Estimating the External Costs of Vehicle Emissions on Freeways in Taiwan

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Abstract: In order to understand the trend of air pollution external costs that vehicles (including passenger car, light trucks and heavy trucks) incur, based on marginal and total cost estimation methods, this paper estimates uses three years' freeway traffic data in Taiwan (2010, 2013, and 2016) to estimate them. The analysis reveals that, for passengers, the range of value for marginal cost and external costs are US$0.02166~ US$0.02192 and US$22.39 million ~ US$30.67 million, respectively. Regarding light trucks, the range of value for marginal costs and external costs are US$0.02311~ US $0.02360 and US$18.53 million ~ US$25.50 million, respectively. Finally, for heavy trucks, the range of value for marginal costs and external costs are US$0.06282~ US $0.06416 and US$13.92 million ~ US$16.46 million, respectively. It is expected that the results of this paper will raise public awareness of the social welfare loss caused by freeway traffic and provide policy-makers with key policy implications.

Keywords: External cost; Air pollution; Vehicles; Freeways

1. INTRODUCTION

Rapid economic development and urbanization have greatly increased the number of freeway passenger cars. While generating economic benefits for the region, this type of traffic also generates damaging environmental effects and social costs (Zito and Salvo, 2009; Hidalgo and Huizenga, 2013). Traditionally, transportation infrastructures, including freeways, have been viewed as public goods whose pricing schemes are set by public authorities. Assuming constant returns to scale in highway investment, government agencies could recover the investment costs of construction by charging tolls equal to the marginal costs of travel. However, such a pricing scheme may not recover the external costs of freeway travel and is difficult to 'measure' when considering air pollution, congestion, and fatality externalities (Nash and Sansom, 2001). A key question, therefore, is how to estimate the level of these externalities to determine the true costs to society from freeway construction and traffic.

Past studies have mostly focused on the estimation of the magnitude of a specific value of the externality of air pollution from traffic (e.g., Yin and Lawphongpanich, 2006; Guo et al., 2010; Michiels *et al.*, 2012; Jandacka *et al.*, 2017). Other studies have attempted to estimate other externalities, such as noise, congestion and fatality (Berechman et al., 2011; Márquez and Cantillo, 2013). However, research into marginal costs regarding freeway traffic is relatively scarce. In one example, in the US, Bigazzi and Figliozzi (2013) investigated marginal costs of freeway traffic congestion with on-road pollution exposure externality and find the expression for marginal external costs of on-road exposure should account for the marginal vehicles emissions, the increased emissions from all vehicles caused by additional congestion from the marginal vehicle, and the additional exposure duration for all travelers caused by additional congestion from the marginal vehicle.

The concept of marginal external costs is crucial for evaluating road pricing schemes and fiscal policy instruments (e.g., fuel tax or vehicle emission taxes) (Jensen *et al.*, 2008). In this paper, three types of vehicles are investigated: passenger cars, light truck and heavy trucks. Passenger cars constitute the majority of the above three transport modes on freeways in Taiwan. Thus, the main objective of this paper is to analyze and estimate the magnitude of the above three types of vehicles and their associated external costs. The results of this paper would raise public awareness in Taiwan regarding the social welfare loss caused by the emissions from freeway traffic and provide policy-makers with crucial policy implication.

The paper is organized as follows. Section 2 reviews the literature related to air pollution and the external costs of road transport. The estimation method is described in Section 3. The external cost analysis follows in Section 4. Finally, Section 5 offers some concluding remarks and recommendations for future research.

