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Pricing and Internalizing Noise Externalities in Road Freight Transportation

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Abstract

People living close to main roads may suffer from the nuisance of traffic and noise pollution. This paper assesses the effect of full routing cost in vehicle routing decisions by internalizing the external cost of noise. On a first step, noise externalities are economically assessed through a contingent valuation procedure. Secondly, a novel methodology is proposed to allocate the external costs to the road network links. Results show significant differences in routing planning depending on the approach: minimization of traditional internal cost versus minimization of full cost. These results encourage further research in pricing and methodologies to internalize externalities.

Keywords: Externality; Contigent Valuation Methodology; Noise; Internalization; Pricing; Vehicle Routing Problem

1. Introduction

According to the European Commission (2016), half of all goods in Europe are moved using road transportation, being the responsible of 5% of the European GDP and employing about 3 million people. Furthermore, road freight transportation accounts for 24% of all greenhouse gases emitted in the European Union which contributed to global warming and it is also source of stress, sleep disturbance and other noise-related issues. Therefore, research on road transportation economic, social, and environmental impacts is of utmost interest.

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Transport planning has long been focused on its economic aspects. Traditionally, researchers have paid great attention to route optimization in order to get the cheapest way to fulfill a transport activity without considering environmental impacts. However, negative externalities of road freight transportation related to air pollution and excessive noise levels are particularly perceptible. In this context, different green transportation concepts aiming to reduce these impacts have recently been presented (Kadziński et al. 2017; Muñoz-Villamizar et al. 2017; Toro et al. 2017). Most optimization models consider emission estimations which are based on routing characteristics such as distance, load levels, vehicle type, or road gradient, and which ultimately depends on fuel consumption. These estimations are then included in the objective function in order to minimize the relevant variable.

By either focusing on monetary or environmental goals, different factors are considered as decision variables. Thus, in order to efficiently account for internal and external routing costs, new pricing models are necessary to incorporate external costs on corporate decision-making processes (Demir et al. 2015). One possibility to evaluate non-market goods, i.e. air pollution, noise, etc., is through the contingent valuation method (CVM) (Istamto et al. 2014). The CVM is based on stated preference surveys in which a population sample is asked for their willingness-to-pay (WTP) to achieve a hypothetical scenario with a greater level of utility. That is, through the CVM a hypothetical market is created for a commodity that could be bought by customers. The obtained value refers to the difference in the welfare of the individual by passing from the current scenario to the new one. Concerning the case-study area we have chosen the Spanish region of Catalonia due its role as connection point between Spain and France crossing the Pyrenees.

The literature presents a wide range of different emission models which typically replace 'traditional' optimization objectives related to costs reduction. In this work, we want to go one step beyond these approaches by internalizing negative externalities. Firstly, external cost from noise pollution is estimated thought stated preference surveys. Secondly, a methodology based on source-receptor relationship is proposed to allocate the external costs to the links. Finally, several instances were generated within the case-study region allowing us to identify transport management insights.

2. Related Literature

An externality refers to a situation in which the costs or benefits of production and/or consumption of goods and services are not reflected in its market price (Pigou, 1920). In other words, externalities are those activities that affect others without paying for them or being compensated. According to Ranaiefar and Regan (2011), negative routing externalities can be classified into four different impact areas: the (i) economy, which includes congestion, road damage and longer travel times; (ii) society, comprising accidents, intrusion and noise pollution; (iii) ecology, encompassing biodiversity destruction and climate change; and (iv) the environment, including waste, air, and water pollution. Many research works have tried to physically measure such externalities. To this respect, Demir et al. (2015) gave an extensive review on externalities modeling in which they accounted for several different methodologies to deal with noise and air pollution, congestion and accidents. Similarly, Demir et al. (2015) also includes a pricing section, concluding that further research should be made in that direction.

In order to internalize such externalities in delivery route planning, monetary values have to be considered to price these factors. Therefore, a large-scale survey, applying the CVM, was conducted in the case-study area, (Catalonia, Spain). This methodology was adopted by authors such as Lera-López et al. (2014) or Lera-López et al. (2012) in a Spanish region to study air and noise pollution obtaining WTP values around €8 per externality, household, and year. In extremely polluted areas, such as Shanghai in China, the value rises to nearly €65 in the similar hypothetical scenario of air quality improvement (Wang et al. 2015).

