Evaluating and Optimization of the Credit Charge-cum-Reward Scheme:Experiments based on a Collaborative Experimental Platform

Chenke Hu[1], Linghao Wang[2], Hongxing Ding[3], Zheng Zhu[2,*], Jun Zhao[4,*], Hai Yang[3]

1. Institute of Intelligent Transportation Systems & Polytechnic Institute, Zhejiang University, Hangzhou, China
2. College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, China
3. Department of Civil and Environment Engineering, Hong Kong University of Science and Technology, Hong Kong, China
4. Department of Civil & Architectural Engineering and Mechanics, University of Arizona, Tucson, Arizona, United States

1. INTRODUCTION

Carbon neutrality is a global long-term goal, and transportation accounts for a large proportion of total carbon emissions(1). Consequently, reducing Greenhouse Gas (GHG) emissions within transportation has emerged as a critical challenge. By deploying a multi-day travel mode choice-related carbon credit and charging/rewarding travelers based on their cumulative credits, the Credit Charge-cum-Reward (CCR) scheme has emerged as a promising strategy to balance equity considerations among citizens while addressing fiscal constraints faced by policymakers(2). This study bridges the gap between theoretical research and practical implementation by developing an experimental platform for multi-person collaborative games to evaluate the performance of CCR and a nudge-integrated CCR in regulatory practices. The methodology translates theoretical frameworks into practical experiments, addressing challenges such as heterogeneity in Values of Time (VOT), optimal charge and reward mechanisms, and precise experimental parameter calibration.

2. CCR SCHEME,PARAMETERS AND THEORETICAL EQUILIBRIUM

CCR scheme

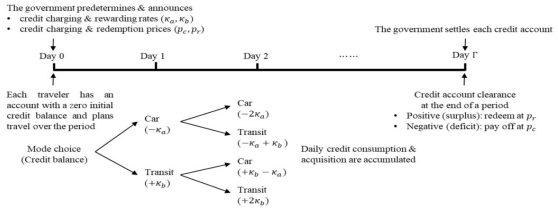

Figure 1. Illustration of the CCR scheme, reprinted from (2)

Consider a specific commuting scenario where there is one public transit route and one car routethat connect a residential area and a central business district. Each day, N (N>0, fixed over the CCR period) travelers with heterogeneous VOTs travel from home to work. Each traveler can either take public transit or drive a private car to meet daily commuting needs.

Scenario setting

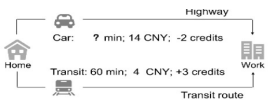

Figure 2. Scenario setting

Consider a specific commuting scenario where there is one public transit route and one car routethat connect a residential area and a central business district. Each day, N ($N>0$, fixed over the CCR period) travelers with heterogeneous VOTs travel from home to work. Each traveler can either take public transit or drive a private car to meet daily commuting needs.

Parameters

Table 1. Parameters in experiments

name	value	name	value
N	15 people	κ_a	2
t_a	$20\times\left(1+0.15\times\left(\frac{V_a}{G}\right)^2\right)$ min	κ_b	3
t_b	60 min	p_c	3CNY
τ_a	14 CNY	p_r	1.5 CNY
τ_b	4 CNY	Γ	20 days
VOTs	[20,36,50]CNY/h(low/meidum/high VOT)		

theoretical equilibrium

Under the CCR scheme, low and high VOT subjects would, respectively, choose transit and car for all the 20 days. And medium VOT subjects would opt for car over 60% of time and transit for the rest of time.

3. EXPERIMENT DESIGN

Procedure

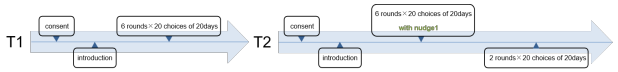

Figure 3. Experiment procedure including relevant steps and variables

Baseline experiment（T1）

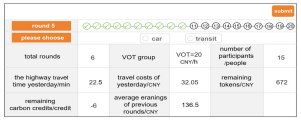

Figure 4. Picture of the platform interface in the T1

every day, subjects need to choose between options 'car' and 'transit' and then submit their decisions by clicking the 'submit' button. After all subjects in the experiment have submitted their decisions, the server calculates the travel metrics. On the new (next) day, calculated metrics are fed back to the subjects，as shown in the Fig.4.

Nudge experiment（T2）

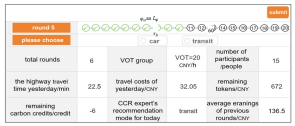

Figure 5. Picture of the platform interface in the T2

we added "CCR expert's recommended mode for today" on the experimental interface in rounds 1 to 6 of T2, as shown in the Fig.5. But in rounds 7 to 8, we cancel the nudge.

4. PLATFORM-BASED EXPERIMENT IMPLEMENTATION

Subjects

150 students from Zhejiang University have participated in the laboratory experiments and received monetary compensation based on their performance.