2. LITERATURE REVIEW

2.1 Externalities of Road Transport

Although some attempts have been made to estimate the external costs of road transport (Jakob *et al.*, 2006; Paruomg *et al.*, 2006; Shepherd, 2008; Litman, 2009; Guo *et al.*, 2010; Santos *et al.*, 2010; Sen *et al.*, 2010; Sturm *et al.*, 2011), the number of studies which use a marginal cost approach are relatively few. In the studies that have been undertaken, Bigazzi and Figliozzi (2013) used internal costs (time and operation) and external costs (congestion, accidents, air pollution and CO_2 emissions) to evaluate freight transport corridors in Colombia. In addition, Ma´rquez and Cantillo (2013) adopted the marginal cost of freeway traffic congestion to investigate on-road pollution exposure externality. It is also notable that the majority of these studies were carried out in the US (Ozbay *et al.*, 2007; Delucchi and McCubbin, 2010; Seong *et al.*, 2011; Bigazzi and Figliozzi, 2013) and Europe (Monzo´n and Guerrero, 2004; Quinet, 2004; Bickel *et al.*, 2006; Fernandez-Barcelo and Campos-Cacheda, 2012; Pérez-Martínez and Vassallo-Magro, 2013; Smith *et al.*, 2013; Jandacka *et al.*, 2017). In addition, many of these studies have focused on intercity or expressway travel (e.g., Forkenbrock, 1999; Beuthe *et al.*, 2002; Ozbay *et al.*, 2007; Berechman *et al.*, 2011).

Nevertheless, some studies related to the external cost of road transport have been undertaken in Asia. Due to the demographic characteristics of a high-density population and its narrow geographical distribution, most of them have given more attention to the external costs of urban roads. These studies have focused on Hong Kong (Cen *et al.*, 2016), Malaysia (Ong *et al.*, 2011), Indonesia (Sugiyanto *et al.*, 2010), Korea (Seo and Kim, 2013), Japan (Mizutani *et al.*, 2011), Turkey (Soylu, 2007), Saudi Arabia (Rahman *et al.*, 2017) and Delhi (India) (Goel and Guttikunda, 2015). In Taiwan, Lee *et al.* (2010) and Liao *et al.* (2009) and Berechman and Tseng (2012) have estimated the external costs of trucks on freeways. This paper adds to this literature through complementing the existing studies that have focused on the emissions and external costs of trucks by further categorize three types of vehicles (passenger cars, light truck and heavy truck) and estimating their marginal and external costs. Tseng *et al.* (2014) investigated the impact of freeway electronic toll collection to the external costs in Taiwan. The key studies are summarized in Table 1.

Table 1 Summary of key transport external costs related studies

Author(s)	Topic	Methodology	Findings
Bigazzi and Figliozzi (2013)	Evaluating the marginal costs of freeway traffic congestion with on-road pollution exposure externality	Marginal private and external cost methods	Health costs of on-road pollution exposure can be a large portion (18%) of marginal social costs near freeway capacity.
Ma´rquez and Cantillo (2013)	Evaluating external costs of freight transport corridors in Colombia	Marginal cost estimation by Equilibrium in Inertia method and Equilibrium in Change	Average external costs were rated equal to 0.014 US $/ton-km for highways
Lee *et al.* (2010)	Comparing external costs of container transportation between short sea shipping and trucking	Activity-based external costs estimation method	Container cargoes transferred within Taiwan caused a total of about US$85 million in external costs of air emissions
Liao *et al.* (2009)	Comparing carbon dioxide emissions of trucking and intermodal container transport in Taiwan	Activity-based external costs estimation method	Replacing long-haul truck transport with the intermodal can significantly reduce carbon dioxide emission significantly
Berechman and Tseng (2012)	Estimating port related emission costs in Kaohsiung port	Activity-based external costs estimation method	The combined environmental costs of ships and trucks are estimated to be over $123 million per year
Tseng *et al.* (2014)	Investigating the external cost of highway electronic toll collection in Taiwan	Activity-based external costs estimation method	The reduction of external costs fell by 60.1% in terms of value of transaction time

2.2 Measurement of Air Emission External Costs

Methods of measuring transport external costs in monetary terms have been examined in several studies[1]. Quinet (2004) reviewed fifteen studies in Western