Physical measure of noise pollution (mainly in decibels) is complex as it takes into account many factors such as surface, tire typology, or meteorology (Kephalopoulos et al., 2012). The consideration of non-traditional factors is more frequent in the case of air pollution, where the Green Vehicle Routing Problem (GVRP) has become a recurrent topic. Since emissions and fuel consumption are related, most of the GVRP research has focused on the minimization of fuel consumption through optimizing a relevant variable (i.e. load, speed, road gradient…) as discussed by Demir et al. (2014) and Lin et al. (2014). An approximation is given by Bektaş and Laporte (2011) where the pollution routing problem is defined. The authors concluded that the minimization of emissions does not result in the minimization of costs, whereas emission costs are quite insignificant in comparison to fuel and driver costs. It is remarkable that those emissions costs are simply computed by a cost figure provided by DEFRA (2007) who estimated the value of a ton of

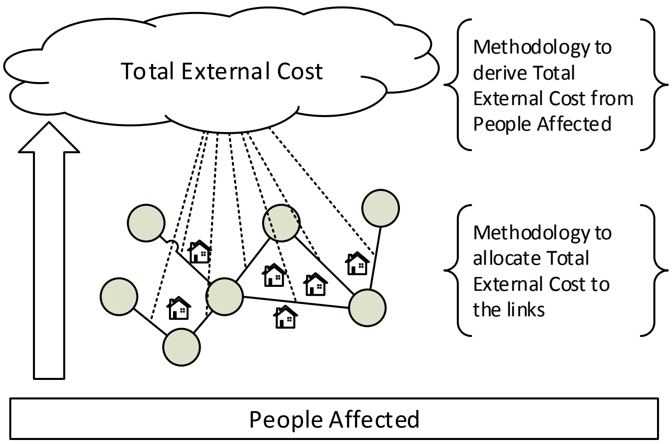
CO_2 in GBP 27 (2002). Fuel consumption is then translated into CO_2 emissions at a rate of 2.32 kg of CO_2 per liter as suggested by Coe (2005). In this last paper there is no evidence of internalization. Zhang et al. (2015) later discussed a similar problem in which internalization of emissions cost was carried out through a similar unit emissions cost value based on fuel consumption. In that case, the cost emission per liter of fuel consumption was set to CNY 0.64, while no information about that figure was provided. Finally, a recent example is presented by Eshtehadi et al. (2017) in which the relationship between fuel consumption and speed is illustrated. According to the authors, there exists inefficiency in the use of fuel at low speeds resulting in higher consumption. Later, a decrease of consumption occur until some point (60-65 km/h) when fuel consumption increases again as a result of aerodynamic drag. Then the fuel consumption may be scaled by the payload.

Certainly, scientific literature has focused on two approaches without mixing. On the one hand, literature about emission measurement, i.e. CO2, where the physical measure is implemented into optimization problems with the goal of obtaining the least polluting solution. On the other hand, literature focused on the economic quantification of some range of externalities but without further implication in logistics activities. Therefore, there is a gap where very few papers have tried to bring some light because either a simplistic vision or an incomplete implementation.

3. Methodology

In this way, the methodology we are going to use consists of two steps as described in Figure 1: (i) deriving the total external cost and (ii) allocating this cost to the edges which usually lodge different kinds of population. Afterwards, when the vehicle passes through the edges these external costs can be added to the internal ones forming the full cost. Finally, the full cost is considered in the route planning process.

Figure 1. Methodology overview



3.1. Total External Cost

The total external cost is the economic valuation of the externality under consideration within a reasonable time period in a given region. To this respect, it is assumed that WTP values given by the population are a good approximation of the economic value of the externality since it takes into account the socioeconomic characteristics and their real externalities affliction (economic quantification of the welfare loss). Thus, the total external cost can be computed as the summation of all WTP obtained values. Once the total external cost is estimated, an approach to allocate it is necessary as next subsection describes.

3.2. Cost Allocation Model

The cost allocation model is partially inspired by the Impact Pathway Approach (European Commission, 2003) in which transport externalities are mainly generated by heavy commercial vehicles (the source) and assumed by the affected people (the recipients) according to the aforementioned methodology. Thus, allocation is made to edges depending on the number of households affected and the intensity of heavy traffic. Therefore, the external cost associated to the edge i is computed according to Equation 1:

$$\boldsymbol{\varepsilon_i} = \frac{\boldsymbol{T_i \cdot H_i}}{\sum_i \boldsymbol{T_i \cdot H_i}} \cdot \boldsymbol{E} \qquad (\boldsymbol{Eq.\,1})$$

Where T_i is the average flow of heavy vehicles passing through edge i, H_i are the households affected in that specific link, and E is the total external cost, with $\sum \boldsymbol{\varepsilon_i} = E$.

