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# The Cost of Traffic Congestion and Marginal Cost of Delay in Bangkok Metropolis

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## Abstract

Traffic congestion in Bangkok, particularly during rush hours, imposes significant private and external economic costs on society, a problem exacerbated by the rapid increase in the number of private vehicles in the city. To the best of our knowledge, no study has estimated the cost of traffic congestion in Thailand using a survey research design. This study aims to estimate both the cost and the marginal cost of heavy traffic during rush hours, utilizing data gathered from 215 commuters in Bangkok and nearby suburbs. The findings indicate that the annual traffic congestion costs per vehicle range between THB 77,021 and THB 76,155 (USD 2,567 and USD 2,538) at 2023 price levels, depending on the greenhouse gas (GHG) damage cost discount rates used. Additionally, the marginal cost of delay per vehicle due to heavy traffic is approximately THB 646 (USD 22) at 2023 price levels. This value can serve as a proxy for the benefit (or avoided cost) that commuters could gain if the government were to implement traffic congestion mitigation measures, such as congestion charges. While imposing fees could be one potential solution to address the traffic problem in Bangkok, further research is needed to determine the appropriate amount of charges, considering factors like the price elasticity of demand for congestion charges and their acceptability to the public.

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## 1. Introduction

Bangkok is one of the most traffic-congested cities in the world, primarily due to the large volume of vehicles plying the very limited road space. In 1991, about 294,300 vehicles were registered in Bangkok, and this number has increased threefold to 967,300 in 2023 (Department of Land Transport [DLT.], 2023). From 1991 to 2023, the average annual growth rate in the number of vehicles in the city has reached 6 percent, and this increase is expected to continue in the coming years. Consequently, the average car speed in the inner areas of Bangkok during rush hours is only about 18 kph, with the most congested stretch of road averaging only 6 kph (Office of Transport and Transport Policy and Planning [OTP.], 2020). These figures remained relatively stable over the years 2011–2020 despite the expansion of public transportation networks in the Bangkok metropolitan region, suggesting that traffic congestion is a chronic problem.

A road where traffic flows smoothly is unrivaled in the sense that drivers will not incur any opportunity cost should another vehicle be added to the current volume of vehicles using the same road. Conversely, once the road becomes congested, there is an opportunity cost from that additional driver, and the road is no longer unrivaled (Kolstad, 2011).

One of the main reasons for traffic congestion is users' uncontrolled access to the road; an additional driver imposes external costs on others in the form of added congestion and longer travel time (Field & Olewiler, 2015). Other external costs include additional expenses due to fuel consumption and vehicle maintenance. Traffic congestion also means that vehicles stuck in traffic consume more energy than usual, thereby leading to increased emissions of CO2, an important greenhouse gas (GHG).

When people decide to travel via road instead of taking other modes of transportation (e.g., Mass Rapid Transit), they consider only their private costs or the expenses they actually pay per kilometer traveled. However, these costs do not take into account the external costs that other road travelers incur, and road users will respond accordingly should there be any changes in these private costs. This then leads to overconsumption and inefficient road use.

In planning transportation infrastructure projects that aim to increase road capacity or build alternative public transport in major cities and metropolitan areas, one of the major factors that planners consider is the high perceived costs of congested roads imposed on society (Wallis & Lupton, 2013). Therefore, congestion cost can also be used as the avoided cost (or a benefit) to society in the event that the government decides to implement traffic congestion-mitigation projects. Most studies have shown that the public opposes the implementation of road charges (e.g., Jaensirisak et al., 2009; Piriyawat et al., 2009), preferring supply-side management (e.g., the construction of new transportation infrastructure) instead. As such, having information on congestion cost as an avoided cost can help project planners develop messages that would convince the public about the need to implement road demand-side management policies (e.g., road charges).

## 2. Literature Review

Previous studies on the cost of traffic congestion have examined the subject under different contexts (e.g., environment, health) and by using different methods. He (2013) estimated Beijing commuters' opportunity cost of time due to heavy traffic during rush hours in 2010 using three different types of vehicles: bus, taxi, and car. The author used the average income of individuals to represent the cost of time delayed due to heavy traffic and found that the annual opportunity cost of time delay was CNY 134.9 billion in 2010, which comprised the opportunity cost of time for private cars (CNY 110.2 billion), taxis (CNY 4.24 billion), and buses (CNY 20.51 billion).

