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From urban congestion pricing to tradable mobility credits: A review

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Abstract

Congestion is still a big challenge for urban mobility while vehicle sharing, eCommerce and autonomous vehicles will likely increase the unit veh-km of each vehicle and the density of vehicles moving on the streets. Urban vehicle congestion pricing schemes have been taken as effective solutions to this problem. This paper first reviews the research and application cases of urban congestion pricing through recent years, although with the well-developed theoretical basis and successful practices in Singapore, London, Stockholm, Milan, etc., public acceptance and equity concerns are still the main issues for such policies' implementation. To circumvent the shortcomings of congestion pricing, a scheme of tradable mobility credits is proposed as an alternative. As travellers are distributed mobility credits within a specific urban area, which are allowed to be traded, those with low vehicle-using demands can sell their credits to those with more demands. Therefore with this scheme, people have the initiative to reduce the use of vehicles. This paper reviews the studies on this new urban mobility management strategy and compared it with ordinary congestion pricing schemes. Finally, we conclude the gap and possible directions for future works.

Keywords: Urban mobility; Traffic congestion; Congestion pricing; Tradable mobility credits.

1. Introduction

Congestion has been the major problem that troubles cities around the world. As a strategy of transportation system management, urban congestion pricing (CP) was carried out as the approach to solve it. Since the early introduction by Pigou (1920) and Knight (1924), it has long been taken as the most socially optimal strategy for the allocation of road capacity (Hau, 2005). In an urban restriction area, vehicles enter or travel within the area will be levied. Especially in recent decades, theories and technologies have been well developed and several cities have practiced their urban charge schemes. However, although there are existences of successful applications, arguments on the implementation

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of CP schemes never stop. Public acceptance is the main obstacle while the equity problem is often considered the core. Thus, the scheme of tradable mobility credits (TMC) is introduced to make up for the shortcoming. It is seen as an alternative to the CP but allows travellers to drive for free with limited quotas. Such schemes of tradable credits are found studies and implementations in various fields. The most well-known one should be the Emission Trading Scheme of the European Union.

Both CP and TMC have gained enough attention, there are still difficulties and unresolved issues. Especially the newer TMC, although theoretical works have been carried out, practical experiences are not seen. This paper aims to present, via a case study of urban congestion pricing and an overview of TMC, valuable insights on the further development of TMC to make it more applicable for future implementation.

The paper is structured as follows. Section 2 reviews the implementation cases of urban congestion pricing in Singapore, London, Stockholm and Milan. Then this part also discusses the arguments on public acceptance of CP schemes. Section 3 reviews the development, theory and recent works on TMC schemes. Finally, section 4 concludes the paper and proposes further research direction on this area.

2. Urban congestion pricing

The main principle of CP is to charge the externalities that are imposed on other users by a new driver entering the network (Knight, 1924; Pigou, 1920). In this case, the equilibrium will achieve when the charging price is equal to the marginal cost of other users. After decades of development, the research of CP has already been well developed. Detailed reviews on the theories and methodologies have been concluded (de Palma and Lindsey, 2011; Tsekeris and Voß, 2009; Yang and Huang, 2005). As a transportation demand management policy, CP leads travellers to change their travel behaviours, reallocate the road to travellers who are willing to pay for the externalities. Besides, CP can raise revenues to fund transport projects like road maintenance and the improvement of public transport. Thus, such scheme is approved by most economists (Lindsey, 2006) to achieve social optimum.

2.1. Implementation cases

Several urban areas around the world have implemented urban congestion pricing schemes to alleviate congestion in the city centres, including Singapore (1975), several Norwegian cities (Bergen, Oslo, Trondheim, etc.), London (2003), Stockholm (2006), Milan (2012) and Gothenburg (2013). Although the charging schemes vary among those cities with their unique features, all those practices show efficient consequences on congestion control. Here, based on literature, we selected Singapore, London, Stockholm and Milan to investigate their CP schemes and impacts.