1 Partial list includes Nash et al. (2001); Beuthe et al. (2002); Ozbay et al. (2007); Delucchi and

Europe and presented an average external transport cost per passenger or per ton-km for cars, buses (coaches) and trucks. The figures were €0.093, €0.043 and €0.054, respectively, revealing that cars are a greater polluter than buses. Ozbay *et al.* (2007) estimated the full marginal cost of freeway passenger transportation (total marginal cost per an additional trip), including vehicle operation, congestion, infrastructure, air pollution, fatality and noise. They reported the full marginal costs of the selected original destinations to within US$1.32 to US$6.02 per hour depending on network conditions and the type of model used. In an Indian context, Sen *et al.* (2010) estimated the marginal external costs for congestion, air pollution, fatality and noise for Delhi’s urban transport for the year 2005. In their study, external costs were divided into two categories: (a) user costs (congestion and fatality costs) and (b) environmental costs (air pollution and noise costs). The results reported were US$ 0.117 dollars/vehicle-km and US$ 0.018 dollars/vehicle-km for cars in peak and off-peak hours, respectively. In Maryland, Zhang and Lu (2013) estimated the full marginal cost of auto and truck travel in different time periods on all roadways.

Vehicle emissions can be highly pollutive, and include sulfur dioxide (SO_2), nitrogen oxides (NOx), hydrogen compounds (HC), carbon monoxide (CO), and particulate matter (PM). In Canada, Zhang *et al.* (2004) have indicated air pollution costs for cars, buses and trucks to be $0.14-$0.16 per passenger-km and $0.83 per ton-km, respectively. For the US, Lemp and Kockelman (2008) found the air pollution costs of car use to be between $0.06 and $0.83 per passenger-km (assuming 1.6 passengers per vehicle). In Beijing, Guo *et al.* (2010) estimated the economic costs of particulate air pollution from road transport (for the years 2004-2008) to be US$282, US$297, US$310, US$323 and US$298 million, respectively. Mashayekh *et al.* (2011) estimated the costs for automobile air emissions for 86 U.S. metropolitan areas and found results showing that total air emission costs are estimated to be $145 million/ day. These external costs averaged US$0.64 per day per person and US$0.05 per vehicle km traveled. Berechman *et al.* (2011) collected four pollutants (VOC, CO, NOx and PM_{10}) and estimated freeway air pollution costs in the US. They reported that full marginal and full average costs for air pollution were US$0.046 and US $0.0003, respectively, during peak hours. Abou-Senna and Radwan (2014) developed a microscopic transportation emissions model to estimate carbon dioxide emissions on limited-access highways in the US. The key studies are summarized as
Table 2.

Table 2 Summary of air emission external costs studies

Author(s)	Topic	Methodology	Findings
Quinet (2004)	Analyzing external transport cost	Ordinary linear regressions	Providing a comparison

McCubbin (2010); Santos et al. (2010); Sen et al. (2010); Anas and Lindsey (2011).

	estimates of transport modes in Western Europe		analysis using car, bus, rail passenger transport, rail freight transport, air passenger transport, and truck data
Ozbay *et al.* (2007)	Estimating the full marginal cost of highway passenger transportation in New Jersey	Using PARAMICS and TransCAD simulation software to estimate various marginal costs	Providing marginal costs for vehicle operating, congestion, accident, environmental, and infrastructure costs.
Sen *et al.* (2010)	Estimating marginal external costs of transport in Delhi	Marginal cost functions	Marginal external costs of congestion, air pollution, road accidents and noise are estimated and discussed
Zhang and Lu (2013)	Estimating marginal-cost vehicle mileage fees	Marginal cost functions	Providing full marginal costs of auto and truck travel over different time periods
Lemp and Kockelman (2008)	Quantifying the external costs of vehicle use	Global warming cost, health cost of emissions, crash cost, and land consumption cost functions	The total of the five external costs examined averaged \$0.236 per mile
Guo *et al.* (2010)	Estimation of economic costs of particulate air pollution from road transport in Beijing	Population exposure level to air pollution and economic costs	Total economic cost of health impacts during 2004-2008 was \$US 272, 297, 310, 323, and 298 million respectively
Berechman *et al.* (2011)	Estimating full marginal costs of highway travel from the Northern New Jersey highway network	Origin-destination spatial level and marginal cost functions	Presenting equity concept among users and developing effective pricing mechanisms
Abou-Senna and Radwan (2014)	Developing a microscopic transportation emissions model to estimate carbon	Experimental analysis by VISSIM/MOVES integration software	Speed management has a significant impact on CO_2 emissions