The Centre for Economics and Business Research (CEBR., 2014), on the other hand, quantified the future economic and environmental costs associated with road congestion in the UK, France, Germany, and the US. Accordingly, the results of CEBR (2014) showed that total economy-wide costs across all four advanced economies are expected to increase from USD 200.7 billion in 2013 to USD 293.1 billion by 2030, or a 46-percent cost increase, due to traffic congestion. At the city level (London, Paris, Stuttgart, and Los Angeles), the study finds that Los Angeles households are expected to incur the highest direct (values of fuel and time wasted) and indirect costs due to congestion (increased costs of doing business), from USD 5,730 per car-commuting household in 2013 to USD 8,555 per household by 2030.

Meanwhile, Transport Canada (2007) calculated the cost of traffic congestion by computing the value of excess delay, fuel use, and greenhouse gas (GHG) emissions. The study estimated that the total annual cost of traffic congestion (in 2002 CAD) ranges from CAD 2.3 billion to CAD 3.7 billion in the major urban areas in Canada. More than 90 percent of this cost is from the value of time that road commuters (drivers and their passengers) lose, while the remainder is from the value of fuel consumed (7%–8%) and GHGs emitted (2%–3%).

These studies, however, have used engineering traffic models to estimate the cost of traffic congestion. Although this method can be used to test the sensitivity of the variables even when the model parameters are varied, it does not consider the heterogeneous characteristics of each variable (e.g., travel distances, travel time). As such, the present study attempts to bridge this gap by estimating the cost of traffic congestion in Bangkok metropolis and nearby suburbs during rush hours (7:00–9:00 a.m. and 4:00–7:00 p.m.) using data gathered from a survey of road users. We focus our estimation on the additional costs (e.g., fuel, time, maintenance) that each commuter incurs when they travel during rush hours.

This study provides two main contributions: information on the total cost of traffic congestion and on the marginal cost of delay caused by traffic congestion. Our study finds that the average annual cost per vehicle of traffic congestion is THB 76,155 (USD 2,567) at 2023 price levels. Further, this study also finds that if the vehicle speed decreases by 1 kph, then this delay would translate to an annual cost per vehicle of THB 646 (USD 22) at 2023 price levels.

The rest of the paper is organized as follows. Section 2 discusses the research methods, whereas Section 3 presents and discusses the results. We then give our conclusions in the last section.

## 3. Research Methodology

In accordance with our aim to provide policymakers with a reference when reviewing the benefits of significant investment decisions, we measure the (average) total costs of congestion (TCC) in this study. We believe that this would be more suitable to use when introducing a demand-side management policy such as congestion charges (Bilbao-Ubillos, 2008). We estimate the TCC by comparing the difference between the observed cost of current travel during rush hours and the cost of travel when the road is free-flowing (zero congestion). We then identify the following: (1) the private costs incurred by commuters, who lose time and are liable to incur other costs due to road congestion; and (2) the external costs that other commuters incur (i.e., the externalities), such as longer travel periods[1], fuel costs, and impact of GHG emissions. We then estimated the relationship between TCC and inverse vehicle speed to determine the marginal cost of delay due to traffic congestion.

We conducted face-to-face survey interviews with people who regularly travel in Bangkok and nearby suburbs in 2015 using the purposive sampling method. We selected our respondents at the beginning of the interview by verifying whether they were within the 20–65-year-old range and whether they regularly commute during rush hours at least three days a week. Once we had confirmed that they had the characteristics of our target group, we continued our interview with them. Otherwise, the interview was discontinued. Our sample totaled 212 commuters who normally commute using private cars in the 26 areas in the Bangkok metropolis[2]. We conducted our survey in both heavy traffic and light traffic conditions. We chose this approach because we are aware that traffic congestion is context-specific and so wanted to ensure that our sample reflects key characteristics of Bangkok traffic. Due to the survey of the 26 different areas around Bangkok's metropolis, this study can serve as an average congestion cost in urban areas and an illustration to further develop the traffic congestion estimation model in the future.

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[1] When commuters enter the road on which there are already cars, the added congestion causes an increase in average travel times for the commuters who are already using the road. The problem occurs because there is uncontrolled access to the road, and by using the road, commuters may impose external costs on others in the form of added congestion and higher travel times (Field & Olewiler, 2015, p. 67).