4. Case Study

A case study has been developed to test the proposed methodology in the Spanish region of Catalonia. This region is particularly important in road freight transportation as it is one of the two major connections of the Iberian Peninsula to the rest of Europe. Actually, according to the Spanish-French Observatory of Road Transport at the Pyrenees (2016) more than 30,000 vehicles use the Mediterranean route daily, being 10,000 of them heavy ones.

4.1. Total external cost and parameter setting.

A contingent valuation survey was conducted in the case study region. To estimate the WTP for reducing traffic-related noise externalities, the population was chosen among inhabitants of Catalonia in Northeast Spain. The region has a population of 7.5 million people where a total of 800 households were surveyed through phone interviews. The questionnaire, which was carried out in December 2013, consisted of 3 sections, as suggested by Mitchell and Carson (1989): (*i*) *introduction*, where the problem is described; *(ii) contingent valuation* that contains open-ended questions used to obtain WTP; and *(iii) classifying questions* aiming to obtaining further information from respondents (age, gender, income, and environmental concerns). The survey results state that an average household is willing to pay €8.52 in order to reduce its noise nuisance. Moreover, a total of 223,280 households are sited within 200 meters along major roads. That results in a total external cost for noise of €1,902,347.

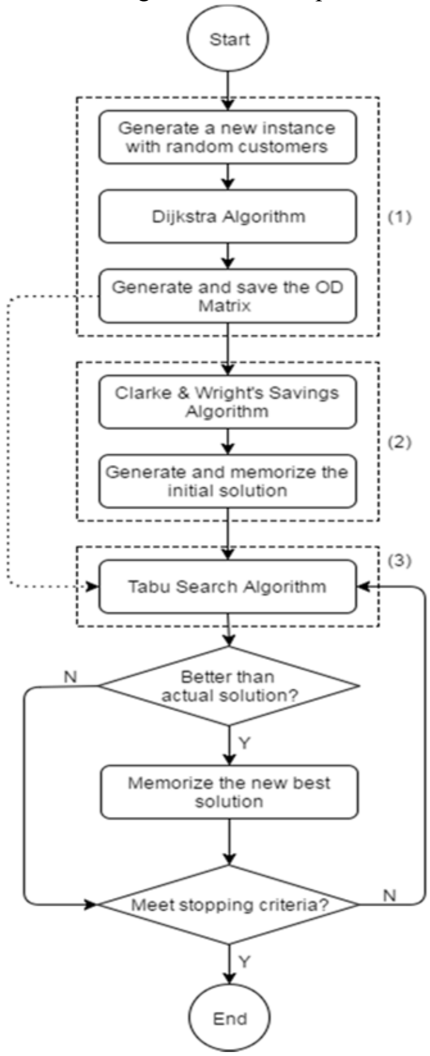
4.2. Solution procedure

The proposed method has been implemented as a Java application, mainly because it allows a rapid, platform-independent development of algorithms that can be used to test our approach.

Our procedure consists of three phases as shown in Figure 2:

- *First phase (1).* The process starts with the generation of a new random instance of customers within the road network of Catalonia. Then, the Dijsktra Algorithm generates the OD matrix (minimum distances) between the depot and all the customers and saves it into an external file.
- *Second phase (2)*: Making use of the file generated, the best solution that CWS heuristic is able to achieve is saved in order to be implemented as an initial solution in the Tabu Search.
- *Third phase (3)*: Improvement of the solution through a Tabu Search. That metaheuristic guides the local search heuristic algorithm to explore the space of solutions beyond local optima. To do so, a flexible memory is implemented based on Taillard et al. (2016), where some previous movements are saved to avoid them during a number of iterations. Its operating core is the following:
  1. Selection of an initial solution (in our case the CWS solution).
  2. Choice of the environment and generation of a new solution.
  3. Evaluation of the objective function.
  4. Update of the best solution.
  5. Stopping Criteria.

