Gas Consumption Information:
A Substitute for Congestion Pricing?

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ABSTRACT-

The low price elasticity of gasoline demand has been shown in different studies. People's weak perception about how much they spend on fuel is considered as an important reason. The purpose of this study is to show how information about gas consumption may change people's behavior. Congestion pricing has been successful in terms of reducing demand and even changing people's decisions. People perceive this pricing as out of pocket cost and take that into account while making decisions. A similar procedure can be implemented for fuel costs. On-line information from transportation networks can be used to estimate the gas consumption cost for each route, using on-road banners or GPS devices. The idea is that as a result of becoming informed about their gas consumption increase when entering traffic congestion, people may take an alternative route or decide not to travel at all. Although it is not possible to estimate the exact change in the price elasticity of gas by introducing this method directly, this study tries to estimate the proper gas price and its effects on people's route choice behavior and compare gas consumption information to congestion pricing scheme. The results from a small network showed that providing this information can improve people's behavior in terms of route choice.

Keywords- Congestion pricing, Gasoline consumption, Route change.

1. INTRODUCTION

Around the world, traffic congestion costs reach billions of dollars in some urban areas (Schwaab and Thielmann 2001). One of the market solutions for reducing congestion is pricing. Externalities pricing, including emission pricing and congestion pricing, can be applied to the additional cost users impose on other users. By changing users' behavior, this pricing can lead to a more Pareto efficient solution (Barr, 2004) in terms of the social welfare of the whole community.

Congestion pricing is a kind of market based solution for the problem. When additional cost of a new user to a network (additional delay suffered from a new user entrance) is ignored, market fails. Congestion pricing reflects this social cost in a way that can lead to optimal or near optimal traffic level. For more in depth discussion, the interested readers are referred to Rouwendal and Verhoef (2006).

Congestion pricing proved to be effective in changing people's behavior in different practical examples (Beevers and Carslaw 2005, Eliasson 2008). Although this depends heavily on the used scheme, people perceive congestion charges as their out of pocket costs. On the other hand, low elasticity of gas demand can be attributed to the fact that people do not perceive fuel consumption costs directly. Therefore, a possible approach can use a similar scheme to congestion pricing. Electronic up-to-date banners can demonstrate gasoline costs when using each route or street.

Two outcomes are possible. First, the information introduced can change gasoline demand elasticity. However, there is no direct way to test this. On the other hand, people may change their route similar to the way they change their route in congestion pricing. The latter will be studied here.

This paper is organized as follows. The second part briefly reviews what the congestion pricing problem and its formulation are. The third part describes what the model will be considering gasoline consumption information, and, consequently, the fourth part estimates what type of function can be used for gasoline consumption estimation. A hypothetical example is introduced, and the results of different problems are analyzed. Finally, the conclusion summarizes the main points.

2. CONGESTION PRICING

Before formulating congestion pricing, the User Equilibrium (UE) problem with fixed demand must be determined. Based on the first Wardrop's principle (Wardrop 1952), UE is a problem in which those paths connecting an Origin/Destination (O/D) pair will be used only if they have equal and minimal user travel costs. This means that in equilibrium, no user can be better off by changing his or her path individually. This is close to what happens in practice.

Let, N(V,A) be a network of concern with V as the set of nodes and A the set of links (streets). Also, let x_{ij} be the flow in link (i,j), and x the (row) vector of link flows. Moreover, let x_p^{ks} be the flow in path p, $p \epsilon P_{ks}$, from origin k to destination s, $(k,s) \epsilon P$, where P is the set of origin-destination pairs, and P_{ks} the set of paths from origin k to destination s. Such flows are generated by O/D demand for travel, d^{ks}, from k to s, $(k,s) \epsilon P$. Finally, let $t_{ij}(x_{ij})$ be the travel time function of link (i,j), $(i,j) \epsilon A$, representing average travel time, which is assumed to be only a function of flow in link (i,j), defined for $x_{ij} \geq 0$. x^* is the user equilibrium (UE) flow with fixed demand in the network $N(V,A)$,where x^* is the solution of the following problem:

$$(UE) \quad \underset{x}{Min} \sum_{(i,j)\in A} \int_{\circ}^{x_{ij}} t_{ij}(u)\,du$$

$$s.t.: \sum_{p\in P_{ks}} x_p^{ks} = d^{ks} \quad ,\forall(k,s)\in P \tag{1}$$

$$x_p^{ks} \geq 0, \forall \mathrm{p} \in \mathrm{P}_{\mathrm{ks}}, \forall(k,s)\in P \tag{2}$$

$$x_{ij} = \sum_{(k,s)\in P} \sum_{p\in P_{ks}} x_p^{ks}.\delta_{ij,p}^{ks} \quad ,\forall\,(i,j)\in A \tag{3}$$

where $\delta_{ij,p}^{ks}$ is 1 if link (i,j)ϵp, pϵP_{ks}, otherwise 0.

