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Estimating Marginal External Environmental Costs of Road Transportation in Iran Case Study Tehran-Qom Free Way

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Abstract

Environmental External costs of road transportation sector are costs which are imposed on environment by users of road transportation and are not compensated for by perpetrators causing it. The most important external costs are the costs of global warming, the costs of air pollution, the costs of noise. These costs and benefits are very important in long-term planning in transportation sector.
The main purpose of this article is offering models of quantitative estimation of introduced costs. Accordingly, first, external costs were identified and introduced. Then, measurable costs on the country roads and models of external costs estimation for Tehran- Qom freeway in the year 1389 were offered and the required data for various external costs estimation were identified.
The costs were estimated not only in terms of per vehicle km, but also in terms of the whole length of the desired road and also in terms of the total desired cost for the total desired road traffic along entire road length.
This estimation has been done per vehicle km for 5 groups of vehicles: cars and vans, minibuses and light duty trucks, buses, heavy duty trucks (16-32t), and heavy duty trucks (> 32t).
Results show that, 3-up axle trucks (with 937.2 Rials) have had the highest share in the environmental marginal external costs per vehicle km.
Computation of total external costs showed that, this freeway incurred environmental external costs equal to 820 billion Rials which entirely clarifies the necessity of authorities' serious attention to the issue of external costs.
Keywords: External Cost, Marginal, Road, Air pollution, global warming, Freeway

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1- Introduction

The external costs of road transportation section are those costs which are imposed on physical, biological and economical-social-cultural environments by road transportation users and are not compensated by their originators. The most important external costs are the global warming cost, air pollution cost, concentration cost as well as accidents cost.

External environmental costs can have determining effects, from economic priority point of view, on the grading of road transportation projects including construction, maintenance, renovation and mobilization of transportation and control systems, in terms of "present net value", and also on the net profit gained after any of the projects is finished. This comparative effect exists even when decision is to be made on other transportation systems (Ayati et al., 2009).

Paying attention to this issue in the process of making macro decision for transportation, can perhaps level the road to cost – benefit analysis of the optimized transportation system.

Many researchers have tried to estimate the external environmental costs of road transport use. Important contributions in this field include the studies by Mayeres (2001)، Delucchi (2000) ،Lindberg (2000,2002) ،De Borger and Proost (1999) ، Bickel et al. (2005,2002,2003,2006) ،Ozbay et al. (2001,2007) ،Parry et al. (2007) ، Rici et al (2008) ،Sen and Tiwari (2009). Results from all these studies reveal that some marginal external costs can be internalized in the process of decision-making; however, some costs are external in nature.

The main objective of this paper is to estimate the environmental external costs. Based on this objective, firstly the environmental external costs are completely recognized and then the measurable costs over the Iran's roads and the cost estimation models have been addressed considering the statistical limitations in Iran. Finally, estimation of these costs in Tehran-Qom Freeway has been performed. This calculation has been performed for per vkm.

2- Identification of Measurable and Modeling Environmental External Costs

Based on the performed evaluations, there are totally 6 types of external costs (air pollution, global warming, noise pollution, water contamination, soil contamination and waste disposal as well as change in land usage and landscape) which are due to external effects of road transportation activities imposed on environment. Based on the performed studies and review of various projects in the field of internalization of external costs, three costs, i.e. air pollution, global warming and noise pollution have more importance than others and their effects on environment are definitely more than other costs. The measurement and modeling capabilities are also available for these costs (in case of existence of proper and relevant data) based on previous studies.

In estimating the environmental external costs, a part of environmental costs is covered by energy taxes and environmental crimes, but this research concentrates on net environmental costs.

3- Models of Estimating the Marginal External Costs of Environment

1-3- Estimation Model of Global Warming Marginal External Cost

In the research literature, there is no theoretical consensus on the method of estimation different effects of global warming. However, two following methods can generally be mentioned:

The damage cost approach which employs the effect route approach is used to estimate the physical effects of global warming and combines these effects with its economical estimations. A replacement approach which is used in calculations to avoid the uncertainties related to evaluation of global warming costs is the evaluation of costs of avoiding CO_2 emission. This method is normally known as avoidance costs or mitigation costs. This method is based on a cost-effectiveness analysis which specifies the minimum cost in order to reach a certain level of reduction of GHG emissions which this reduction level is determined in accordance with the policies of the authorities. Many studies have employed the avoidance cost method such as those mentioned in UNITE & ExternE Nellthorp (2001).