[2] The areas where we conducted the survey were Bang Na-Trat Road, Borommaratchachonnani Road, Chaeng Watthana Road, Charansanitwong Road, Kaset-Nawamin Road, Lat Phrao Road, Nawamin Road, New Phetchaburi Road, Ngam Wong Wan Road, Phahonyothin Road, Phatthanakan Road, Rama II Road, Rama IV Road, Rama IX Road, Rama VI Road, Ram Inthra Road, Ramkhamhaeng Road, Ratchadaphisek Road, Ratchadamnoen Road, Seri Buranaphon Road, Seri Thai Road, Silom Road, Sathon Road, Srinakarin Road, Sukhumvit Road, and Vibhavadi Rangsit Road.

The questionnaire consisted of two main sections:

1) Commuting data of private vehicle owners – place of work, travel time, time of commuting, how far and how long it takes to get to their destination during rush hours and non-rush hours
2) Socioeconomic information of the respondents – age, income, occupation, and educational level

We divide the analysis into two sections: (1) estimating the cost of traffic congestion during rush hours, and (2) estimating the marginal cost of delay due to traffic congestion.

### 3.1 Estimating the cost of traffic congestion

We extend the method used in the study of He (2013), where the author estimated the opportunity cost of time due to road congestion. In particular, we include other congestion costs such as additional fuel cost, maintenance costs, and costs of GHG emissions. Meanwhile, the cost of traffic congestion is defined as the additional travel cost during the rush-hour period, which translates to the difference between the travel cost during rush-hour periods (7:00–9:00 a.m. and 4:00–7:00 p.m.) and that during non-rush-hour periods.

The congestion cost (CC) is the sum of private cost (PC) and external cost (EC). The private cost is comprised of opportunity cost of time (OC) and fuel and maintenance costs (FMC). Thus, we calculate the cost using the equation below:

$$PC = (OC + FMC) \tag{1}$$

*Private cost*

We previously mentioned that private cost is the sum of opportunity cost of time and fuel and maintenance costs, whereas the external cost is the cost of GHG emission impacts. Private cost includes the additional opportunity cost of time and fuel and maintenance costs. We exclude toll fees in our analysis since it is difficult to determine commuters' reason for using expressways—whether it is because of traffic congestion or because of drivers' preference. The opportunity cost of time entails the amount of income that a commuter sacrifices due to the extra travel time caused by traffic congestion, which can be expressed as follows:

$$OC = (T_R - T_{NR}) \times Inc \tag{2}$$

where $T_R$ and $T_{NR}$ are the commuters' travel time during rush-hour and non-rush-hour periods, respectively, and Inc is the hourly wage of the respondent (baht/hour). We calculated an hourly wage based on the monthly salary of the respondent.

*FMC* can be estimated by finding the difference between fuel and maintenance costs during a rush-hour period and those during the non-rush-hour period as follows:

$$FMC = (FC_R - FC_{NR}) + (MC_R - MC_{NR}) \tag{3}$$

where $FC_R$ and $FC_{NR}$ are fuel costs during a rush-hour period and a non-rush-hour period, respectively, and $MC_R$ and $MC_{NR}$ are the maintenance costs during rush-hour and non-rush-hour periods, respectively. We follow the example of (cite papers) in calculating fuel and maintenance costs ($FC_{NR}$ and $MC_{NR}$) during a non-rush hour period by using fuel and maintenance costs during a rush hour period ($F_R$ and $MC_R$) as the starting points and scaling them down by multiplying with the relevant ratios ($c_F$ and $c_M$ respectively Therefore, we then estimate $FC_{NR}$ and $MC_{NR}$ using the following equations:

$$FC_{NR} = FC_R \times c_F \quad (4)$$

$$MC_{NR} = MC_R \times c_M \quad (5)$$

where $c_F$ is the ratio of the fuel consumption[3] during the non-rush-hour period to the fuel consumption during the rush-hour period, and $c_M$ is the ratio of the maintenance cost during the non-rush-period to the maintenance cost during the rush-hour period.

