



Mode share equilibrium with tradable credit scheme and license plate rationing

L Balzer, L Leclercq

► To cite this version:

L Balzer, L Leclercq. Mode share equilibrium with tradable credit scheme and license plate rationing. 10th Symposium of the European Association for Research in Transportation, hEART2022, Jun 2022, Louvain, Belgium. pp.4. hal-04662220

HAL Id: hal-04662220

<https://hal.science/hal-04662220v1>

Submitted on 25 Jul 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Mode share equilibrium with tradable credit scheme and license plate rationing

L. Balzer^{*,1} and L. Leclercq¹

¹ Univ Gustave Eiffel, ENTPE, LICIT, F-69675 Lyon, France
louis.balzer@univ-eiffel.fr

SHORT SUMMARY

License plate rationing (LPR) is an established measure to decrease car demand and thus decrease exhaust gas emissions. However, it has significant drawbacks: drivers can circumvent this policy by acquiring a second vehicle, and it does not account for the users' necessity to drive their car. The Tradable Credit Scheme (TCS) was introduced about one decade ago as another Demand Management Strategy (DMS). We propose comparing LPR and TCS over a large and realistic simulation test case (morning commute in Lyon), considering several days as a horizon. A trip-based Macroscopic Fundamental Diagram (MFD) represents the congestion dynamics. The modal split between private cars and Public Transportation (PT) is computed at equilibrium. We show the TCS surpasses the LPR in terms of both social costs and carbon emissions.

Keywords: license plate rationing; mode choice; tradable credit scheme; traffic flow theory; transport economics and policy; trip-based MFD.

1 INTRODUCTION

Most cities around the world face traffic congestion. It induces productivity losses, contributes to climate change, and increases the risks of respiratory illnesses. Several DMS are investigated in the literature to reduce the number of private cars on the road network. The TCS requires users to have credits to travel by private car. The goal is to foster PT usage. Those credits are issued by the regulating entity and can be freely traded with other users. The market determines the credit price, see Lessan & Fu (2019) for an overview of TCS. Yang & Wang (2011) is the first mathematical formulation of a TCS for a network considering BPR (Bureau of Public Roads) cost functions.

LPR restricts the use of personal cars by allowing only cars with odd plate numbers to drive every other day and cars with even plates to drive on the remaining days. It has been implemented in several cities and is usually enforced during pollution peaks. However, in Nie (2017a) and Nie (2017b), the author shows for a single Origin-Destination pair that LPR is ineffective as it fosters the acquisition of a second car. He presents TCS as a good alternative.

In most of the works on TCS, the congestion model is based on the BPR cost function. As the BPR function is a static model, the travel time depends only on the number of vehicles using the road segment and does not account for congestion dynamics. We use here the trip-based MFD concept (Mariotte *et al.* (2017), Lamotte & Geroliminis (2018)) as an alternative. It considers the time-evolution of traffic congestion over the network at a large scale and takes into account the heterogeneity of the trip lengths.

This paper investigates the equilibrium of a trip-based MFD under a TCS over several days and compares it with LPR. The demand is elastic as we account for modal choice: car or PT. The need for driving private cars may vary over days, e.g., when picking up someone or buying groceries. To account for this, riding PT on given days induces a penalty. The novelty lies in simultaneously considering the congestion dynamics with an MFD framework and comparing TCS against LPR across different days.

2 METHODOLOGY

The users are aggregated into N groups. Each group i consists of γ_i travelers, has a fixed trip length l_i and departure time t_i . It means the travelers of the same group are starting simultaneously and following the same route. Thus, they have the same car and PT travel time. Its degree-of-freedom is the ratio of car users per day d : $x_{d,i}$. As we are using a trip-based MFD framework, the travel time per car T_i of the group i is defined by:

$$l_i = \int_{t_i}^{t_i+T_i} V(t) dt. \quad (1)$$

We assume the travel time per PT $T_{i,PT}$ is independent of the vehicles' accumulation and depends only on the route, i.e., the Origin-Destination (OD) pair. We retrieve the PT travel times from a city planner application that gathers historical data characterizing typical traffic conditions and PT timetables. We also assume the car travel times only depend on car accumulation. The trip-based MFD already accounts for typical PT operations. The costs for a traveler of a group i on a day d is given by:

$$\begin{cases} C_{i,car}(d) &= \alpha T_i(\mathbf{x}_d) + (\tau - \kappa) p_d; \\ C_{i,PT}(d) &= \alpha T_{i,PT} + \mu_i(d) - \kappa p_d, \end{cases} \quad (2)$$

where α is the value-of-time (VoT), τ the credit charge: the number of credits needed to drive a car, p_d the credit price, the allocation κ : the number of credits each traveler gets for free from the regulator, and $\mu_i(d)$ the penalty for using PT on day d . It represents a day-specific crucial need to use the car. The decision process is based on logit. The share of group i which *wants* to take the car is:

$$\psi_{d,i}(\mathbf{x}_d, p) = \frac{e^{-\theta C_{i,car}(d)}}{e^{-\theta C_{i,car}(d)} + e^{-\theta C_{i,PT}(d)}}, \quad (3)$$

with θ the coefficient of the logit.