	dioxide emissions on highways	

3. METHODOLOGY

In this paper, marginal external costs are defined as the costs of transporting an additional trip-maker or vehicle over a segment of the freeway. Such an approach has been extensively used for the computation of freeway congestion tolls, and has also been used for levying Pigouvian type taxes on other traffic related externalities (Mayeres *et al.*, 1996; Nash and Sansom, 2001; Berechman, 2009; Maffii and Parolin, 2010).

3.1 Data

The study site selected for this paper is the First and Third National Freeway in Taiwan. First National Freeway was completed on the 31st of October, 1978.[2] The total length of the road is 432.5 km. It has 74 interchanges and six service areas. Third National Freeway was completed on the 25st of February, 2008. The total length of the road is 437.1 km. It has 71 interchanges and seven service areas. Traffic data (including traffic volume and average speed) is provided by the Taiwan Area National Freeway Bureau in Taiwan[3]. The data period covers three different years: 2010, 2013, and 2016 (1 January~31 December). The database includes hourly and daily southbound and northbound traffic counts from the study area. Based on the 2011 Highway Capacity Manual in Taiwan, the PCUs (Passenger Car Unit) for light trucks and heavy trucks are 1.0 and 2.0, respectively (Institute of Transportation, 2011).

3.2 Estimation Method

In Taiwan, Su *et al.* (2016) presented a new estimation methodology (considering on-road dynamics of in-use vehicles) to evaluate energy saving and carbon dioxide reduction in Taiwanese transport projects. The construction of the Wu-Yang Viaduct of Highway 1 and the improvement of the Zhubei Interchange of Highway 1 were chosen as pilot cases.

In this paper, marginal air pollution cost is defined as the cost of transporting an additional trip-maker or vehicle over a specific segment of the freeway. Such an approach has been used extensively for the computation of levying Pigouvian type taxes on traffic related externalities (Mayeres *et al.*, 1996; Nash and Sansom, 2001; Berechman, 2009).

In addition, in this paper, the total and marginal air pollution cost functions are

[2] Electronic toll collection system was introduced on 30 December 2003.

[3] Taiwan Area National Freeway Bureau, Ministry of Transportation and Communication https://www.freeway.gov.tw/english/Default.aspx

cited from Berechman *et al.* (2011) and shown in Table 1.[4] In these two functions, C_{air} and MC_{air} represent the total air pollution external cost and marginal air pollution external costs, respectively. F represents the fuel consumption function. In order to consider true vehicle travelling data in Taiwan, fuel consumption functions for passenger cars, light trucks and heavy trucks are cited from Su *et al.* (2016), given that this source is widely used in Taiwan focused freeway studies. As Table 1 shows, total air pollution cost is adversely affected by traffic volume and fuel consumption. Marginal air pollution external cost is also affected by fuel consumption in that the more fuel that is consumed, the higher are the air pollution external costs.

Table 1. Total and marginal air pollution cost functions

Cost Type	Function
Total air pollution external cost	$C_{air} = V\times(0.01094+0.211\times F)$
Marginal air pollution external cost	$MC_{air}=0.010904+0.211(F+\partial F/\partial V)$

Where
C_{air}=total air pollution cost (US$)
$F_{car}=0.0641+(0.8293/S)-0.0009S+0.0000077S^2$
$F_{light\ truck}=0.1027+(0.2145/S)-0.0016S+0.000013S^2$
$F_{heavy\ truck}=0.5601+(0.0179/S)-0.0096S+0.000073S^2$
F is the fuel consumption function, which is used to estimate the quantities of the pollutants (liter/km)(Su *et al.*, 2016)
V=traffic volume (per km)
S=average speed (km/hour)

4. CALCULATIONS AND RESULTS

4.1 External Cost Analysis

As shown in Table 2, in 2016, the total air pollution external costs for passenger cars, light trucks and heavy trucks were US$30.67 million, US$25.50 million, US $16.46 million, respectively. Evidently, the trend of external costs is gradually increasing due to fact that the total volume of vehicles has continued to grow during 2010~2016. Also, the growth rate of vehicles during the period of 2010~2013 was about 3~3.5 times higher than in the period of 2013~2016 for these three types of vehicles.

