gebruik van rechten te realiseren.

Experiment II was eenvoudiger van opzet. Participanten rapporteerden enkel het aantal ritten en het geschatte aantal kilometers dat zij gemaakt hadden voor verschillende activiteitencategorieën in de voorafgaande 7 dagen. Vervolgens werd hen een scenario gepresenteerd waarin zij ofwel een zeker tekort ofwel een zeker overschot aan rechten hadden, waarbij de mate van tekort/overschot niet afhankelijk was van de door hun opgegeven kilometers maar willekeurig was toegekend. Participanten konden aangeven voor welke activiteitencategorieën zij aanpassingen wilden maken in reactie op het scenario.

Beide experimenten sloten af met een vragenlijst over houdingen ten opzichte van congestie, persoonlijk autogebruik en de verhandelbare kilometerrechten maatregel.

Gedragseffecten

De resultaten van experiment I, zoals besproken in hoofdstuk 3, laten zien dat de verhandelbare kilometerrechten maatregel, zoals getest in dit onderzoek, een substantiële verandering in autogebruik onder forenzen teweeg kan brengen. Alle participanten samen brachten hun aantal autokilometers terug met 20,2% in het eerste scenario en 24,1% in het tweede scenario, waar het aantal beschikbare rechten voor de gehele groep participanten correspondeerde met een reductiedoel van respectievelijk 17,5% en 32,2% van het totale aantal autokilometers. Leeftijd, huishouden, geslacht en woonomgeving zijn relevante factoren in de bereidheid om autogebruik aan te passen, waarbij jongeren, mannen, degenen met een groter huishouden en degenen die in een stedelijke omgeving wonen meer geneigd zijn om te veranderen. Wanneer gekeken wordt naar ritten- en activiteitenpatronen blijkt dat deze patronen voor de genoemde groepen flexibeler, diverser en/of minder noodzakelijk zijn, wat mogelijk een rol speelt bij de mate van bereidheid tot aanpassen.

Wanneer gekeken wordt naar de typen ritten die veranderd worden (hoofdstuk 4), blijkt dat ritten die uitgevoerd worden voor sport, hobby en recreatie het meest worden aangepast en ritten die zijn gerelateerd aan werk en onderwijs het minst. Zoals te verwachten hangt dit sterk samen met de gerapporteerde mate van belang en flexibiliteit van deze ritten/activiteiten. Het veranderen van vervoerswijze is de meest gekozen veranderingsstrategie, waarbij de fiets tweemaal zo vaak gekozen wordt als het openbaar vervoer. In bijna 25% van de gevallen van verandering is gekozen voor het annuleren van de rit. Vanuit het experiment is het echter helaas niet vast te stellen of het hier gaat om het geheel stoppen, thuis uitvoeren of uitstellen van de activiteit. Slechts 5% van de gevallen van verandering betreft het herschikken van de activiteit in het opgegeven activiteitenpatroon. Deze optie leverde over het algemeen maar een kleine besparing van de rechten op; te verwachten is dat deze optie populairder zal zijn wanneer de maatregel onderscheid maakt naar tijdsperioden, bijvoorbeeld wanneer reizen buiten de spits geen of minder rechten kost. Op basis van modelschattingen blijken rit- en persoonskenmerken ook in de keuze van de veranderingsstrategieën blijken belangrijke factoren te zijn.

De uitkomsten van experiment II, die in hoofdstuk 5 besproken zijn, laten een lagere bereidheid tot het aanpassen van autogebruik zien. 30% en 15% van de participanten in Nederland rapporteerden een bereidheid tot aanpassing in het geval van een tekort respectievelijk overschot aan rechten. Daarbij moet worden opgemerkt dat de groepen participanten en de opzet van het experiment fors verschilden met die van experiment I. Beide experimenten dienden een ander doel en mogen daarom ook niet een op een met elkaar vergeleken worden. In Beijing gaf zo'n 60% van de participanten aan hun autogebruik te hebben veranderd mocht de maatregel betrekking hebben op de door hun gerapporteerde ritten, zowel in het geval van een tekort aan rechten als in het geval van een overschot aan rechten. Verklaringen voor dit verschil tussen Nederland en Beijing moeten gezocht worden in de sterk verschillende context. Beijing is een megastad, waar alternatieven voor autogebruik ruim voorhanden zijn, wat niet het geval is voor alle Nederlandse regio's, en waar een groter deel van de inwoners wellicht gevoeliger is voor kosten vanwege de grotere verschillen in inkomen. Verder manifesteren congestie en autogerelateerde luchtvervuiling zich op ongekende schaal in Beijing en geven de inwoners van Beijing aan sterk ontevreden te zijn met de huidige maatregelen die bedoeld zijn om autogebruik te beteugelen, zoals het verbod op gebruik van de auto gedurende één dag per week en de loterij die wordt gebruikt om nieuwe vergunningen voor auto's uit te geven.