The ratio of fuel consumption ($c_F$) and maintenance costs ($c_M$) can be calculated using the data from the U.S. Environmental Protection Agency (EPA., 2017) on the proportion of gas mileages in highways (as a proxy for the non-rush-hour period) and in the city (as a proxy for the rush-hour period) (Table 1). The $c_F$ can be calculated as follows:

$$c_F = \frac{\text{Gas mileages during non-rush hour period}}{\text{Gas mileages during rush-hour-period.}} \quad (6)$$

The $c_M$, on the other hand, is the ratio of maintenance cost during non-rush-hour over the maintenance cost during the rush-hour period as shown below:

$$c_M = \frac{\text{Maintenance cost during non-rush hour period}}{\text{Maintenance cost during rush-hour period.}} \quad (7)$$

Table 1: Ratio of fuel consumption ($c_F$) by engine sizes of vehicles

| Engine Size (cc) | Gas Mileage during Rush-Hour-Period (gallon per mile) | Gas Mileage during Non-Rush-Hour Period (gallon per mile) | $c_F$ |
|---|---|---|---|
| <1,500 | 0.0244 | 0.0227 | 0.93 |
| 1,500 | 0.0303 | 0.0244 | 0.80 |
| 1,800 | 0.0333 | 0.0256 | 0.77 |
| 2,000 | 0.0323 | 0.0244 | 0.76 |
| >2,000 | 0.0385 | 0.0303 | 0.79 |

Source: https://www.fueleconomy.gov/feg/findacar.shtml.

[3] Fuel consumption is measured by the amount of fuel consumed per distance travelled. In our paper, the unit of fuel consumption is gallon per mile.

We apply the standard maintenance costs that a Thai automobile company uses as a proxy for the maintenance costs during non-rush-hour periods. On the other hand, the data on the maintenance costs during rush-hour periods are obtained from our survey data (Table 2).

Table 2: Ratio of the maintenance cost ($c_M$) by engine sizes of vehicles

| Engine Size (cc) | Maintenance Cost during Non-rush Hour Period (THB per km)[1] | Maintenance Cost during Rush-Hour Period (THB per km)[2] | $c_M$ |
|---|---|---|---|
| <1,500 | 0.2643 | 0.6580 | 0.40 |
| 1,500 | 0.3269 | 0.7707 | 0.42 |
| 1,800 | 0.3327 | 0.9196 | 0.36 |
| 2,000 | 0.3337 | 0.9374 | 0.36 |
| >2,000 | 0.3567 | 1.1369 | 0.31 |

Sources: [1]Honda. Retrieved from https://www.honda.co.th/service/periodical/detail. [2] Survey data

Note: All monetary values are shown in 2023 baht, with prior year values inflated using Thailand's consumer price index. Prices rose by approximately 11.9% from 2015 to 2023.

*External cost*

We estimate the net external cost by calculating the difference between GHG emission costs during rush-hour and non-rush-hour periods. The data on GHG emission costs were obtained from the US EPA (2015) study, which considered the impacts of climate change on agricultural yield, health risks, and disaster risks at discount rates of 2.5%, 3%, and 5%. Our analysis focuses on the 2.5% and 5% discount rates to determine the lower and upper bounds of the costs. We estimate the external cost using the following equation:

$$EC = (GHGC_R - GHGC_{NR}) \times GHCC \tag{8}$$

where $EC$ is the net external cost of GHG emission; $GHGC_R$ and $GHGC_{NR}$ are the amount of GHG emissions during rush-hour and non-rush-hour periods, respectively; and $GHCC$ is the unit of GHG emission cost for one-metric-ton $CO_2$ equivalent.

The GHG emissions during the rush-hour period ($GHGC_R$) are estimated by multiplying fuel consumption ($FU$) by the GHG emission factor per unit of fuel consumed ($E_{GHG}$):

$$GHGC_R = FU \times E_{GHG} \tag{9}$$

The data on fuel consumption ($FU$) were obtained from a survey, while the GHG emission factor per unit of fuel consumed ($E_{GHG}$) was sourced from the Intergovernmental Panel on Climate Change (TGO, 2011) (see Table 3). Conversely, the GHG emissions during the non-rush-hour period ($GHGC_{NR}$) can be calculated by multiplying the GHG emissions during the rush-hour period ($GHGC_R$) by the ratio of fuel consumption ($c_F$):

$$GHGC_{NR} = GHGC_R \times c_F. \quad (10)$$

Table 3: GHG emission level of each fuel category

| Fuel Type | $E_{GHG}$ (kg $CO_2$ per unit) |
|---|---|
| Benzene 91/95/Gasohol 91/95 (L) | 2.190 |
| NGV (kg) | 2.247 |
| E 20/85 (L) | 2.190 |
| Diesel (L) | 2.745 |
| LPG (L) | 1.536 |

Source: TGO. (2011)

Note: All monetary values are shown in 2023 baht, with prior year values inflated using Thailand's consumer price index. Prices rose by approximately 11.9% from 2015 to 2023.