Table 2. Summary of marginal and external costs

Year	Marginal cost of passenger cars (US$/km)	Marginal cost of light trucks(US$/km)	Marginal cost of heavy trucks(US$/km)	Total external cost of passenger cars (million US$)	Total external cost of light trucks (million US$)	Total external cost of heavy trucks (million US$)

[4] The main pollutants used for the calculation of pollution costs were VOC, CO_2, CO, NOx and PM_{10}. Carbon dioxide (CO_2) is emitted during the combustion of fossil fuels, making up about 75~80% of greenhouse gas (GHG) emissions (Liao *et al.*, 2009; Nocera and Cavallaro, 2012).

2010	0.02166	0.02311	0.06282	22.39	18.53	13.92
2013	0.02182	0.02336	0.06314	24.21	19.95	14.21
2016	0.02192	0.02360	0.06416	30.67	25.50	16.46
Total				77.27	63.98	44.59

Taking year 2016 as example, the main implication of marginal cost is that an additional unit of passenger car traffic on freeways will generate air pollution costs of about US$0.02166 (per km of travel). This figure is close to the research finding in the U.S. Metropolitan areas (US$0.0188 per km of travel (Mashayeky *et al.*, 2011)). When multiplying the total distance of passenger car traveled on this freeway, the total external costs of air pollution amount to US$30.67 million in 2016.

5. DISCUSSION AND CONCLUSIONS

This paper has focused on the marginal and external costs associated with air pollution from freeway passenger cars, light trucks and heavy trucks in Taiwan. Taking the year 2016 as an example, it has shown that although the value of external costs for passenger cars is highest (US$ 30.67 million) due to higher traffic volume, followed by light trucks (US$ 25.50 million) and heavy trucks (US$ 16.46 million), the highest marginal costs are for heavy trucks (US$ 0.06416), followed by light trucks (US$ 0.02360) and passenger cars (US$ 0.02192).

Currently, the standard toll per km in Taiwan Area National Freeway is calculated based on distance travelled daily and vehicle types. Three toll types are used in the current mechanism. First, if the distance travelled daily is less than 20 km, the journey is toll-free for all types of vehicles. Second, within distances travelled daily between 20~200 km, passenger cars and light trucks are charged $US 0.04 per km and heavy trucks charged what averages to be $US0.05 per km.[5] Finally, if the distance travelled daily is more than 200 km, passenger cars and light trucks are charged $US 0.03 per km and heavy trucks charged what averages to be $US0.037 per km.[6]

However, these tolls could arguably be further adjusted with flexibility mechanisms when considering their true external social costs. Generally, the external social cost of vehicles is seldom considered because it is difficult to measure. This difficulty is due to the fact that it involves many complex factors (such as emission costs, congestion costs, accident costs, etc.) and these factors are themselves in turn affected by factors such as user driving behavior, vehicle conditions, and the road environment (for example weather conditions, freeway maintenance conditions, etc).

[5] These fares may be adjusted when there is a long weekend, a consecutive holiday or a special holiday. Also, toll-free journeys are allowed during specific times (e.g. midnight period) in order to avoid traffic jams. Furthermore, some toll discounts are offered on specific segments of the freeway during particular holidays. The toll charges and conditions for buses are the same as for heavy trucks.

[6] Trailers are charged $US0.06 within distances travelled daily between 20~200 km. When the distance travelled daily is more than 200 km, trailers are charged $US 0.045.