Resultaten uit Beijing laten ook zien dat een deel van de participanten aangeeft juist hun autogebruik te willen intensifiëren onder de VKR maatregel, zelfs in een situatie van een tekort aan rechten. In Nederland is deze trend nagenoeg afwezig. Dit kan mogelijk verklaard worden doordat een deel van de inwoners van Beijing hun huidige behoefte aan autogebruik beperkt ziet zijn door de huidige maatregelen en de hoge congestieniveaus. Mogelijkerwijs verwachten zij dat de VKR maatregel betere wegcondities garandeert en zijn zij bereid om de noodzakelijke extra rechten die voorzien in hun werkelijke behoeften aan te schaffen, waarbij de hogere monetaire kosten voor het inkopen van rechten opwegen tegen de huidige kosten van beperkte behoeftebevrediging en wachttijd in de file.

Acceptatie

In hoofdstuk 6 is de sociale acceptatie van de verhandelbare kilometerrechten maatregel, zoals gedefinieerd in dit proefschrift, en haar determinanten onderzocht op basis van gegevens van experiment II. Zoals verwacht zijn er grote verschillen tussen Nederland en Beijing op dit gebied, die samenhangen met de sterk verschillende contexten. In Nederland ziet 21,6% van de participanten de maatregel in meer of mindere mate als acceptabel, terwijl dit cijfer in Beijing 67,0% is. De relatief hoge acceptatiegraad voor Beijing kan mogelijk verklaard worden doordat de problemen van autogebruik in termen van congestie en luchtvervuiling als een urgenter probleem wordt ervaren, waardoor inwoners van deze stad meer overtuigd zijn van de noodzaak van een effectieve aanpak ervan. Daarnaast zijn de inwoners van Beijing al bekend met de huidige strenge maatregelen om autogebruik in te perken, die over het algemeen als niet-effectief en oneerlijk worden gezien. Ongeveer twee derde van de participanten ziet de VKR maatregel als een effectievere en eerlijkere maatregel dan het huidige verbod op autogebruik gedurende één dag in de week. In Nederland, waar de VKR maatregel met de maatregel van kilometerheffing, een vast bedrag per kilometer, vergeleken is, beoordeelde 25,6% en 27,1% de maatregel als effectiever respectievelijk eerlijker dan kilometerheffing.

Wat de determinanten van de acceptatie van de maatregel betreft laten de modelschattingen zien dat subjectieve evaluaties van de maatregel een groter effect hebben dan sociaal-demografische kenmerken. Met name de ervaren eerlijkheid/rechtvaardigheid en de verwachte effectiviteit spelen een grote rol. In het geval van sociaal-demografische kenmerken speelt alleen inkomen een rol, waarbij zowel in Nederland als in China de maatregel een hogere mate van acceptatie heeft onder participanten met een hoger inkomen. Meer dan eens wordt beargumenteerd dat de VKR maatregel tegemoetkomt aan de feit dat in gevallen van conventionele wegbeprijzing huishoudens met een lager inkomen relatief slechter af zijn dan huishoudens met een hoger inkomen. In het geval van VKR wordt namelijk elke deelnemer een minimum aantal 'gratis' rechten verleent en daarbij zijn huishoudens met lagere inkomens vaak de huishoudens die minder kilometers maken en daardoor eerder in staat zijn rechten te kunnen verkopen. Dit vertaalt zich echter niet in het wegvallen van het 'klassieke' verschil in steun voor beprijzen van autogebruik tussen hogere en lagere inkomens dat zich gewoonlijk manifesteert in het geval van conventionele beprijzingsmaatregelen. Een reden waarom participanten met een lager inkomen de maatregel als minder acceptabel vinden kan zijn dat zij verwachten dat in een markt de vraag naar rechten de prijs van de rechten zal opstuwen en zo de rechten voornamelijk naar de huishoudens met een hoger inkomen zullen vloeien. Dit lijkt vooral in Beijing een rol te spelen, waar er grote verschillen in inkomens zijn en een sterke competitie voor de schaarse ruimte op de weg bestaat. In Beijing speelt ervaren eerlijkheid/rechtvaardigheid een sterkere rol als determinant van acceptatie dan in Nederland. Verder gaf een grote groep van participanten in Beijing in de ruimte voor opmerkingen aan bezorgd te zijn voor deze potentiële trend.