Recent studies mostly emphasize on using the damage cost approach. The DLR project, performed in 2006, has estimated an amount of 70 € for each tone of CO_2 released in Germany and Switzerland. The HEATCO project which was performed in early 2006, has offered different estimations for different years. Based on this project, the price of each tone of released CO_2 is equal to 22 € during years 2000-2009, while this price has been estimated to be equal to 26 € for years 2010 to 2019. An amount of 32 € for years 2020-2029 and an amount of 40 € for years 2030-2040 are among other values of this project Bickel (2005). In this research, the following model is used to calculate the external cost of global warming:

$$C_{GW} = \sum_{i=1}^{5} \left(EF_{dir}(m,v,g,l) \times DF_{dir}(m,g) + FC(m,v,f,l) \times DF_{FP}(m,f) \right) \quad (1)$$

Where,

i: vehicle type;

C_{GW}: cost of global warming resulted from CO_2 emission.

EF_{dir}: direct emission factor for CO2

DF_{dir}: damage factor due to direct emission of CO2

FC: fuel consumption factor for desired vehicle

f :fuel type

m: transportation method (rail/road, etc.)

v: vehicle technology, environmental standards, etc.

g: CO_2 greenhouse gas

l: urban/non-urban place

2-3- Estimation Model of Marginal External Costs of Air Pollution

Precise estimation of air pollution requires the existence of extensive information about air pollution effects and insertion of this information in special software designed for estimation of air pollution cost. In Iran, the aforesaid information is not available, nor is the software related to calculation of external costs for air pollution. It should be noted that application of these software requires extra costs of almost several hundred thousands of dollars. As a result, to estimate the air pollution cost in this paper, the same approach was used which has been employed for estimation of global warming cost. In other words, the emission coefficient factors of different pollutants are multiplied by these pollutants' emission costs for different vehicles in order to obtain the approximate air pollution cost in this freeway. Among different air pollutants, the followings have more importance and most of air pollution

effects are caused by these pollutants. As a result, pollutants like the CO, NOx, NMVOC and SPM are considered in calculating air pollution cost. The model employed for calculating air pollution cost is presented as follows:

$$C_{AP} = \sum_{i=1}^{5}\sum_{j=1}^{4}(EF_{dir}(f) \times DF_{dir} + FC(f) \times DF_{FP}(f)) \quad (2)$$

Where
i = vehicle type;
J= air pollutant type;
C_{AP} = air pollution cost;
EF_{dir} = pollutant's direct emission factor;
DF_{dir} = damage factor due to pollutant emission;
FC = fuel consumption factor for desired vehicle;
DF_{FP}=damage factor due to fuel production;
f = fuel type.

3-3 Estimation Model of External Cost of Noise Pollution

In studies conducted for measuring noise pollution around the world, two main approaches have usually been employed which are bottom-up and top-down approaches. As an example, UNITE (2003b) and INFRAS/IWW (2003, 2004a) Maibach (2008) have calculated the marginal cost of noise pollution for all transportation methods using bottom-up approach, while the ECMT(1998) project has employed the top-down approach. The bottom-up approach has been introduced in ExternE project and is generally the same as effect route approach. The presented model calculates noise pollution's external cost based on bottom-up approach (effect route approach). This model has been used in GRACE project Sen (2009).

$$C_N = \mathrm{NLI}(l,t,b,s) \times \mathrm{VA}(v,l) \times \mathrm{Pop}(l) \times \mathrm{DF}(b,c) \quad (3)$$

Where,
C_N: noise pollution cost (unit currency/one (km*vehicle))
NLI: increase of noise pollution level due to adding one vehicle (dB)
VA: voice adjustment level of the vehicle in the road
P_{OP}: population affected by noise pollution (people/km)
DF: damage factor (unit currency/dB/people)
L: place (urban/non-urban)
t: time (night/day)
b: background voice level (high/low)
s: state of traffic (peak/non-peak)
v: vehicle type (personal/heavy duty, etc.)
c: country

4- Applying models numerically to Tehran – Qom free way.

Tehran – Qom free way, starting from the south of Tehran and ending in Qom, is the connecting bridge between Tehran and south (and south western part) of Iran and is 138 km long. This is the second most travelled road in the country (after Tehran – Karaj free way).