<u>Singapore</u>

Singapore implemented the Area Licensing Scheme (ALS) in 1975. This was a manual-enforced cordon toll system based on gantries at entry points of Restricted Zone (RZ). Drivers needed to buy licenses in advance to enter and travel within the central area during morning peak hours from 7:30 to 9:30 am. Three weeks after the introduction, the charging hours were extended to 10:15 am to respond to the occurring traffic just after 9:30 am (Fan et al., 1992). And initially, they thought that the restriction of morning peak hours would show a 'mirror image' on the evening outbound traffic, so there was not charging for evening peak hours. However, as such an image did not materialize, ALS is added to the evening peak from 4:30 pm to 7:30 pm (Phang and Toh, 2004) in 1989. Finally in 1994, in order to make the traffic more even throughout the day, ALS was extended to the inter-peak period with a lower charging rate. However, ALS was considered to make the road network underutilized (Santos, 2005). After the introduction, the average speeds within the RZ increased to 36 km/h while the expectation was 20-30 km/h. And the peak-hour traffic flow reduced by 45-50% while the original target was 20-30% (Phang and Toh, 2004). McCarthy and Tay (1993) argued that the charging rate was about 50% above the optimal level.

In 1998, ALS was replaced by Electronic Road Pricing (ERP), which made the charging scheme more convenient and efficient. Now drivers do not need to buy various licenses in advance, instead, an In-vehicle Unit is installed on the windscreen of each vehicle with a stored-value card. And with sensors on the gantries at each entrance of RZ, ERP charges vehicles when passing the gantries. The ERP system bases on the rationale of optimal average speeds. The optimal average speed for expressways should be 45-65 km/h while 20-30 km/h for arterial roads. The rates and charges are reviewed every quarter and set in 30-minute blocks which means that the rates can be differentiated regarding the real-time congestion level. Therefore the charge will be reduced if the average road speeds are higher than the optimal level and vice versa (Goh, 2002; Yap, 2005). On the other hand, alongside pricing, Singapore also develops its public transit services (Santos, 2005). As commuters shifted from private vehicles to public transport modes, the share of public transport increased from 33% to 69% (Phang and Toh, 2004).

London

Following Singapore and several Norwegian cities, London introduced its Congestion Charge scheme in 2003. It's a kind of area licensing scheme (Santos and Shaffer, 2004). During weekdays between 7:00 am and 6:30 pm, drivers needed to pay a fee in advance to travel within the central area delimited by the Inner Ring Road. Once paid, drivers can pass the cordon with unlimited journeys in a single day. The heavy goods vehicles were charged three times the normal rate at the beginning. Meanwhile, exemptions and discounts exist. For example, vehicles belonging to the residents of the central area enjoy a 90% discount. Then in 2007, the Congestion Charge zone was extended, making it totally covers 39 km^2. Now the Congestion Charge has been extended to the entire week, a flat daily charge is asked (regardless of the vehicle types and entry time) from 7:00 am to 10:00 pm to travel within the Congestion Charge zone.

Before the implementation of Congestion Charge, traffic within the charging zone was expected to reduce by 20% to 30% and average speeds would increase by 10% to 15%. Several months after, the traffic dropped by 27% and the average speeds climbed from 14 km/h to 17 km/h (TfL, 2003 and 2004). Additionally alongside the Congestion Charge scheme, London has put investment in public transport sectors, promoting the network, convenience and the level of service (Givoni, 2012; Santos, 2008). This reuse of revenues helps it to increase public acceptance and attracted 50% of the former vehicle users to shift to public transportation.

Stockholm

In 2006, Stockholm carried out its CP scheme as a seven-month trial. It was a time-differentiated charge scheme with the cordon around the inner city of Stockholm. Charges were made once vehicles pass the border. Then after evaluation of the trial and a referendum, the scheme has been permanently implemented since August 2007. Vehicles would be levied (the price depends on the time of day) when pass the cordon on weekdays from 6:30 am to 18:30 pm. Meanwhile, around 30% of vehicles were exemptions including buses and alternative-fuel cars (Eliasson, 2008). The target was a reduction of 10-15% of traffic across the cordon. As a result, compared with the corresponding months of 2005, every month the number of vehicles passing the border decreased 20-30% in the trial period (Eliasson et al., 2009). And the most interesting point of Stockholm is the change of public acceptance. Before the trial, only 36% of Stockholm citizens were in favour of the CP scheme. Then public acceptance increased gradually after the implementation. Later in September 2006, the referendum showed that 53% of voters supported to remain the charging scheme (Borjesson et al., 2012).

The revenues collected were dedicated to public transport during the trial. Like Singapore and London, the success of the implementations of CP in Stockholm is partly attributed to their well-developed public transit systems (Kottenhoff and Brundell Freij, 2009; Menon and Guttikunda 2010).