Wetenschappelijke bijdrage en toekomstig onderzoek

Dit proefschrift levert een belangrijke nieuwe bijdrage aan bestaande kennis in de zin dat het vanuit een *activity-based* benadering, mede beïnvloed door de tijdgeografie, verwachte effecten van VKR programma's heeft verkend. In tegenstelling tot het beperkte aantal studies dat tot dusverre verschenen is, is in de benadering van deze studie aangesloten bij de werkelijke activiteitenpatronen van de participanten gedurende meerdere dagen. Hierdoor is het empirische onderzoek gesitueerd in de behoeften, mogelijkheden en beperkingen die de deelnemers ervaren met betrekking tot hun dagelijkse activiteitenparticipatie en gebruik van vervoersmiddelen, waardoor de effecten op een realistischer manier kunnen worden geschat. Daarbij is de *stated adaptation* techniek zoals gebruik in experiment I een waardevol onderzoeksinstrument gebleken. De online applicatie was in staat om multidimensionale aanpassingen (combinaties van aanpassingen) te vangen, wat niet altijd het geval is in bestaande toepassingen van de relatief nieuwe *stated adaptation* benadering.

Een andere belangrijke bijdrage van dit onderzoek is dat het het belang van subjectieve evaluaties en attitudes in responses jegens en steun voor de VKR maatregel laat zien. Dit besef is uiteraard gemeengoed in de op de psychologie georiënteerde studies, maar het belang van subjectieve evaluaties en attitudes wordt niet altijd even goed onderkend in de meer economische studies. Dit onderzoek laat bijvoorbeeld zien dat ervaren autoafhankelijkheid, niet alleen in instrumentele zin maar ook in affectieve en symbolische zin, een sterke rol heeft in de responses van autogebruikers. Deze factoren zijn met name relevant gebleken in het vergelijken van de Nederlandse en Chinese contexten, met elk hun eigen autoculturen.

Het bestuderen van responses in zowel Nederland als Beijing is een derde waardevolle toevoeging aan de huidige wetenschappelijke kennis. Hoewel de beide contexten dusdanig verschillen dat er nauwelijks sprake kan zijn van een directe vergelijking, biedt deze studie wel een antwoord op de dringende behoefte aan een verrijking van de literatuur op het gebied van het (anders) beprijzen van autogebruik vanuit niet-westerse contexten. Dit proefschrift levert zowel een eerste verkenning van VKR effecten vanuit een Chinese context als een grondige discussie van de wijze waarop lokale geografische, institutionele en culture factoren responses kunnen hebben bepaald en waarom het belangrijk is dit in acht te nemen bij beleidsoverwegingen. Tegelijk zijn er facetten die mogelijk van waarde zijn bij het duiden van verschillen in responses die geen plek hebben kunnen krijgen in dit onderzoek. Er is in het proefschrift gesteld dat verschillen in denken over de rol van overheid, persoonlijke vrijheid en percepties van rechtvaardigheid, die als concept meerdere aspecten kunnen behelzen, een rol kunnen spelen bij het verder begrijpen van contextuele verschillen, maar de precieze rol zal verder uitgediept moeten worden in toekomstig onderzoek.

Geografische context bleek ook relevant te zijn wanneer naar meer gedetailleerde aanpassingspatronen werd gekeken voor de Nederlandse situatie. Dit wordt ook niet altijd door de literatuur op het gebied van (anders) beprijzen van autogebruik op waarde geschat, maar is wel degelijk van belang om mee te nemen bij het beter bepalen van de effecten van prijsbeleid. Autogebruik is namelijk per definitie geografisch van aard.