Selection of this free way has not been accidental; availability and importance of the information, data and statistics about this road were the main criteria for its selection. The statistics related to travel counting have been taken from those in "Road Maintenance and Transportation Organization" of Iran. They are released monthly

and also daily by the "organization". The annual mean of the daily travel counting has been considered as the daily traffic volume for our selected free way. Classifying vehicles into 5 groups: cars and vans, minibuses and light duty trucks, buses, heavy duty trucks (16-32t), and heavy duty trucks (> 32t), is based on the "Organization"'s classification.

Our statistical community includes all mean daily traffic volume in Tehran – Qom free way in 2010.

To estimate the cost for each tone of different released pollutants, the values of other countries can be used and these values can be adjusted using adjustment index based on purchasing power parity for Iran. For calculation purpose, the adjustment index and comparison of purchasing power parity in European Union countries (its 15 members in 1998) and Iran (in years 1998 and 2009) were employed and the adjustment index was finally calculated as 0.2318.

5- Results

5- 1- Estimation of Marginal External Cost due to Global Warming in Tehran-Qom Freeway

Taking into consideration the presented model, three parameters have key roles in calculation of this cost, which their values were calculated for Tehran-Qom Freeway.

a) The price for each tone of released CO_2

In this research, a value of 20 € for each tone of released CO_2 was used. This value is an average estimation obtained from all values of European Union's different countries to meet the objectives of Kyoto Treaty Maibach (2008) (based on this treaty, the industrial countries must reduce the emission of greenhouse gases by 5% with respect to emissions in 1990 and over 10 years). Given this fact that Iran's purchasing power parity has been about one-fourth of that of European countries, so the value of 5 € was obtained for each tone of CO_2 released in Iran.

b) The Amount of CO_2 Emitted by Each Class of Vehicles:

In this research, the amount of CO_2 emitted by each vehicle was obtained via the fuel consumption value of each vehicle per km multiplied by the emission coefficient corresponding to CO_2. To determine the amount of fuel consumption, firstly the available status of road transportation fleet and then the amount of road-type fuel consumption in this freeway were evaluated. Based on statistics adopted from automobile manufacturing companies and Iran Road Maintenance & Transportation Organization (RMTO), the mean fuel consumption value for all types of vehicles in Iran was obtained based on their life per kilometer. The obtained results are summarized in Table 1.

5-2- Estimation of Marginal External Cost of Air Pollution for Tehran-Qom Freeway

Based on the presented model, three parameters have key roles for calculation of this cost which their values were calculated for Tehran-Qom freeway:

a) The price for each tone of released pollutant:

To value the physical effects of air pollutants imposed on people's health, an adjustment index known as purchasing power parity in comparison with European countries was used and the monetary value of health effects was calculated in terms of Euro in Iran for year 2011.

b) The Amount of Emitted Pollutant by Each Class of Vehicles:

The average amount of pollutants for each vehicle in each km of road was calculated using the average fuel consumption value of the vehicle per km of road multiplied by emission coefficients of the related air pollutants. These values have been presented in Table 2.

c) The Amount of Emitted Pollutant resulted from Fuel Production Processes

The pollutant resulted from fuel production processes, is among other model parameters which its information must be inserted into model. Table 3 shows the amounts of pollutants resulted from fuel production processes per g/kg.

Other variables and data required for calculation of air pollution's external cost and the obtained results have been summarized in Table 4.

Factors like vehicle age, climate conditions, infrastructure type and its quality will be effective on the amounts of different pollutants emitted by different vehicles. Considering these factors in the model wasn't possible and as a result the values mentioned in above table for emission coefficients of different vehicles are average values.

5-3- Estimation of the Marginal External Costs of Noise Pollution

To estimate the noise pollution cost over Iran's roads, the presented model can be used. This model requires special information such as Receive-Response functions which are indicative of following items: the individuals who have suffered from related diseases as a result of noise pollution of road transportation activities, the population affected by noise pollution for the selected road, the cost related to different effects of noise pollution, the background noise level which is determinant of the amount of noise which causes suffering of different people, and the noise level of different vehicles based on vehicle classification.

The need for the mentioned information, lack of access to these data inside the country and lack of possibility to use all the information of studies performed in other countries caused impossibility of estimation of noise pollution's external cost for Tehran-Qom Freeway in this paper.

5-4- Estimation all Kinds of External Costs Effective on the Environment over Tehran-Qom Freeway

The obtained results for all kinds of the calculated costs have been presented in Table 5.

A comparison between different costs obtained in Table 6 shows that among these two external costs for different vehicles, the air pollution cost has gained the most shares. Among all vehicle types, over-three-axle trucks create the highest external cost which its main reason is the high air pollution cost for this type of vehicles.