Milan

Milan first implemented an urban vehicle charge scheme called Ecopass in 2008. But the difference from other cases is that it was a traffic pollution charge while congestion reduction was just a side-goal. The charge was set based on the Euro emission standards. A daily charge was imposed on vehicles enter the traffic restricted zone between 7:30 am and 7:30 pm. Different levels of discounts were granted to low-emission vehicles and frequent users (Rotaris et al., 2010). The Ecopass program terminated by the end of 2011 and was replaced by Area C. The new Area C scheme has the same charging zone, technology and time period as former Ecopass. As Area C is a congestion charge instead of a pollution charge, vehicles are imposed the same daily charge regardless of their emission standard. And in order to increase acceptance, residents who live within the area have 40 free entrances per month and need to pay for extra trips while commercial vehicles also benefit from discounts (Beria, 2016).

After the implementation of Ecopass, commercial and private traffic showed a reduction of 16.2% in 2010, compared to 2007. The daily average emission of PM10 decreased by 25% within the area. However, in four years, the environmental-friendly vehicles entering increased by 478% and commercial vehicles increased by 1400%. Then as the impacts of Area C, traffic volume reduced by 36% while PM10 emission reduced by 27% (Martino, 2011). In terms of the revenues, unlike the Ecopass was criticized for its lack of transparency on the revenue reinvestment, with Area C they reinvested the revenues to improve public transport and sustainable mobility modes (Beria, 2016).

Cases summary

These cases prove the effectiveness of such CP schemes on urban congestion control and the successful results gained the endorsement of citizens. These four successful cases have a common feature is that the approach of CP is just one of a basket of policies to manage congestion. Another important point is the investment in alternative transport modes, especially public transport. Kottenhoff and Brundell Freij (2009) concluded that public transport may serve a very necessary role in CP policy package. Sole CP schemes will change the drivers' route and travel time to show the reduction of traffic during peak-hour windows (Santos, 2005) while public transport systems can help reduce the use of vehicles and attract mode shifting. The redistribution of revenues is also considered as one of the auxiliary amendments of CP to deal with inequality and make the policy more acceptable (Tian, 2015). On the other hand, the simplicity of the policies is important. The failure in Edinburgh and Manchester showed people's dislike of complicated mechanisms. In Singapore and Milan, people show higher acceptance to simpler schemes of ERP and Area C than the former ALS and Ecopass respectively (Gu et al., 2018; Hensher and Li, 2013).

2.2. Public acceptance

However, although with sufficient theoretical studies, urban congestion pricing schemes can only find limited practical applications across the world. The main obstacle to the implementation of CP is public acceptance (Albalate and Bel, 2009; Banister, 2003; Glazer and Niskanen, 2000). Citizens have long taken the free use of roads for granted. Naturally, it is difficult to gain public acceptance to charge a good which is always for free. Cities including Hong Kong, New York, Edinburg and Manchester are the cases that failed to introduce CP schemes (Albalate and Bel, 2009; Gu et al., 2018). Even in Stockholm's referendum, they ignored the opposition from suburban areas where residents rely more on vehicles to commute to the urban centre.

On the other hand, equity is greatly concerned by stakeholders (Perera and Thompson, 2020) and is taken as the core of acceptance (Langmyhr, 1997; Viegas, 2001). People tend to take CP as an extra tax on drivers. And it makes low-income drivers gave the roads to those with higher income or have high value of time (VOT). Meanwhile, if the revenues are not used to improve the public transport system, those low-income drivers would be the victims of CP. In the context of out-of-pocket charges, low-income drivers and people with reduced mobility are faced with more severe travelling burdens and further limitations on travel options (Gu et al., 2018). Therefore, in London, Stockholm and Milan there are various discounts for some specific groups. In the cases of Hong Kong, New York and Edinburg, the designs of CP policies did not pay enough attention to equity problems, which became the main reason for people's opposition (Larson and Sasanuma, 2010; Pretty, 1988; Ryley and Gjersoe, 2006). Accordingly, a more acceptable and fairer approach is needed.

