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

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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 future 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.

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Tradable credits; road pricing; travel demand measure; travel behaviour; behavioural economics; cognitive psychology

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 (Jones, 1998; Schade & Schlag, 2003). 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 policy-makers identify Tradable Credits (TC) as a promising powerful and innovative alternative (e.g. Raux, 2004; Verhoef, Nijkamp, & Rietveld, 1997; Viegas, 2001).

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

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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 (Baumol & Oates, 1988; Dales, 1963; 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, for example, the EU Emission Trading Scheme, fishing quotas (Costello, Gaines, & Lynham, 2008; Newell, Sanchirico, & Kerr, 2005) and airport slot allocations (Fukui, 2010; Wit & Burghouwt, 2008), 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. Goddard, 1999; Raux, 2004; Raux & Marlot, 2005; Viegas, 2001; Wadud, Noland, & Graham, 2008). 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. Nie, 2012; Wang, Gao, Xu, & Sun, 2014; Xiao, Qian, & Zhang, 2013; Yang & Wang, 2011). The third domain consists of studies that empirically investigate travel behaviour under TC schemes at 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 future 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; Ben-Elia & Avineri, 2015; Gaker & Walker, 2011; Metcalfe & Dolan, 2012). 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. Travel-related responses under TC schemes

Table 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).

2.1. Empirical results

The work by Wallace, Irvine, Wright, and Fleming (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 cycle. In their experiment, Capstick and Lewis (2010) 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, Capstick, and Poortinga (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, Bristow, and Wardman (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

Table 1. Summary of transport-related tradable credit studies.

Study	Methodology	*N*	Location	TC scheme	Compared measure	Main results	Link with behavioural economics/cognitive psychology
Wallace et al. (2010)	Survey questionnaire and interviews	334 (survey)	English Midlands, UK	Personal Carbon Trading (PCT)	None	Lower willingness to change travel compared to other carbon-saving actions	None
Harwatt et al. (2011)	Interviews	60	Leeds, UK	PCT (only personal transport)	Fuel price increase (FPI)	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)	Simulation experiment	64	UK	PCT	None	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)	Experimental survey questionnaire	1096	UK	Personal Carbon Allowance (PCA)	Energy tax and Carbon tax	• 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)	Simulation experiment	189	Southeast England, UK	PCT	Carbon tax	• 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

(*Continued*)

Table 1. Continued.

Study	Methodology	*N*	Location	TC scheme	Compared measure	Main results	Link with behavioural economics/cognitive psychology
Raux et al. (2015a)	Stated choice experiment	~300	France	PCT (only personal transport)	Carbon tax	• 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)	Stated choice experiment	900	France	PCT (only personal transport)	Several policies, including bonus-malus and tax	• 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)	Survey questionnaire	500	Austin, Texas, USA	Credit-Based Congestion Pricing (CBCP)	Congestion pricing	CBCP could compete with other transport policy measures to alleviate congestion	None
Aziz et al. (2015)	Experimental game	Unknown	Purdue, Indiana, USA	Personal Mobility Carbon Allowance	None	Development of experimental game to include market dynamics	Learning effects: spending of credits improves over time

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, Tight, Bristow, and Gühnemann (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, Croissant, and Pons (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, Chevalier, Bougna, and Hilton (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. 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 1000 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 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 1000 kilometre holiday trip.

The work by Aziz, Ukkusuri, and Romero (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.

2.3. 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 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, Kramer, Nielsen, & Schlag, 2011; Ubbels & Verhoef, 2005; Washbrook, Haider, & Jaccard, 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 (Capstick & Lewis, 2010; Parag et al., 2011; Raux et al., 2015a; Zanni et al., 2013), set of activities/trips (Aziz et al., 2015; Harwatt et al., 2011; Kockelman & Kalmanje, 2005) 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; Gärling et al., 2002; Jones, Koppelman, & Orfeuil, 1990), 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.

3. Behavioural approaches to decision-making under TC

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 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, Gao, Xu, & Yang, 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 (see for an overview Table 2).

Table 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) and 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) and 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) and 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) and van Dijk and van 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 (1974)	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)and Loomes and Sugden (1982)	People anticipate the possibility of regret felt if an 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) and 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

3.1. Facing gains and losses

3.1.1. Gains versus 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 (Bolderdijk, Knockaert, Steg, & Verhoef, 2011; Mazureck & van Hattem, 2006) 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 (Ben-Elia & Ettema, 2011; Ettema, Knockaert, & Verhoef, 2010; Knockaert, Tseng, Verhoef, & Rouwendal, 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, Ben-Elia, Ettema, and van Delden (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, Knetsch, & Thaler, 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 (Schwanen & Ettema, 2009; Senbil & Kitamura, 2004). 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", that is, 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.

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, 2002; 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 Section 3.3.5.). 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 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.

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 (Levin, Schneider, & Gaeth, 1998; Tversky & Kahneman, 1981). For example, Hardisty, Johnson, and Weber (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. (2011) 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 section, 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.

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", that is, 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 (Antonides, de Groot, & van Raaij, 2011; Heath & Soll, 1996; Thaler, 1999). 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, Mak, and Idson (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, 2005; 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.

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.

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 (Bonsall, Shires, Maule, Matthews, & Beale, 2007; Franke & Kaniok, 2013; Link, 2015). 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", that is, mental short-cuts (rules of thumb) to ease the effort of decision-making, or to prefer the status quo, that is, to stick to the current situation (Gigerenzer, Hertwig, & Pachur, 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.

3.3.2. Endowment effect under uncertainty

Although the endowment effect (see Section 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.

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 (Ben-Elia, Ishaq, & Shiftan, 2012; Chorus, 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, that is, 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 facing a potential credit shortage/surplus later are typical TC circumstances in which the concept of regret anticipation could offer a helpful framework for understanding the outcome of such trade-offs.

3.3.4. Immediacy effect

In behavioural economics and cognitive psychology, *intertemporal choices* have received much attention (Berns, Laibson, & Loewenstein, 2007; Frederick, Loewenstein, & O'Donoghue, 2002; Read, 2004). 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 (Ainslie, 1975; Lynch & Zauberman, 2006; Shefrin & Thaler, 1992). 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.

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 (Ben-Elia & Avineri, 2015; Thorndike, 1898). At the same time, the decision-making literature showed that highly uncertain choice contexts hampers learning, that is, decision-makers seem to move towards random choice when the payoff variability increases (Busemeyer & Townsend, 1993; Myers & Sadler, 1960). Interestingly, the investigation of decision-making in iterative, feedback-based decisions has 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.

4. Conclusion and future research

This paper contributed in two ways to the recent increase in interest in the concept of 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; Gärling et al., 2002; Jones et al., 1990). 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 to present 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 have recently been applied to test the effect of travel time information on road choice (Avineri & Prashker, 2006; Ben-Elia & Shiftan, 2010), provides 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 (Hollander & Prashker, 2006; Levinson, 2005). 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.

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