Of course, it should be taken into consideration that this total costs is for one (km*vehicle), while because more pickups and passenger cars travel in the freeway,

so the total external costs for all pickups and passenger cars over entire length of the freeway can be more than other types of vehicles.

5-5- Estimation of the Total Environmental External Costs of Tehran-Qom Freeway in 2011

In order to calculate the total external costs of Tehran-Qom Freeway in 2011, firstly the total external costs of Tehran-Qom Freeway for one km of road was obtained using the external cost of one (km*vehicle) multiplied by total daily vehicles in Tehran-Qom Freeway and it was found out that Tehran-Qom Freeway undertakes an environmental external cost equivalent to 820 billion Rials.

6- Conclusions

This evaluation showed that the most important environmental external costs of land transportation include global warming cost, air pollution cost and noise pollution cost that the proper models were introduced to calculate these costs.

For Tehran-Qom Freeway, the air pollution and global warming costs were estimated. These costs were estimated in the following formats: (km*vehicle), entire length of the desired freeway and total desired cost for total desired traffic within entire length of the freeway.

The obtained results showed that among all kinds of vehicles, over-three-axle trucks cause the highest level of external cost per (km*vehicle). Also among all kinds of the external costs, the air pollution cost has gained the highest percentage of external costs.

A look to the enormous figures presented for annual environmental external costs of Tehran-Qom Freeway reveals the very high importance of external costs in Iran and in road transportation section. These figures may be unreal and surprising for many people involved in road transportation section, but the reality of current conditions of road transportation in this Freeway is what mentioned before. Lack of considering external costs in pricing of Iran's roads has given rise to such high costs for the government and people.

In this Freeway, a sum of money is collected from drivers as toll payment which is negligible when compared to costs resulted from this research. As a result, re-pricing of this Freeway and other roads of Iran is one of the most fundamental solutions to compensate the external costs over Iran's roads. Collecting the actual toll from transportation users is a fact that not only would compensate the external costs, but also the experiences of other countries show that it would cause traffic reduction in Iran's roads. This in turn would result in the reduction of accidents and air pollution, use of infrastructure and other external effects of road transportation.

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Table 1: marginal cost of air warming by vehicles in each km of the road (author's calculations)

Vehicle type	Cars and Vans	Minibuses and light duty trucks	Buses	heavy duty trucks 16-32t	Heavy duty trucks> 32t
Average consumption per km (Liter)	**0.12**	**0.35**	**0.51**	**0.49**	**0.52**
Amount of emitted CO_2 (DF_{fp} ،DF_{dir})	*80000*				
Average value of CO_2 emission by vehicle for each km of the road per Gram (EF_{dir})	**231**	**904**	**1318**	**1266**	**1344**
Average amount of fuel consumption for each km of the road per Liter (AC)	**0.12**	**0.35**	**0.51**	**0.49**	**0.52**
Amount of produced CO_2 resulted from fuel production processes per g/kg (EP)	**560**	**400**	**400**	**400**	**400**
Average amount of CO_2 emission in terms of g per each km of the road resulted from fuel production process (FC=AC*EP)	**67.2**	**140**	**204**	**196**	**208**
Equation: $C_{GW} = \sum_{i=1}^{5} (EF_{dir}(m,v,g,l) \times DF_{dir}(m,g) + FC(m,v,f,l) \times DF_{FP}(m,f))$					
Marginal cost of air warming by vehicle for each km of the road per Rial (C_{GW})	**23.856**	**83.520**	**121.760**	**116.960**	**124.160**

* The amount of released CO_2 in exchange for producing one kg of gas and gas oil are equal to 560 g and 44 g, respectively.

* **12000 Rials = 1 Dollar**

Table 2: Average value of air pollutants emission in one (km*vehicle) (author's calculations)

Vehicle type	Cars and Vans	Minibuses and light duty trucks	Buses	heavy duty trucks 16-32t	Heavy duty trucks> 32t
Average value of CO_2 emission by vehicle per km of the road (Gram)	**8**	**4.6**	**6.7**	**6.4**	**6.8**
Average value of NO_X emission by vehicle per km of the road (Gram)	**3.7**	**17**	**26.21**	**25.22**	**26.73**
Average value of SPM emission by vehicle per km of the road (Gram)	**1.6**	**4.7**	**6.9**	**6.6**	**7.07**
Average value of NMVOC emission by vehicle per km of the road (Gram)	**0.2**	**0.49**	**0.71**	**0.68**	**0.728**