To internalize these external costs, the results of this paper can be used to evaluate optimal road pricing (e.g., Pigouvian tolls) when considering private market prices plus the estimated external costs. These results can help calculate transportation costs when conducting a cost-benefit analysis of a new road investment. For example, a higher emission tax, should be levied from heavy truck users (either individuals or companies), followed by light truck users and passenger car users.

It should be noted that the emissions of various types vehicles in real traffic situations differ significantly due to complicated factors that affect fuel efficiency, such as slope, geometric design of road sections, weather conditions, peak/off-peak travel congestion, and so on. Therefore, the estimates of this paper are still uncertain, and more research is needed in this field. Regarding future research, four potential suggestions include: First, uncertainty and sensitivity analysis when other influencing factors are considered in the future. Such an approach can improve the estimation methods used in this paper; Second, other traffic externality functions (e.g. congestion, noise, accident and increased maintenance costs, etc.) could also be surveyed as similar or related topics. Third, exploring efficient taxes and charges to internalize air pollution related to externalities since there is a strong link between them (Santos *et al.*, 2010). Finally, based on the "polluter pay" principle, it is suggested that more accurate standard tolls be charged for various vehicle types according to their true external costs. For example, standard tolls for passenger vehicles and cargo vehicles should be different due to the various different vehicle characteristics. Also, due to the reason that peak flows may result in more fuel consumption, air pollution and congestion costs, peak/off peak pricing based on user driving periods could be further considered for various different vehicles in the future.

ACKNOWLEDGEMENTS

Financial support for this paper was provided by Ministry of Science Technology, Taiwan (NSC 101-2410-H-424-015).The author is indebted to the Taiwan Area National Freeway Bureau, who provided the data set used in this paper.

REFERENCES

Abou-Senna, H., Radwan, E. (2014) Developing a microscopic transportation emissions model to estimate carbon dioxide emissions on limited-access highways. *Transportation Research Record*, 2428, 44-53.

Anas, A., Lindsey, R. (2011) Reducing urban road transportation externalities: road pricing in theory and in practice. *Review of Environment Economics Policy* 5, 66-88.

Andersson, H., Jonsson, L., Ö gren, M. (2013) Benefit measures for noise abatement: calculations for road and rail traffic noise. *European Transport Research Review* 5, 135-148.