3. Tradable mobility credits

3.1. Early works

In order to tackle the most concerned equity problem of CP and gain public acceptance, a kind of scheme based on tradable mobility credits is proposed as an alternative (Fiorello, 2010; Gulipalli et al., 2008; Raux, 2004). The general concept is simple. Users are allocated a limited number of mobility credits during a certain period. When driving within a charging area or go through a charge cordon, drivers will be charged the credits rather than out-of-pocket monetary. Those who exhaust the credits need to buy from authorities or other users. Tian (2015) described it as a stick-carrot mixed approach while traditional CP was seen as a stick. In this situation, drivers with low VOTs have the initiative to reduce their use of vehicles and get a bonus by selling their surplus credits while those with higher VOTs will pay for the congestion externalities. In fact, in the field of congestion control, the idea of mobility credits is not a new concept. Daganzo (1995) proposed a hybrid scheme of rationing and pricing. This scheme can be seen as the allocation of mobility quotas without tradability. Viegas (2001) used the concept of "mobility rights" to deliberate over the quota scheme. He described that, at present, drivers get unlimited quotas of mobility rights to drive and the free allocation of limited quotas could be seen as a reduction of the current situation.

Early research mainly focused on concept development, policy design, qualitative analysis and discuss the potential of implementation and reactions from stakeholders. To tackle congestion externalities, Verhoef et al. (1997) proposed several different types of tradable permit schemes that are based on ownership, distance, fuel consumption and parking, respectively. Then the idea of TMC is proposed more definitely. Raux (2004) stated transferable permits could be an intermediate solution for congestion problems. Later he further defined the tradable driving rights scheme with which those inhabitants are allocated certain quotas of driving right and allowed to trade their unused quotas with those who need excessive trips (Raux, 2007). In parallel, Kockelman and Kalmanje (2005) designed a revenue-neutral credit-based congestion pricing (CBCP) policy. Registered vehicle owners get a monthly monetary allowance of travel credits. They do not need to pay money unless they use out of the credits and those with unused credits can stock up for next month or exchange for cash. And further work based on expert surveys gave it a more detailed refinement (Gulipalli et al., 2008). Ch'ng (2010) hypothesized a tradable credits system with a two-sided auction market where the price of mobility credits is determined by demand and supply. Based on an experiment of auction market, he explored that transactions allow revenues to be returned to drivers who shift to other alternative modes and the equilibrium of utility among both sellers and buyers will realise.

In general, the TMC schemes have the following features: 1) the administration department determines the total amount of credits and allocates them to eligible individuals; 2) the exchange of credits is allowed: individuals that travel less can sell their credits to those who exhaust the credits; 3) like congestion pricing schemes, the charging rates of mobility credits may vary depending on the time, location, route or vehicle type.

3.2. Quantitative studies and development

The idea of such a scheme is simple but deeper works that more than conceptual discussions are needed. In the recent decade, investigations started to concentrate more on quantitative studies. Fiorello et al. (2010) took Genoa as a case study, developed a system dynamic model of Genoa Mobility Rights to estimate the impact of TMC on individuals with a sequential procedure. Yang and Wang (2011) introduced a system of tradable travel credits and developed the quantitative analysis as well as modelling of the scheme. They assumed a situation with homogeneous travellers to trade their travel credits in a free and competitive market without the interference of the authority. After that, they further investigated the complicated situation of heterogeneous drivers that have different VOTs (Wang et al., 2012). Then more following works contribute to the scenario of heterogeneous users. In order to promote a more equitable TMC scheme, Wu et al. (2012) developed a modelling framework to reckon the impacts of the distribution of credits on travellers with different income and geographic features. He et al. (2013) stated that the authority needs to deal with not only individual travellers but also transportation firms (such as logistic companies and transit agencies). The differentiated scheme will allocate different numbers of credits to these two kinds of users and also charge them differently. Zhu et al. (2014) assumed travellers with continuously distributed VOTs and established a scheme that can decentralize a given target network flow pattern into a user equilibrium link flow pattern.

And recent years, an increasing number of articles are seen in this field. Nie and Yin (2013) designed a new TMC scheme that rewards credits to travellers who avoid peak-hour window or choose other alternative modes. Their work assigns that even a very simple TMC scheme can achieve significant efficiency. Miralinaghi and Peeta (2016) proposed a multi-period TMC scheme that travellers are allowed to use or sell the credits in the current period or transfer to future periods. They argue that this scheme can stabilize the price of credits. Xiao et al. (2019) proposed a link-based cyclic tradable credit scheme in which the compensatory credits could be charged from or subsidized to the users. In terms of sustainable-oriented transport, Wang et al. (2020) combined the TMC scheme with a link capacity improvement measure and proposed a bi-objective bi-level model to balance economic development and environmental issues.