Dit onderzoek is gebaseerd op vooraf bepaalde scenario's en heeft deelnemers gevraagd om op retrospectieve wijze hun opgegeven autogebruik te evalueren bij een vaste prijs per kilometerrecht. Dit levert waardevolle kennis op over hoe deelnemers hun rechten wensen in te zetten en maakt het mogelijk om het effect van gerapporteerde activiteiten/rit kenmerken expliciet te meten bij het inzetten van rechten. Echter, een waar VKR programma maakt gebruik van een markt waarin de prijs per recht variabel is en afhangt van vraag en aanbod. Het is daarom belangrijk dat toekomstig onderzoek inzet op gedragingen van autogebruikers in een dynamische VKR omgeving, waarin deelnemers met elkaar kunnen handelen, prijzen variabel zijn, en deelnemers keuzes moeten maken over activiteiten/ritten die voor hen in tijd liggen. Hierbij is het van belang om nadrukkelijk na te gaan wat het effect van onzekerheid en handelen over een langere tijdshorizon is, omdat dit de kenmerken zijn die de maatregel uniek maken en waarvan op basis van in hoofdstuk 2 behandelde literatuur verwacht kan worden dat het specifieke gedragsmechanismen in werking zet.

Field trials en *gaming* kunnen waardevolle instrumenten bieden in een dergelijke dynamische onderzoekscontext. Tegelijk is het ook belangrijk om *disaggrated* benaderingen, waarvan deze studie een voorbeeld is, en *aggregated* benaderingen, waarin netwerkeffecten centraal staan, samen te brengen. Door bijvoorbeeld *bi-level* optimalisatie kunnen beslissingen van individuele autogebruikers geïntegreerd worden met de attributen van de maatregel op hogere schaal, zoals de verdeling van rechten over gebruikers en verkeersstromen in een netwerk.

Beleidsimplicaties

Op het moment van schrijven is er met groeiende congestieniveaus in Nederland weer hernieuwde aandacht voor alternatieve beprijzingsmaatregelen voor autogebruik. In Beijing is er onvrede over de bestaande strikte maatregelen, die veel negatieve neveneffecten blijken te hebben en door veel inwoners als oneerlijk worden beschouwd. Dit maakt de discussie over de VKR maatregel als beprijzingsalternatief erg relevant.

De resultaten laten zien dat in de Nederlandse context de maatregel qua effectiviteit kan concurreren met een conventionele kilometerheffing, waarvan de effecten in andere recente studies zijn verkend. Weliswaar is de maatregel in theorie altijd effectief omdat de reductie in autokilometers altijd overeen zal komen met de door de autoriteit gestelde limiet – de markt zorgt daarvoor. Wat deze studie echter laat zien is dat een VKR programma waarin de rechten een vaste prijs hebben, en die als een mogelijke variant gedacht kan worden, al tot een substantiële reductie van autokilometers kan leiden. Ook kan een sterke bereidwilligheid om autogebruik aan te passen erop duiden dat mogelijke prijsopdrijving van de waarde van de rechten in een ware markt niet direct te verwachten is voor de Nederlandse context.

Vanuit beleidsoptiek kan een VKR variant met een vaste prijs per recht, of een variant waarin de prijs in een beperkte bandbreedte mag variëren, een aantrekkelijke optie zijn. Auteurs hebben gewezen op de mogelijkheid van een VKR programma waarin de autoriteit zich committeert aan het uitbrengen en opkopen van rechten voor een vooraf gestelde minimum respectievelijk maximum prijs. Een dergelijk programma zou excessieve prijzen kunnen voorkomen en zou speculatie kunnen tegengaan. Hoewel een dergelijk programma in theorie minder efficiënt is, kan het de maatregel minder complex maken. Complexiteit is namelijk een serieuze barrière is voor acceptatie en implementatie van beleidsmaatregelen. Ook kan een dergelijk programma de gedachte dat de maatregel vooral degenen met een grotere koopkracht bevoordeelt adresseren, een gedachte die als relevant is gebleken in dit onderzoek.

De maatschappelijke steun voor de maatregel is een cruciale factor bij implementatie. Onder autobezitters in het algemeen ziet 21,6% de onderzochte maatregel als acceptabel. Dit is een relatief laag percentage, dat ook lager is dan de sociale steun voor de conventionele beprijzingsmaatregelen. Wel moet gezegd worden dat de maatregel geheel nieuw was voor de deelnemers. Op basis van andere studies is het te verwachten dat steun toeneemt wanneer men meer kennis en ervaring van een maatregel heeft. Verder gaf een groot deel van de deelnemers (36%) aan een neutrale houding ten opzichte van de maatregel te hebben. Het is te verwachten dat door bepaalde aanpassingen in het ontwerp van de maatregel de maatschappelijke steun vergroot kan worden. Daarom is het belangrijk om nader in kaart te brengen welke aspecten van VKR programma's (type deelnemers, mate van differentiatie, overdraagbaarheid van rechten, etc.) belangrijk zijn voor de acceptatiegraad en op welke manier zij de acceptatiegraad kunnen verhogen.