Berechman, J. (2009) Estimation of the full marginal costs of port related truck traffic. *Evaluation and Program Planning* 32, 390-396.
Berechman, Y., Bartin, B., Yanmaz-Tuzel, O., Ozbay, K. (2011) The full marginal costs of highway travel: methods and empirical estimation for North America. Chapter 19 in *A Handbook in Transport Economics*, Edward Elgar Publishing Inc. Williston, VT USA.
Berechman, J., Tseng, P.H. (2012) Estimating the environmental costs of port related emissions: The case of Kaohsiung, *Transportation Research Part D* 17, 35-38.
Beuthe, M., Degrandsart, F., Geerts, J.F., Jourquin, B. (2002) External costs of the Belgian interurban freight traffic: a network analysis of their internalization. *Transportation Research Part D* 7, 285-301.
Bickel, P., Friedrich, R., Link, H., Stewart, L., Nash, C. (2006) Introducing environmental externalities into transport pricing: measurement and implications. *Transport Reviews* 26, 389-415.
Bigazzi, A.Y., Figliozzi, M. (2013) Marginal costs of freeway traffic congestion with on-road pollution exposure externality. *Transportation Research Part A* 57, 12-24.
Cen, X., Lo, H.K., Li, L. (2016) A framework for estimating traffic emissions: The development of Passenger Car Emission Unit. *Transportation Research Part D* 44, 78-92.
Delucchi, M.A., McCubbin, D.R. (2010) External costs of transport in the U.S. Institute of Transportation Studies, University of California, Davis, U.S.
Fernandez-Barcelo, I., Campos-Cacheda, J.M. (2012) Estimate of social and environmental costs for the urban distribution of goods. Practical case for the city of Barcelona. *Procedia - Social and Behavioral Science* 39, 818-830.
Forkenbrock, D.J. (1999) External costs of intercity truck freight transportation. *Transportation Research Part A* 33, 505-526.
Goel, R.G., Guttikunda, S.K. (2015) Evolution of on-road vehicle exhaust emissions in Delhi. *Atmospheric Environment* 105, 78-90.
Guo, X.R., Cheng, S.Y., Chen, D.S., Zhou, Y., Wang, H.Y. (2010) Estimation of economic costs of particulate air pollution from road transport in China. *Atmospheric Environment* 44, 3369-3377.
Hidalgo, D., Huizenga, C. (2013) Implementation of sustainable urban transport in Latin America. *Research in Transportation Economics* 40, 66-77.
Institute of Transportation (2011) 2011 Highway Capacity Manual in Taiwan, Ministry of Transportation and Communication.
Jakob, A., Craig, J.L., Fisher, G. (2006) Transport cost analysis: a case study of the total costs of private and public transport in Auckland. *Environmental Science & Policy* 9, 55-66.
Jandacka, D., Durcanska, D., Bujdos, M. (2017) The contribution of road traffic to particulate matter and metals in air pollution in the vicinity of an urban road. *Transportation Research Part D* 50, 397-408.
Jensen, S.S., Willumsen, E., Brandt, J., Kristensen, N.B. (2008) Evaluation of exposure factors applied in marginal external cost analysis of transportation related air pollution. *Transportation Research Part D* 13, 255-273.
Lee, P.T.W., Hu, K.C., Chen, T. (2010) External costs of domestic container transportation: short-sea shipping versus trucking in Taiwan. *Transport Revivews* 30 315-335.
Lemp, J.D., Kockelman, K.M. (2008) Quantifying the external costs of vehicle use: evidence from America's top-selling light-duty models. *Transportation Research Part D* 13, 491-504.

Liao, C.H., Tseng, P.H., Lu, C.S. (2009) Comparing carbon dioxide emissions of trucking and intermodal container transport in Taiwan. *Transportation Research Part D* 14, 493-496.
Litman, T. (2009) Transportation cost and benefit analysis: techniques, estimates and implications. Victoria Transport Policy Institute, Victoria, Canada.
Maffii, S., Parolin, R. (2010) Applying social marginal costs pricing to the road sector. *Research in Transportation Economics* 30, 38-42.
Ma´rquez, L., Cantillo, V. (2013) Evaluating strategic freight transport corridors including external costs. *Transportation Planning and Technology* 36(6), 529-546.
Mashayekh, Y., Jaramillo, P., Chester, M., Hendrickson, C., Weber, C. (2011) Costs of automobile air emissions in U.S. metropolitan areas. *Transportation Research Record* 2233, 120-127.
Mayeres, I., Ochelen, S., Proost, S. (1996) The marginal external costs of urban transport. *Transportation Research Part D* 1, 111-130.
Michiels, H., Mayeres, I., Panis, L.I., Nocker, L.D., Deutsch, F., Lefebvre, W. (2012) PM2.5 and NOx from traffic: Human health impacts, external costs and policy implications from the Belgian perspective. *Transportation Research Part D* 17, 569-577.
Mizutani, F., Suzuki, Y., Sakai, H. (2011) Estimation of social costs of transport in Japan. *Urban Studies* 48 3537-3559.
Nash, C., Sansom, T. (2001) Pricing European transport systems. *Journal of Transportation Economics Policy* 35, 363-380.
Nash, C., Sansom, T., Still, B. (2001) Modifying transport prices to internalize externalities: evidence from European case studies. *Regional Science & Urban Economics* 31, 413-431.
Nocera, S., Cavallaro, F. (2012) Economic evaluation of future carbon dioxide impacts from Italian highways. *Procedia - Social and Behavioral Sciences* 54, 1360-1369.
Ong, H.C., Mahlia, T.M.I., Masjuki, H.H. (2011) A review on emissions and mitigation strategies for road transport in Malaysia. *Renewable and Sustainable Energy Reviews* 15, 3516-3522.
Ozbay, K., Bartin, B., Yanmaz-Tuzel, O., Berechman, J. (2007) Alternative methods for estimating full marginal costs of highway transportation. *Transportation Research Part A* 41, 768-786.
Paruomg, M., Mizokami, S., Kakimoto, R. (2006) Value of traffic externalities from attribute-based stated choice: route choice experiment. *Transportation Research Record* 1954, 52-56.
Pérez-Martínez, P.J., Vassallo-Magro, J.M. (2013) Changes in the external costs of freight surface transport in Spain. *Research in Transportation Economics* 42, 61-76.
Quinet, E.A, (2004) Meta-analysis of Western European external costs estimates. *Transportation Research Part D* 9, 465-476.
Rahman, S.M., Khondaker, A.N., Hasan, M.A., Reza, I. (2017) Greenhouse gas emissions from road transportation in Saudi Arabia - a challenging frontier. *Renewable and Sustainable Energy Reviews* 69, 812-821.
Santos, G., Behrendt, H., Maconi, L., Shirvani, T., Teytelboym, A. (2010) Externalities and economic policies in road transport. *Research in Transportation Economics* 28, 2-45.
Sen, A., Tiwari, G., Upadhyay, V. (2010) Estimating marginal external costs of transport in Delhi. *Transport Policy* 17, 27-37.