### 3.2 Marginal Cost of Delay Due to Traffic Congestion

We estimate the marginal cost of delay caused by traffic congestion by analyzing the relationship between the cost of traffic congestion and vehicle speed. The pattern of these two datasets follows a nonlinear model, which is compatible with the reciprocal model (Gujarati, 2003). Mathematically, this relationship can be expressed as follows:

$$CC_i = \beta_1 + \beta_2 \left(\frac{1}{V_i}\right) + \epsilon_i \quad (11)$$

where $CC_i$ annual traffic congestion cost of sample *i*, $V_i$ is the vehicle speed of sample *i* during the rush-hour period (in kph), $\beta_1$ and $\beta_2$ are the parameters, and $\epsilon_i$ is the error term of sample *i.*

Equation (11) shows that congestion cost and vehicle speed are inversely related. As such, we can estimate the marginal cost of delay by computing the slope in Equation (11) $\left(\frac{dC_i}{dV_i} = -\beta_2 \left(\frac{1}{V_i^2}\right)\right)$. The slope of the relationship between the cost of traffic congestion and inverse speed indicates how much the congestion cost changes when the vehicle speed decreases by one unit (kph). To estimate these changes, we calculate the parameters $\beta_1$ and $\beta_2$ using Tobit regression models.

## 4. Results and Discussion

Table 4 shows that the average age of the vehicles in our sample is 5.5 years. Respondents who commute using their own cars during morning rush hours travel an average distance of 20.8 km, 4.8 days per week. The average travel time during rush hours (one-way trip) is about 1 hour (64 minutes). In contrast, the average travel time during non-rush hours (one-way trip) is only half an hour (29.27 minutes). Consequently, the average speed during rush hours (20.2 kph) is slower than during non-rush hours (44.32 kph). The monthly fuel cost and toll fees are approximately THB 3,691 (USD 123) and THB 1,354 (USD 45), respectively, while the annual maintenance cost is around THB 11,484 (USD 383).

Table 4: Respondents' profile

| Characteristics | Average | Minimum | Maximum | SD |
|---|---|---|---|---|
| Commuting information during rush hours and non-rush hours | | | | |
| Age of vehicle (years) | 5.52 | 0.36 | 20 | 3.92 |
| Number of days traveling using private cars (days/week) | 4.78 | 3.00 | 5 | 0.60 |
| Travel distance (km/ one-way trip) | 20.82 | 1.50 | 150 | 16.45 |
| Travel time during rush hours (min/ one-way trip) | 64.29 | 5.00 | 180 | 32.37 |
| Travel time during non-rush hours (min/ one-way trip) | 29.27 | 5.00 | 120 | 16.14 |
| Vehicle speed during rush hours (kph) | 20.21 | 5.00 | 70 | 11.99 |
| Vehicle speed during non-rush hours (kph) | 44.32 | 9.00 | 120 | 23 |
| Main purpose for traveling during rush hours is to go to work (% of respondents) | 92.90 | – | – | – |
| Information on travel costs | | | | |
| Fuel cost (THB/month) | 3,691 (USD 123) | 169 (USD 6) | 16,854 (USD 562) | 2,131 (USD 71) |
| Toll fee (THB/month) | 1,354 (USD 45) | 34 (USD 1) | 11,236 (USD 375) | 1,697 (USD 57) |
| Maintenance cost (THB/year) | 11,484 (USD 383) | 1,124 (USD 37) | 179,775 (USD 5,993) | 16,161 (USD 539) |
| Sociodemographic characteristics | | | | |
| Gender (% of females) | 54.88 | – | – | – |
| Age (years) | 39.00 | 23 | 65 | 10.00 |
| Years of schooling (years) | 16.68 | 23 | 9 | 1.83 |
| Monthly income (THB/month) | 37,536 (USD 1,251) | 8,427 (USD 281) | 115,169 (USD 3,839) | 20,540 (USD 685) |

*Note*s. 1. SD = standard deviation.

2. USD 1 = THB 30.

3. All monetary values are shown in 2023 prices.

Table 4 also shows that there are slightly more female participants (55 percent) than male participants. The average age and years of schooling of the commuters are 39 years and 17 years (equivalent to a Bachelor's degree), respectively, while the average monthly income is about THB 37,536 (USD 1,251) at the 2023 price level.