De steun voor de VKR maatregel is groter in Beijing, waar 67% van de ondervraagde autobezitters de maatregel acceptabel vindt. Dit hangt in grote mate samen met de ontevredenheid met de huidige maatregelen. Tegelijk laten resultaten zien dat een deel van de autobezitters geneigd is om autogebruik te intensiveren wanneer de VKR maatregel de huidige restrictie voor autogebruik zou vervangen. In de context van Beijing, met een sterke vraag naar autogebruik, heeft dit belangrijke gevolgen voor de beschikbaarheid van rechten. Sterke competitie zou de vraagprijs van de rechten fors kunnen opdrijven, wat weer implicaties heeft in termen van rechtvaardigheid en acceptatie van de maatregel. Het is duidelijk dat dergelijke tendensen verder aandacht dienen te krijgen in zowel onderzoek als maatschappelijke en politieke discussies.

Vanuit het perspectief van beleid moet er ook op gewezen worden dat de VKR maatregel, in tegenstelling tot conventionele vormen van beprijzing, in essentie budgetneutraal is. De maatregel leidt tot geldstromen die binnen de groep van autogebruikers circuleren in plaats van richting de overheid vloeien. Het is dus lastig om VKR als een volwaardig alternatief te zien voor de huidige autobelastingen vanuit het gezichtspunt van de overheid. Een alternatief dat door de literatuur aangeboden wordt is om rechten te verdelen op basis van een veiling in plaats van op basis van een vrije verdeling, waardoor opbrengsten worden gegenereerd om het stelsel van belastingen op autobezit en autogebruik te kunnen herzien. Ook is implementatie van VKR mogelijk op kleinere schaal, daar waar de problemen van congestie het grootst zijn, waardoor de maatregel naast bestaande maatregelen kan bestaan. Het is dan zaak dat deelnemers overtuigd zijn van de meerwaarde van VKR, dat gelegen is in het garanderen van een vrije doorstroom, om een nieuwe maatregel naast de reeds bestaande te accepteren. Ook is het denkbaar om de rechten aan een andere entiteit dan kilometers te koppelen, al naar gelang beleidsdoelen. Verhandelbare rechten systemen kunnen bijvoorbeeld ook ontworpen worden in relatie tot ritten in de spits en parkeren.

Dit proefschrift heeft zich gericht op een VKR systeem waarbij er vanuit het oogpunt van begrijpelijkheid voor de participanten niet is gedifferentieerd naar tijd en locatie. In theorie is een VKR programma dat onderscheid maakt in tijd en locatie efficiënter in het terugdringen van negatieve externaliteiten, waarbij bijvoorbeeld ook nog gedifferentieerd kan worden naar milieudruk van de auto. Echter, onderzoek laat zien dat er een spanning is tussen de theoretische wenselijkheid van flexibele prijsstructuren en de mate waarin mensen op rationele en effectieve wijze hierop kunnen reageren. Ook is het te veronderstellen dat de acceptatie sterk afhangt van de mate waarin een maatregel voor deelnemers begrijpelijk en de effecten te verwachten zijn. Daarom zal een wenselijk VKR programma altijd een juiste balans weten te vinden tussen theoretische efficiëntie en maatschappelijke acceptatie.

Curriculum Vitae

Nico Dogterom was born on 16 September 1987 in Leiden, the Netherlands. He completed the Bachelor programme Human Geography and Planning at Utrecht University in 2009. During his Bachelor studies he also participated in the Honours College Geosciences. In 2009, he started the Research Master programme Human Geography and Planning at Utrecht University. As part of this programme, he studied at Lancaster University, United Kingdom, for a couple of months.

After graduating in 2012, Nico completed several small research projects at the department of Human Geography and Planning at Utrecht University before he started his PhD research at the same department. In October-November 2016, he visited Beijing Jiaotong University to work together with the partners in the research project, which led to the two joint papers included in this thesis. One joint paper, Chapter 5, was nominated for the Best Student-Led Paper at the WSTLUR 2017 conference in Brisbane, Australia.

During his PhD research, Nico acted as a representative in the PhD councils of the Faculty Geosciences (Utrecht Geograduates) and the University (Promovendi Overleg Utrecht). Since 2014, he is a member of the editorial team of AGORA magazine.

As of September 2017, Nico works as a postdoctoral researcher at the department of Human Geography and Planning at Utrecht University, studying the effects of the built environment characteristics on cycling behaviour, using virtual reality technology.