Figure 2. Solution procedure



5. Results

A real road network in Catalonia, Spain, was used to test the proposed methodology. It consists of more than 330 edges and 310 nodes. Different cases of minimizing Internal Cost (IC), External Cost (EC) and Full Cost (FC) were set as the objective function for the Vehicle Routing Problem (VRP). Note that the IC corresponds to the traditional distance-based VRP in which a cost parameter of 1.12 €/km has been applied. This value is appropriate for an average articulated truck operating in Spain (Spanish Ministry of Transportation, 2015). The EC refers to the cost assigned to edges through Equation 1 whereas FC is the summation of IC and EC.

A total of 10 customers and one depot were randomly assigned to the nodes and 5 instances were created in which the initial proposed WTP value varied from €8.52 to 3 times higher. A Visual Basic program was developed to create 30 runs per instance in order to take stochasticity effects into account. Results indicate that similar results are obtained when increasing the number of customers, although these are not reported due to space limitations. Moreover, truck capacities were set to 50 and customer demands were randomly assigned in the interval [1, 12.5]. Before each run, customers are randomly reassigned to the nodes, then our solution procedure is applied with the three proposed objectives, i.e. min IC, min EC and min FC. Preliminary results are shown in Table 1, where values correspond to the average for the 30 runs.

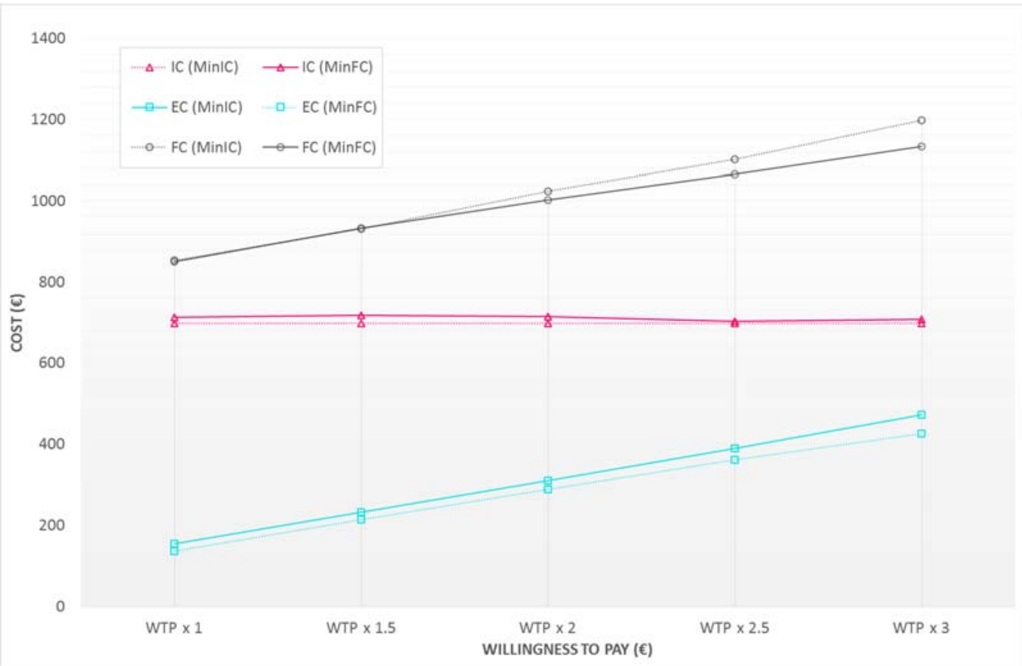
Table 1 Numerical results corresponding to Min IC, EC and FC

	Min IC			**Min EC**			**Min FC**		
	IC	EC	FC	IC	EC	FC	IC	EC	FC
WTP x 1.0	699	154	854	1035	124	1160	713	137	850
WTP x 1.5	699	232	931	1050	187	1237	718	214	933
WTP x 2.0	699	311	1025	1070	240	1311	715	288	1003
WTP x 2.5	699	389	1103	1090	301	1391	704	361	1065
WTP x 3.0	699	472	1198	1084	358	1443	709	425	1134

According to Table 1, internalization of external costs would increase total costs by 21%-22% (FC/IC), having further implication in the routing design. Focusing on the base scenario (WTPx1.0), Min IC and Min EC show extreme solutions, being Min FC the intermediate one. When minimizing full cost (Min FC) instead of internal costs (Min IC), the IC raises by 2% whilst the EC drops by 11%. This leads to a more profitable FC (difference with Min IC is -0.5%) which highly improves (-5%) in a hypothetical scenario of WTPx3.0. The ratio EC/FC is also improved when full cost is minimized instead of internal cost (16% and 18% respectively), although the best ratio is obtained when we minimize the external cost (10%). The values obtained are in line with those from the literature (Márquez and Cantillo, 2013). The results show that even in the WTPx1.0 scenario, our approach of optimizing the full cost leads to more efficient solutions.