The credit price is defined by the market-clearing condition (MCC): the price is non-zero if and only if all the issued credits are consumed. Furthermore, the number of consumed credits cannot exceed the number of allocated ones. The equilibrium is reached when the modal shares equal the modal decisions. It is formalized with the following set of equations for a day d :

$$\begin{cases} \psi_d &= \mathbf{x}_d; \\ p_d \left(\sum_{i=1}^N \gamma_i (\kappa - \tau x_{d,i}) \right) &= 0; \\ \sum_{i=1}^N \gamma_i (\tau x_{d,i} - \kappa) &\leq 0. \end{cases} \quad (4)$$

A cost function is formulated to minimize the gap between the modal shares and logit-based decisions. At the same time, the MCC should hold. It is added into the cost function to avoid non-affine constraints for computational purposes. The quadratic cost function is defined as

$$J = \frac{1}{2} \sum_{i=1}^N (x_{d,i} - \psi_{d,i})^2 + \eta \frac{1}{\sum_{i=1}^N \gamma_i} p_d \left(\sum_{i=1}^N \gamma_i (\kappa - \tau x_{d,i}) \right), \quad (5)$$

with η the coefficient related to the MCC.

The computation of the quadratic function is based on the linearization of the travel times with respect to the modal shares.

$$T_i = T_{0,i} + \nabla \mathbf{T}_i \cdot \Delta \mathbf{x}_d + o(\Delta \mathbf{x}_d). \quad (6)$$

One main aspect of this contribution quantifies the extra travel time induced by one user to the users (a.k.a. marginal external cost) in a trip-based MFD framework. See (Balzer & Leclercq (2021)) for more precisions.

When implementing LPR, the same framework is used. The main difference is that there is neither a credit charge nor a credit cap. Part of the population is always allowed to drive for different reasons,

such as low-emission cars or drivers with special authorizations. This ratio is the LPR tuning parameter. For the rest of the groups, only half of them are allowed to drive every two days. Only the other half can drive on the other days. For those groups allowed to drive their cars, their modal shares are equal to their logit-based decisions at equilibrium. For the other groups, their modal shares are equal to zero on this day, and they are forced to ride the PT.

3 RESULTS AND DISCUSSION

To illustrate the proposed methodology, we simulate a typical morning commute in Lyon between 7:00 and 10:00. We use the same demand and network as in Balzer & Leclercq (2021). The 384 200 travelers are aggregated into 1 374 groups. It ensures at least one group for each of the 224 OD pairs for each hour and at most 1 000 travelers per group. It is a compromise between numerical complexity and accounting for the diversity of the trips. We compute the modal equilibrium without DMS, with LPR and TCS for ten different days. The number of travelers facing a penalty for using the PT is represented in Fig. 1. The toll equivalent is defined as the out-of-pocket money one traveler spends to buy the additional credits needed to drive its car: $(\tau - \kappa)p_d$. The satisfaction rate is the proportion of travelers who need to drive their cars and drive them compared to the number of travelers who need to drive their cars. The social cost is defined as the sum of the travel time weighted by the VoT and the PT penalty. To assess the contribution of the personal car drivers to global warming, we compute the carbon emission using a COPERT IV model with the parameters from Lejri *et al.* (2018). The numbers are the ratio of users allowed to drive their car under the TCS κ/τ (e.g., 33% means there is a maximum of one car driver for three travelers), and the share of groups exempted from the LPR (they can drive their cars every day). The toll price equivalent is correlated to the number of travelers facing the PT penalty. The price rises with the demand. Using DMS increases the penalty cost but also reduces the total travel time. DMS decreases both social costs and carbon emissions. A TCS with a ratio of 33% decreases the carbon emission by about 50%, the social cost by around 20%, and the satisfaction rate by only a few points. The Pareto front of the TCS dominates the one formed by the LPR. It means implementing TCS instead of LPR allows for better compromises in terms of social cost, carbon emissions, and travelers' satisfaction.

4 CONCLUSION

We set up a TCS in a trip-based MFD framework. We compare the TCS against LPR with different ratios of travelers allowed to drive their car and groups exempt from the LPR. The use case of a typical morning commute in Lyon shows that the TCS allows for better compromises between total travel time and carbon emission. The TCS brings more flexibility than LPR: it permits the choice of the number of cars allowed on the network without having the regulator choose who can drive and who can not. The credit market regulates it instead of an arbitrary decision based on license plate number, which is unrelated to the users' utilities and necessities to drive their car. Since the ability to drive the car is linked to the ability to purchase credits, the issue of equality between travelers with different revenue levels emerges. Future work should account for users' heterogeneity because some cannot afford to buy credits when they are too expensive. We should propose countermeasures to ensure their access to the road network.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement no. 953783 (DIT4TraM).