Seo, Y., Kim, S. M. (2013). Estimation of greenhouse gas emissions from road traffic: A case study in Korea. *Renewable and Sustainable Energy Reviews* 28, 777-787.
Seong, J.C., Park, T.H., Ko, J.H., Chang, S.I., Kim, M., Holt, J.B., Mehdi, M.R. (2011) Modeling of road traffic noise and estimated human exposure in Pulton county, Georgia, USA. *Environmental International* 37, 1336-1341.
Shepherd, S.P. (2008) The effect of complex models of externalities on estimated optimal tolls. *Transportation* 35, 559-577.
Smith, T.W., Axon, C.J., Darton, R.C. (2013). The impact on human health of car-related air pollution in the UK, 1995-2005. *Atmospheric Environment* 77, 260-266.
Soylu, S. (2007) Estimation of Turkish road transport emissions. *Energy Policy* 35, 4088-4094.
Sturm, J., Chowdhur, M., Dunning, A., Ogle, J. (2011) Analysis of cost estimation disclosure in environmental impact statements for surface transportation projects. *Transportation* 38, 525-544.
Su, C.W., Yang, Y.W., Chang, Y.C., Wen, P.C., Chen, P.C., Yu, H.M., Hu, Y.C., Jheng, J.Y., Chung, P.J., Wu, Z.Y. (2016) *The Study for Deployment and Improvement of Economic Appraisal Tool for Transport Project*, Institute of Transportation, Ministry of Transportation and Communication, Taiwan.
Sugiyanto, G., Malkhamah, S., Munawar, A., Sutomo, H. (2010) Estimation of congestion cost of private passenger car users in Malioboro, Yogyakarta. *Civil Engineering Dimension* 12, 92-97.
Tseng, P.H., Liu, D.Y., Chien, S. (2014) Investigating the impact of highway electronic toll collection to the external costs: a case in Taiwan. *Technological Forecasting & Social Change* 86, 265-272.
Yin, Y., Lawphongpanich, S. (2006) Internalizing emission externality on road networks. *Transportation Research Part D* 11, 292-301.
Zhang, A., Boardman, A.E., Gillen, D., Waters, W.G. (2004) Towards estimating the social and environmental transportation in Canada. Centre for Transportation Studies, Sauder School of Business, The University of British Columbia, Vancouver, Canada.
Zhang, L., Lu, Y. (2013) Implementing marginal-cost vehicle mileage fees on the Maryland statewide road network. *Transportation Research Record* 2345, 53-62.
Zito, P., Salvo, G. (2009) Toward an urban transport sustainability index: an European comparison. *European Transport Research Review* 3, 179-195.