The effect of increasing the value of the externality (WTP) is better described in Figure 3. On one hand, FC and EC show an increasing tendency as the WTP values go up. On the other hand, the greater the WTP values are, the higher the difference is between the FC when FC is minimized and the same cost when IC is minimized.

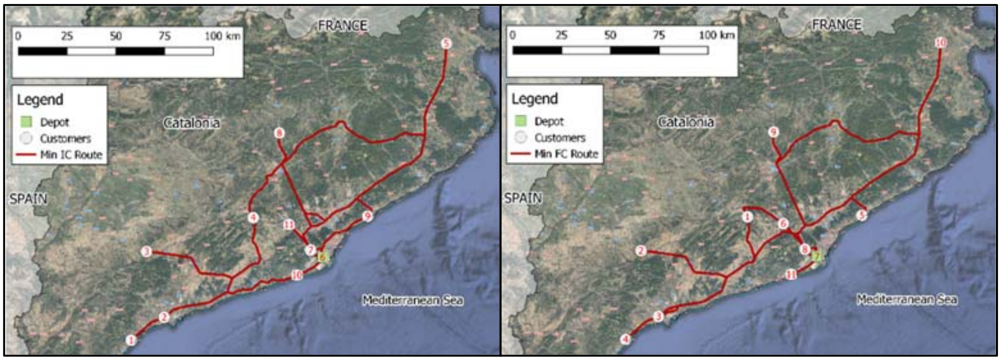
Figure 3. Results comparison varying initial WTP up to 3 times higher



In this case-study, the internalization of the external cost caused by noise would lead to a significant change in the routing planning. An illustrative outcome is described in Figure 4. Numbers in circles represent the order in which the customers are being visited. In this scenario, trucks have to return to the depot only once. Routes vary depending on the variable being minimized: internal cost (left) or full cost (right). Note that routes obtained when the full cost is minimized (i.e. when the externalities are being considered) avoid passing through high-density areas such as

Barcelona downtown or other littoral areas. As seen in Table 1, the avoidance of certain edges needed to take noise into account increases the internal cost, although the full cost is minimized.

Figure 4. Changes in routing planning minimizing IC (left) and minimizing FC (right)



6. Conclusions and further research

Profit and loss accounts of transportation firms contemplate costs related to operational activities such as purchases of raw materials, salaries of employees, or assets depreciation, among others. Nevertheless, costs in environmental/social terms are not included in their conventional balance reports and, therefore, they are beyond their control. By definition, externalities are outside the market mechanisms, i.e. they are not reflected in prices. Thus, externalities are not always considered by transport companies which leads to inefficiencies in the market and to the environment and social detriment. Significant externalities arise from road transportation that should be added to the traditional internal cost in order to achieve a full fair cost. By internalizing external costs, transport companies will consider such effects in their decision making processes and so they would be measured, controlled and optimized.

Moreover, research on transportation externalities is of highest interest as cities and regions are becoming more sustainable. From a social point of view, noise pollution emitted from traffic may increase the risk of heart disease, hearing loss, stress, or sleep disturbances. This work addresses the topic of internalizing the external cost of noise. For this purpose, a contingent valuation survey was conducted in Catalonia, Spain, to derive the external cost of noise. A novel methodology is later implemented to allocate the total external cost caused by noise to every link in the road network.

Results suggest that transport decisions (for example, routing planning) would significantly change if internalization were performed. First, accounting for external costs leads to an increase in costs of about 20%; secondly, a new optimization dimension is presented in which full cost replaces the traditional internal cost optimization.

Future research directions involve the internalization of a wider range of externalities such as air pollution, congestion or accidents. Moreover, a more sophisticated methodology would be required to quantify these externalities, as well as for estimating the total external costs. Finally, an effective and realistic tool for internalization would be necessary, for example through taxes or tolls.

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