Table 2. Basic information of the subjects in each session

Session	Male	Undergraduate	Age
T1	43%	54%	22.66
T2	59%	58%	22.51
Mean	51%	56%	22.58

Implementation

- The experiments lasted about 60 minutes each.
- At the beginning of each round, each subject is given a certain number of tokens. The earnings for each round are calculated by subtracting the travel costs of a full round from the tokens. Cumulative earnings of multiple rounds are converted to Chinese Yuan at a fixed ratio. This payoff plus a 25 CNY show-up fee is a subject's total reward. Excluding the show-up fee, the mean payoffs in the two sessions are about 46.2 CNY for T1 and 54.2 CNY for T2.

Figure 6. Photo of the experimental site

Table 3. initial tokens and conversion ratio of three groups

	VOT = 20 CNY/h	VOT = 36 CNY/h	VOT = 50 CNY/h
Initial tokens(CNY)	480	800	980
Conversion ratio	100:9	100:6.5	100:5

5. RESULTS

φ_m denotes the proportion of car usage until day m of a certain VOT group in this current round, L_φ denotes the convergence value of φ_m within a round (i.e., the value of φ_m on the day Γ), and σ denotes the deviation between L_φ and the theoretical value.

1）conclusion1：

T1 reveals notable mode-choice deviations in high-VOT groups between the experiment and the theoretical model, highlighting the irrational behavior in practice. Notably, such irrational behavior undermines the fiscal advantages of the CCR and threatens its sustainability: The government initially expected a revenue of 10 CNY/person per round, but in T1, it converges to an revenue (i.e., the revenue of the round 6) of only 1.08 CNY/person per round.

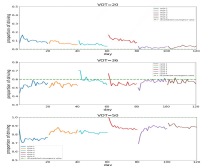

Figure 7. Proportion of driving for three groups in session T1

Table 4. L_φ for three groups of rounds 3 to 6 in session T1

Round	VOT=20 CNY/h	VOT=36 CNY/h	VOT=50 CNY/h
Round 3	0.035（3.5%）	0.543（9.5%）	0.824（17.6%）
Round 4	0.080（8.0%）	0.541（9.8%）	0.859（14.1%）
Round 5	0.028（2.8%）	0.580（3.3%）	0.869（13.1%）
Round 6	0.037（3.7%）	0.570（5.0%）	0.884（11.6%）
Mean value	0.045（4.5%）	0.559（4.1%）	0.859（14.1%）
Standard deviation	0.020	0.017	0.022

2）conclusion2：

The introduction of the nudge("expert recommendation") within the CCR scheme showed promising results, aligning outcomes more closely with theoretical expectations without additional costs to the government. This approach significantly impacted high VOT groups, expanding government revenue to over 3 times.

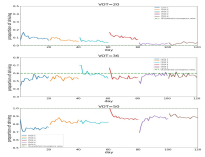

Figure 8. Proportion of driving for three groups in session T2

Table 5. Changes of σ from T1 to T2 (rounds 3 to 6)

Round	VOT=20 CNY/h	VOT=36 CNY/h	VOT=50 CNY/h
Round 3	0.035（3.5%）	0.543（9.5%）	0.824（17.6%）
Round 4	0.080（8.0%）	0.541（9.8%）	0.859（14.1%）
Round 5	0.028（2.8%）	0.580（3.3%）	0.869（13.1%）
Round 6	0.037（3.7%）	0.570（5.0%）	0.884（11.6%）
Mean value	0.045（4.5%）	0.559（4.1%）	0.859（14.1%）
Standard deviation	0.020	0.017	0.022

3）conclusion3：

In the context of the CCR scheme, short-term nudges can have long-term effects by cultivating habits of travelers: We conduct a t-test hypothesis test with a significance level of 5% on the L_φ between the rounds 5-6 and 7-8 and the tests are accepted for all three VOT groups (p-values: 0.2048, 0.3949, 0.7952), showing no remarkable difference after the removal of nudge.

Table 6. Average value of φ_m with variance value in T2

	VOT=20CNY/h		VOT=36CNY/h		VOT=50CNY/h	
Rounds	Rounds 5-6	Rounds 7-8	Rounds 5-6	Rounds 7-8	Rounds 5-6	Rounds 7-8
Mean φ_m	0.0344	0.0212	0.5780	0.5820	0.9230	0.9240
Variance φ_m	2.1e-05	5.1e-06	0.0002	0.0005	0.0002	0.0007

1.U.S. Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. U.S. Environmental Protection Agency, 2022.
2.Ding, H., and Others. Credit Charge-cum-Reward Scheme for Green Multi-Modal Mobility. Transportation Research Part B: Methodological, 2023. 178(January): 102852.