### 4.1 Cost of Traffic Congestion

As mentioned earlier, the cost of traffic congestion is the sum of the private cost and the external cost. The private cost includes the opportunity cost of time, fuel, and maintenance. In this study, we find that the annual cost of traffic congestion per vehicle is approximately THB 77,021 (USD 2,567) at the 2023 price level, using a 5% GHG damage cost discount rate, and about THB 76,155 (USD 2,539) at the 2023 price level, using a 2.5% GHG damage cost discount rate (Table 5).

Table 5: Costs of traffic congestion

| Cost | Baht/year (USD/year) | Baht/trip (USD/trip) | Baht/hour (USD/hour) | Baht/km (USD/km) |
|---|---|---|---|---|
| Opportunity cost of additional traveling time (OC) | 61,401.24 | 128.09 | 117.00 | 6.10 |
| | (2,046.71) | (4.30) | (3.90) | (0.20) |
| Additional fuel and maintenance costs (FMC) | 14,542.25 | 30.30 | 27.60 | 1.30 |
| | (484.74) | (1.00) | (0.90) | (0.04) |
| External cost of CO2 using a 5-percent discount rate | 211.69 | 0.34 | 0.34 | 0.02 |
| | (7.10) | (0.01) | (0.01) | (0.001) |
| External cost of CO2 using a 2.5-percent discount rate | 1,077.98 | 2.36 | 2.02 | 0.10 |
| | (35.93) | (0.08) | (0.07) | (0.003) |
| Cost (SC) using a 5-percent discount rate | 76,155.00 | 158.76 | 145.28 | 7.42 |
| | (2,538.50) | (5.29) | (4.84) | (0.25) |
| Cost (SC) using a 2.5-percent discount rate | 77,021.00 | 158.76 | 146.90 | 7.45 |
| | (2,567.00) | (5.29) | (4.90) | (0.25) |

Notes: 1. USD 1 = THB 30.

2. All monetary values are shown in 2023 prices.

The average opportunity cost of time per vehicle is approximately THB 61,401.24 (USD 2,046.71) per year, accounting for 85 percent of the total cost of traffic congestion. This result is consistent with the findings of Transport Canada (2007), which reported that the value of time, representing about 90 percent, constituted the highest proportion of traffic congestion costs.

Based on the 2023 vehicle registration data for Bangkok, there were approximately 4,453,994 passenger vehicles[4] on the roads of the metropolis daily (DLT., 2023). If we use this figure as a proxy for the number of vehicles on the road, the annual total cost of traffic congestion would be THB 339,193 million (USD 11,306 million) at the 2023 price level, using a 5 percent GHG damage cost discount rate. However, it is important to note that the estimated cost in this study represents the lower-bound value and does not include other external costs, such as health costs and increased costs of doing business.

4.2 Marginal Cost of Delay Caused by Congestion

In this section, we estimate the marginal cost of delay due to traffic congestion using Equation (11), which describes the relationship between the cost of traffic congestion and inverse speed. The dependent variables in the Tobit regressions for the first two models (models 1 and 2) represent the costs of traffic congestion at a 2.5 percent GHG damage cost discount rate, while the dependent variables in the last two models represent the costs of traffic congestion at a 5 percent GHG damage cost discount rate (Table 6).

When we control for sociodemographic factors (models 2 and 4), the inverse speed ($speed^{-1}$) becomes more statistically significant. This indicates that as vehicle speed decreases, the cost of congestion, particularly in models that control for sociodemographic factors, increases further at a 5 percent significance level. This also implies that if vehicles move even slower, commuters would incur higher costs (e.g., opportunity cost of time, fuel costs, and maintenance costs). The other controlled variables (vehicle age, gender, commuter age) have no significant effect on the cost of traffic congestion; however, the coefficients for respondents' income in models 2 and 4 are positive at a 1percent significance level. This is because the opportunity cost of time is higher for wealthier commuters compared to those with lower incomes.

We can estimate the marginal cost of delay by estimating the slope in Equation (11) $\left(\frac{dC_i}{dV_i} = -\beta_2\left(\frac{1}{V_i^2}\right)\right)$. This indicates that if vehicle speed decreases by 1 kph, the annual cost per vehicle would range between THB 646 and THB 648 (approximately USD 22) at the 2023 price level, assuming the average speed of 20.29 kph from the survey data. The marginal cost of delay can then be used to establish a lower-bound fee to simulate road charges in congested areas during rush-hour periods. The road charge, or congestion charge, is a type of Pigouvian tax designed to change car users' behavior, particularly by encouraging commuters to shift from using private cars to mass transit modes.