Meanwhile, as a transportation system management policy, participants' responses are important. Bao et al. (2014) adopted a disutility function to study travellers' loss aversion behaviour for credit collection during route choice procedure. Xu and Grant-Muller (2016) captured simulation analysis in Beijing to appraise the TMC's influence on people's mode choice and travel pattern. Tian et al. (2019) studied people's interaction with each other as well as with intelligent virtual agents in the situations of credit trading and route choice. A more detailed review of the behavioural impacts is concluded by Dogterom et al. (2017). And necessarily, in terms of the issue of public acceptance, TMC gains better support from the public. The work by Kockelman and Kalmanje (2005) in Austin, Texas proved TMC as a viable and competitive alternative. Likewise, a survey carried out in the UK revealed better public acceptance of TMC than CP and participants approved its fairness (Harwatt et al., 2011).

3.3. Current problems

TMC is a new congestion management approach and there have not found practical implementations by now. Some issues still ask for more insights.

The administrative cost is the main issue that researchers concern about for TMC. Authorities need to work on the verification of eligible receivers, allocation of credits, monitoring the use and transactions, etc. Therefore, the administrative cost of TMC scheme will be higher than ordinary CP schemes (Fan and Jiang, 2013; Nie, 2012; Verhoef et al., 1997). Especially, the transaction cost is a new matter that needs to be taken into consideration but by now has not gained enough attention. He et al. (2013) concluded that transaction cost will reduce the trading volume of mobility credits and change the price as well as the travellers' route choice. Zhang et al. (2021) found that transaction cost can lead negative influence on travel utility for people with low VOTs and suggested to impose equity constraint in TMC design.

Additionally, TMC is seen as an alternative to CP. While the redistribution of revenues on the alternative mobility modes is widely approbated in CP schemes, in TMC there are not enough insights. Revenues could be collected as a commission fee in the free-market schemes or collected directly in the schemes like CBCP. In fact, CBCP may be much convenient for the administration department to redistribute the bonus to drivers and to other transport projects. Authorities need to balance the proportion of revenues that rewarding to drivers and investing in transport projects, as well as administrative costs should be considered.

Another issue is that researchers now have not reached a consensus about the credit receivers. In general, we can divide the objects into two groups. One is a more limited group that only referred to drivers or car owners (Ch'ng, 2010; Kockelman and Kalmanje, 2005; Verhoef, 1997) while another includes all taxpayers or local inhabitants (Fiorello, 2010; Raux, 2007; Viegas, 2001; Yang and Wang, 2011). It is important to determine the appropriate TMC users which are highly relevant to the quantification of the total amount of credits. If the system adopts a free trade market or the auction scheme for transactions, the trading price and operational costs will be influenced by the number of credits.

4. Conclusion

In this article, starting from urban congestion pricing, we review the successful experiences in Singapore, London, Stockholm and Milan. Sufficient research works and practical cases have shown that public acceptance is the main obstacle for the implementation of CP schemes and the core factor should be equity. Thus, we then review the literature on TMC schemes, which was proposed as a fairer congestion management approach to circumvent the shortcoming of CP. Although plentiful conceptual, qualitative and quantitative works have been carried out, by now TMC schemes still lack implementation practices. The TMC presents more complicated management and operation systems than traditional CP. Taking the cases of CP as a reference, future research is recommended to improve TMC schemes more applicable.

First, more specific work can be done in terms of heterogeneous users. The feedbacks of those CP cases show that the delivery industry enjoys smooth traffic in urban areas. The abatement of congestion, especially during peak-hour windows, allows the delivery industry to arrange their schedule more flexibly. More importantly, while with frequent trips and larger size, urban freight vehicles contribute more to urban congestion. Therefore, in the scenario of heterogeneous users, future works of TMC could draw more attention to urban freight delivery and balance the relationship between freight vehicles and private vehicles.

Besides, the reuse of revenues on the public transport system or active mobility modes is essential. As drivers shift from vehicles to other means of transport like public transits (metro, commuter rail, bus, etc.) and active modes (bicycle, walking and PMDs), the level of service of these modes should get a promotion. Hence, further research can focus on the balance of the bonus enjoyed by individuals and the revenues reinvested in alternative transport projects.

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