Table 3- Amounts of pollutants resulted from fuel production processes per g/kg [8]

Fuel type	Co	SPM	NOx	SO2	NMVOC
Gas	560	0.105	1.10	1.90	1.80
Gas oil	400	0.047	0.96	1.40	0.62

Table 4- External cost of air pollution by the vehicle per km of the road (author's calculations)

	Cars and Vans	Minibuses and light duty trucks	Buses	heavy duty trucks 16-32t	Heavy duty trucks> 32t
The price for each tonne of released CO (DF_{dir} , $DF_{fp)}$	410000 Rials				
The price for each tonne of released NOx (DF_{dir} , DF_{fp})	12000000 Rials				
The price for each tonne of released SPM (DF_{dir} , DF_{fp})	64000000 Rials				
The price for each tonne of released NMVOC (DF_{dir}, DF_{fp})	4480000 Rials				
Average value of CO_2 emission by vehicle per km of the road (Gram) (EF_{dir})	**8**	**4.6**	**6.7**	**6.4**	**6.8**

Average value of NO_X emission by vehicle per km of the road (Gram) (EF_{dir})	**3.7**	**17**	**26.21**	**25.22**	**26.73**
Average value of SPM emission by vehicle per km of the road (Gram) (EF_{dir})	**1.6**	**4.7**	**6.9**	**6.6**	**7.07**
Average value of NMVOC emission by vehicle per km of the road (Gram)(EF_{dir})	**0.2**	**0.49**	**0.71**	**0.68**	**0.728**
The average amount of fuel consumption in each km of the road per Liter (AC)	**0.12**	**0.35**	**0.51**	**0.49**	**0.52**
The amount of CO generated as a result of fuel production processes per g/kg (EP)	*	*	*	*	*
The amount of NO_X generated as a result of fuel production processes per g/kg (EP)	**1.1**	**0.96**	**0.96**	**0.96**	**0.96**
The amount of SPM generated as a result of fuel production processes per g/kg (EP)	**0.105**	**0.047**	**0.047**	**0.047**	**0.047**
The amount of NMVOC generated as a result of fuel production processes per g/kg (EP)	**1.8**	**0.62**	**0.62**	**0.62**	**0.62**
Average amount of CO emission resulted from fuel production process per Gram in each km of the road (FC=AC*EP)	*	*	*	*	*
Average amount of NO_X emission resulted from fuel production process per Gram in each km of the road (FC=AC*EP)	**0.13**	**0.336**	**0.49**	**0.47**	**0.5**
Average amount of SPM emission resulted from fuel production process per Gram in each km of the road (FC=AC*EP)	**0.0126**	**0.01645**	**0.024**	**0.023**	**0.0244**
Average amount of NMVOC emission resulted from fuel production process per Gram in each km of the road (FC=AC*EP)	**0.216**	**0.217**	**0.316**	**0.3**	**0.322**
Equation $C_{AP} = \sum_{i=1}^{5}\sum_{j=1}^{4}(EF_{dir}(f) \times DF_{dir} + FC(f) \times DF_{FP}(f))$					
Marginal cost of air pollution by the vehicle (per km of the road) (CGW) (Rial)	**184.187**	**531.246**	**796**	**763**	**813.75**

*****No information is available.

** Information has been presented based on Table 3.

Table 5: average amount of all kinds of external costs for Tehran-Qom freeway based on (km*vehicle) (Rials) (author's calculations)

	Type of vehicle				
Average value for all types of external costs	Cars and Vans	Minibuses and light duty trucks	Buses	heavy duty trucks 16-32t	Heavy duty trucks> 32t
Global warming	**23**	**83.5**	**116**	**121.7**	**124.1**
Air Pollution	**184**	**531.2**	**763**	**796**	**813.1**
Total	**207**	**614.7**	**897**	**917.7**	**937.2**

Table 6: Total annual external costs of Tehran-Qom freeway in 2011 (billion Rials) (author's calculations)

Type of vehicle						
Average value for all types of external costs	Cars and Vans	Minibuses and light duty trucks	Buses	heavy duty trucks 16-32t	Heavy duty trucks> 32t	**Total**
Global warming	**63.15**	**1.45**	**12.86**	**8.23**	**11.02**	**96.73**
Air pollution	**505.24**	**9.28**	**84.11**	**54.15**	**72.24**	**725**
Total	**568.39**	**10.77**	**96.97**	**62.38**	**83.26**	**821.77**