[4] This figure does not include motorcycles, tractors, or motorized three-wheeled taxis (tuk-tuks). It should be noted that the registered number of vehicles is likely lower than the actual number of vehicles on the road, meaning that our estimation represents a lower-bound value.

Table 6: Tobit regressions on the cost of traffic congestion

| Variable | Dependent Variable: Cost of Traffic Congestion | | | |
|---|---|---|---|---|
| | 2.5% GHG Damage Cost Discount Rate | | 5% GHG Damage Cost Discount Rate | |
| Controlled Sociodemographic Variables | No | Yes | No | Yes |
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Constant | 55.097*** | -21.509 | 54.177*** | -21.908 |
| | (9.740) | 26.192 | (9.673) | (26.065) |
| $Speed^{-1}$ | 277.111* | 266.115** | 277.968* | 266.77** |
| | (160.738) | (130.004) | (159.618) | (128.956) |
| Age of vehicle | – | .254 | – | .248 |
| | | (.805) | | (.799) |
| Gender (male = 1) | – | 10.053 | – | 9.759 |
| | | (7.445) | | (7.421) |
| Commuter's age | – | .215 | – | .209 |
| | | (.444) | | (.441) |
| Commuter's income | – | 1.686*** | – | 1.683*** |
| | | (.321) | | (.320) |
| No. of samples | 212 | 212 | 212 | 212 |
| AIC | 2375.674 | 2309.815 | 2374.269 | 2308.403 |

*Notes*. 1. ***, **, and * are values that are statistically significant at 1 percent, 5 percent, and 10 percent levels of significance, respectively.

2. Numbers in ( ) are standard deviations.

3. All monetary values are shown in 2023 thousand baht, with prior year values inflated using Thailand's consumer price index. Prices rose by approximately 11.9% from 2015 to 2023.

Thailand has been actively addressing the traffic congestion problem in Bangkok from the supply side by expanding transportation infrastructure. However, the outcomes of these measures are not long-lasting, as the effect of induced travel demand diminishes the benefits of newly added transport capacities (Jaensirisak et al., 2009). Consequently, the idea of travel demand-side management (e.g., road charges) has been proposed as an alternative policy to help address the problem from the demand perspective.

The value presented in this study can serve as a starting point for implementing a Pigouvian tax in the form of road charges during rush hours. However, before implementing such a road charge scheme, further research is needed to understand the factors that will influence public acceptance of the necessity of road charges.

## 5. Conclusions and Recommendations

Our findings provide additional empirical evidence on the cost of traffic congestion by using a survey research design that accounts for the heterogeneous characteristics of each commuter. The results of our study show that the annual costs of traffic congestion per vehicle range between THB 76,155 (USD 2,539) and THB 77,021 (USD 2,567) at the 2023 price level, depending on different GHG damage cost discount rates. These values can serve as a proxy for the benefits (or avoided costs) of congestion mitigation measures.

We also find that if vehicle speed decreases by one unit (i.e., 1 kph), the annual cost per vehicle would range from THB 646 to THB 648 (approximately USD 22) at the 2023 price level. Accordingly, the marginal cost of delay can be used to establish a lower-bound fee to simulate road charges in congested areas during rush-hour periods. Congestion charges could be one solution to address traffic congestion in Bangkok. However, the exact amount of congestion charges to be imposed on commuters requires further study, including research on the price elasticity of demand for congestion charges and the public's acceptability of such charges.

While we have made every effort to be meticulous in this research, we acknowledge the following limitations. The estimation in this study likely underestimates the costs of traffic congestion because limited data precluded the inclusion of non-recurrent congestion costs (e.g., congestion caused by random events such as bad weather or accidents) and other related costs such as noise pollution and stress (Transport Canada, 2007). Furthermore, this study does not account for other impacts of traffic congestion, such as health effects from particulate matter (PM2.5) and the increased costs of doing business in congested conditions. For example, transporting goods in and out of congested cities is more costly, and attending business meetings becomes more time-consuming when roads are congested (CBER., 2014).

Nevertheless, our work can be seen as a first step. Replication of this methodology for multiple estimations of traffic congestion costs, whether using the same approach or incorporating additional related impacts as mentioned above, would enhance the potential to generalize the results of traffic congestion cost estimations.

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