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Road pricing for congestion and accident externalities for mixed traffic of motorcycles and automobiles

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A B S T R A C T

Motorcycles play an important role in sharing the trip demand with automobiles for commuting, especially in many cities in Asia. However, the accident cost of a trip by motorcycle is higher than that of an automobile. This study analyzes the road pricing for the congestion and accident externalities of mixed traffic of automobiles and motorcycles. A model for equilibrium trips with no taxation and that for optimal trips with taxation are explored. The model is then applied to the Tucheng City–Banciao City–Taipei central business district corridor in Taipei metropolitan area. The findings in this case study show that the tax for accident externality is larger than that for congestion externality.

1. Introduction

Most studies on traffic congestion improvement are conducted by levying a congestion tax focused mainly on automobiles but not on motorcycles (Keeler and Small, 1977; Small, 1983; Newbery, 1990; Liu and McDonald, 1999; Chu and Tsai, 2008). The major reason is that these studies on road congestion tax focus on cities or metropolitan areas in Western countries. In most cities in the West, motorcycles are just a mode for recreation instead of a mode for commuting. However, motorcycles play an important role in sharing the transportation trip demand for commuting with automobiles in many cities in Asia. Based on a phone survey on transportation mode choices for commuter trips in Taipei City, 37.6% of the trips are by public transit, 35.1% are by motorcycle, and only 15.8% are by private car. The Taipei metropolitan area, including Taipei City and New Taipei City, has only 1.63 million registered automobiles compared with 3.40 million registered motorcycles. Automobile and motorcycle ownership comprise 250 and 521 vehicles per 1000 people, respectively (Department of Transportation, Taipei City Government, 2010). Motorcycles are cheaper than automobiles and are thus usually owned by people with low income. Motorcycles occupy a smaller space than automobiles when they are operated on roads or parked in parking lots. Hence, traffic congestion influences an automobile trip more seriously than a motorcycle trip. However, in terms of safety, a motorcycle is more dangerous than an automobile. Motorcycles are less stable than automobiles, especially in heavy traffic. When an accident occurs, injuries to those on motorcycles are more severe than those in automobiles. A traf-

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fic accident survey showed that 85 fatal traffic accidents that resulted in 154 casualties (including 94 deaths and 60 injuries) occurred in Taipei in 2007. Among the 94 fatalities, 53.2% were on motorcycles.

Levying a congestion tax on road users is typically employed to lessen the traffic congestion problem from a theoretical perspective, and it has been implemented in certain cities (Small and Gomez-Ibanez, 1998). However, levying a congestion tax solely on automobiles would not lead to efficient road usage by a mixed traffic with automobiles and motorcycles. Levying a congestion tax for automobiles would only increase motorcycle trip demand, which is not tolled. Another major externality that results in inefficient road usage by mixed traffic is related to traffic accidents. Vickrey (1968) clearly conceptualized accident externality from the quantity of driving and found that the group with higher traffic density has substantially higher accident rates. Belmont (1953) and Lundy (1965) used a cross-section approach to determine the relationship between accident rates and traffic volume. They found that accident rates increase with traffic volume. However, these studies did not conceptualize the problem as an externality. The external costs involve all costs imposed on others and not borne by the person whose activity generates the costs. Elvik (1994) classified accident external costs as system, physical, and traffic volume externalities. He stated that "system externalities are costs that road users impose on the rest of society, physical externalities are costs that one group of road users imposes upon another in crashes in which both groups are involved, and traffic volume externalities are the costs imposed on other road users when an additional road user joins traffic". In terms of the magnitude of the three components of accident externalities, Elvik (1994) estimated that system externalities and physical injury externalities, respectively account for 30% and 10% of the total cost of traffic injury based on crash data in Norway. By contrast, quantifying traffic volume externalities is relatively difficult because of the limitation in accurately estimating the marginal impact an additional road user imposes on others. Furthermore, accident externalities or costs vary among different roadway types where highway design specifications and designated speed limits differ. In the context of mixed traffic in urban arterials and interurban highways, these roadway facilities are more likely to be associated with high crash externalities because high motorcycle crash probabilities are generally observed and severe casualties are involved, even though the traveling speeds or speed limits are relatively lower than those of intercity expressways or freeways. Quantifying the cost items in a monetary value by considering the safety-related and mobility-related aspects is not an easy task (Haight, 1994). Direct accident cost includes crash clean-up, injury treatment, property damage, workplace disruption, and insurance claim processing. In addition to direct costs, accident costs for the effects of injury on individuals must be accounted; accident costs can be appropriately measured by two methods, namely, years lost plus direct costs and willingness to pay (Miller, 1991). Nevertheless, certain research estimated accident externalities from various aspects and analyzed possible policy tools such as car taxes and auto insurance for internalizing external costs (Elvik, 1994; Edlin and Karaca-Mandic, 2006; Sieber and Bicker, 2008). Distance-based pricing or per-mile premiums for auto insurance policies have been regarded as a desirable tool for economic efficiency and equity (Litman, 2011; Edlin, 2003; Parry, 2004). This pricing scheme has a policy implication that fairly internalizes accident-related externalities.

Our study attempts to model the road pricing problem with mixed traffic comprising automobiles and motorcycles. Congestion and accidents are the two major externalities explored in this study. Externality is defined from an economic perspective as the effect of the actions of one road user on the well-being of others in a road system. Externality is a cause of market failure, which can be internalized in the model by levying Pigouvian taxes on road users. Accident/congestion externality can be calculated as the difference between accident/congestion marginal cost and accident/congestion average cost at optimal traffic volume, which can yield maximum well-being.[3] The accident costs for each mode are estimated for each county as the probability of being involved in a traffic accident and the average accident cost of a certain traffic accident based on the report on road traffic accidents in Taiwan. The average accident cost is calculated by severity levels (i.e., no injury but property loss, injury, and fatality). The fatalities are valued by the willingness-to-pay approach, and the accident cost is estimated using the value of statistical life (VSL). The cross-section accident costs are then used for a regression analysis of the accident cost function of traffic volume. The accident cost function of each mode with traffic volume is then used to calculate the accident externality, that is, the Pigouvian accident tax stated above.

The remainder of this paper is organized as follows: The structure of the model is established in Section 2. The model for equilibrium trips and optimal trips with taxation are analyzed in Section 3. The model is applied to a real case in a traffic corridor, the Tucheng City–Banciao City–Taipei central business district (CBD hereafter) corridor in a Taipei metropolitan area, which is discussed in Section 4. Section 5 provides the summary with concluding remarks.

2. The model

A trip demand function by each mode between two points is assumed. The origin is a household location, and the destination is a working place (for instance, the CBD in a city). The inverse trip demand function by automobile and that by motorcycle (a denotes automobile and m denotes motorcycle hereafter) at a peak hour is given by

$$P_i = \overline{P}_i - b_i Q_i, \quad \text{for } i = a, m, \tag{1}$$

[3] The accident externality explored in this study is equivalent to the physical externality in Elvik (1994). Specifically, our study analyzes the physical externalities directly and the traffic volume externalities indirectly. The congestion externalities include the effects from traffic accident, although this effect is not separated from traffic volume effects without accident because of data limitation.