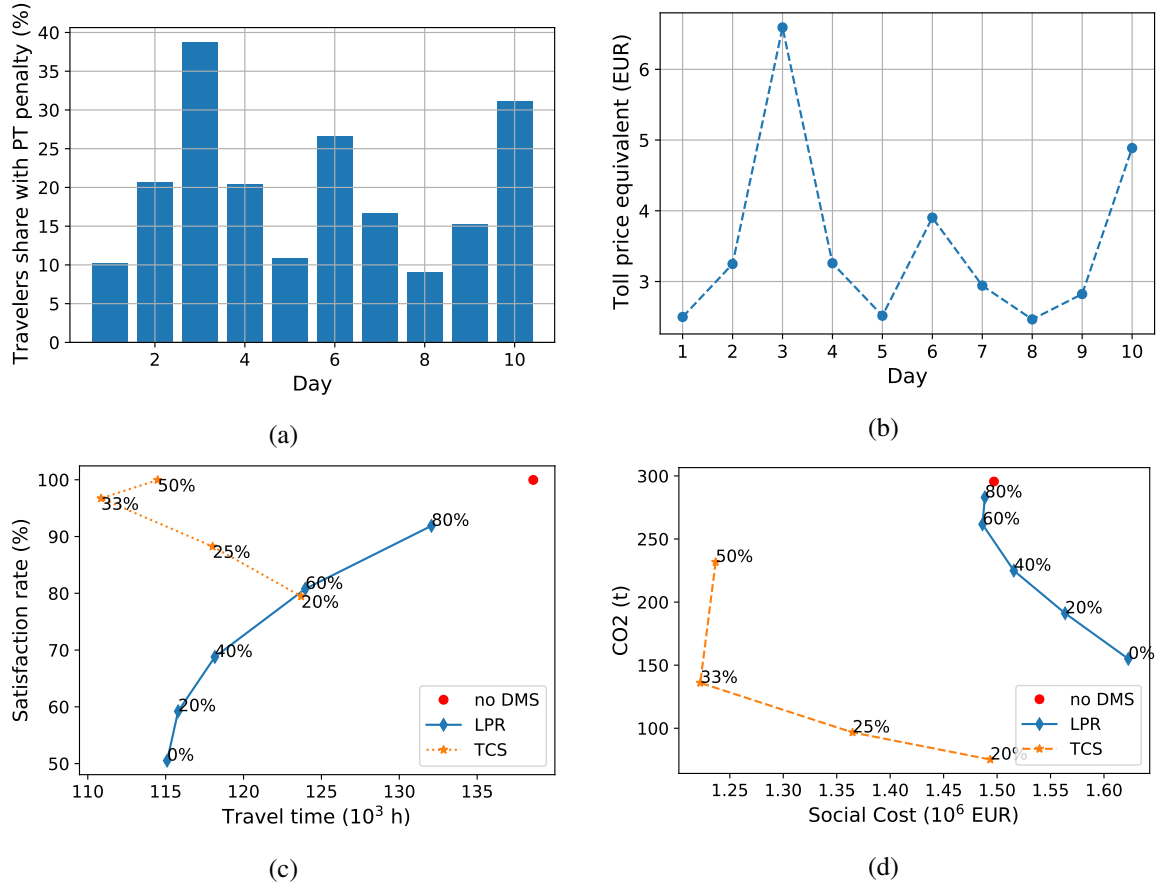


Figure 1 – (a) Distribution of PT penalty, (b) toll equivalent for a ratio allocation/charge of 33% across the ten days, average over the days of (c) total travel time vs. satisfaction rate, and (d) social cost vs. network carbon emission.

References

- Balzer, Louis, & Leclercq, Ludovic. 2021. *Modal equilibrium of a tradable credit scheme with a trip-based MFD and logit-based decision-making*. Submitted to *Transportation Research Part C: Emerging Technologies* <http://arxiv.org/abs/2112.07277>.
- Lamotte, Raphaël, & Geroliminis, Nikolas. 2018. The morning commute in urban areas with heterogeneous trip lengths. *Transportation Research Part B: Methodological*, **117**(11), 794–810.
- Lejri, Delphine, Can, Arnaud, Schiper, Nicole, & Leclercq, Ludovic. 2018. Accounting for traffic speed dynamics when calculating COPERT and PHEM pollutant emissions at the urban scale. *Transportation Research Part D: Transport and Environment*, **63**(8), 588–603.
- Lessan, Javad, & Fu, Liping. 2019. Credit- and permit-based travel demand management state-of-the-art methodological advances. *Transportmetrica A: Transport Science*.
- Mariotte, Guilhem, Leclercq, Ludovic, & Laval, Jorge A. 2017. Macroscopic urban dynamics: Analytical and numerical comparisons of existing models. *Transportation Research Part B: Methodological*, **101**(7), 245–267.
- Nie, Yu (Marco). 2017a. On the potential remedies for license plate rationing. *Economics of Transportation*, **9**(3), 37–50.
- Nie, Yu (Marco). 2017b. Why is license plate rationing not a good transport policy? *Transportmetrica A: Transport Science*, **13**(1), 1–23.
- Yang, Hai, & Wang, Xiaolei. 2011. Managing network mobility with tradable credits. *Transportation Research Part B: Methodological*, **45**(3), 580–594.