The model used in this study is based on the assumption that people behave as considered in the UE problem. In addition, travel time is not the only cost imposed on each user. An additional cost for congestion or other externalities is charged from users to encourage them to pursue a more socially efficient behavior. In this new equilibrium, travel times of competing routes may be different but their total costs, including congestion tolls, are the same.

The other important part of the problem is how to determine these costs to achieve the goal of increasing social welfare. The solution based on market organization is to charge the marginal social cost of driving each user imposed on other users. For congestion pricing, charges are set close to the amount that minimizes total travel time in a network; optimized charges lead to System Equilibrium (SE) flow pattern (considering that all the other costs are related to travel time: gas consumption, emissions). The optimized temporal charge for link a is equal to:

$$C_a(x_a)=x_a * dt_a(x_a)/dx_a \tag{4}$$

where Xa is the volume of link a and ta is the travel time function for that link with its derivative (Sheffi 1984); It can be shown that solving UE with the above mentioned costs (ta+ca) leads to SE flow pattern.

A practical note about congestion pricing is that it is impossible to charge all links of a network, at least with present technologies. Even if it is possible, this can make users indifferent in some aspects; whenever all the links are priced, users may not correctly perceive their price difference as is assumed in the theoretical model. Consequently, an alternative solution called second best pricing is used for real life problems (Rouwendal and Verhoef 2006).

3. GASOLINE CONSUMPTION INFORMATION (GCI) MODEL

The gasoline consumption information model also uses the Wardrop's as its principle considering that now c_{ij} is the generalized cost associated with traveling on link i-j rather than just the travel time t_{ij} (the mentioned UE problem is only changed by replacing t_{ij} with c_{ij}):

$$c_{ij} = t_{ij} + g_{ij} \tag{5}$$

where g_{ij} is the gas consumption expenditure, in terms of time, for using each link i-j which is assumed to be available for all the links (on line information system like GPS systems). In this new condition, more complete travel costs including fuel consumption costs will be taken into account and may result in a more stable UE pattern and an increase in social welfare. The main difference between Gas Consumption Information (GCI) model and SE model is that the additional costs in GSI are the gas consumption expenditure while additional costs in SE are the marginal social costs.

The effect of this information should be tested in practical and diverse conditions. Here, a hypothetical example will be studied and analyzed. Further work considers a real network and the consequences of providing fuel consumption information.

4. GASOLINE CONSUMPTION FOR EACH LINK

As the first step of modeling, a simple fuel consumption function is needed. The function estimates total gasoline consumption for each link based on different traffic flows. Some assumptions are made for simplicity. The first assumption is that gas consumption is the same for all the vehicles in a network. This is not true in real life. But if an average vehicle is considered, this assumption will not be problematic. The second assumption is that users drive in urban areas. Thus, their consumption is in the congested parts of the gas consumption curve. It should be noted that stop and go driving (acceleration and deceleration) causes higher gas consumption for urban areas than rural areas. Figure 1 shows the fuel consumption for steady state (constant speed) and congested driving (Ahn et al. 2002). Finally, travel time functions (Table1 appendix) give average time spent on each link and the average time, transferable to speed, is used for gasoline consumption computation.

The dashed curve on Figure1 shows the estimated gas consumption curve for each vehicle based on the provided speed on the link. The function is:

$$\text{Fuel consumption (Lr/100km)} = 140/(\text{speed(km/hr)}) + 3.5. \qquad (6)$$

It should be noted that this function is only applicable to the congested part (as shown in the figure).

To compute the function for a link, the mentioned term in (5) should be multiplied by its length, divided by 100 to change it into 100 km, and the speed should be expressed as the length of each link over time spent on it. This calculation gives the fuel consumption using each link. But the cost used in UE and other problems is in terms of time. To change this gas consumption to time, the gas price is considered \$0.6 /liter, and the value of time for each person is considered \$20 per hour, as an average. Therefore, the gas consumption cost function, in terms of time, would be:

$$g_{ij} = 0.0003 * (140 * t_{ij}(x_{ij}) + 3.5 * L_{ij}) \qquad (7)$$

which is a function of the traffic volume (x_{ij}) and the length (L_{ij}) of the link.

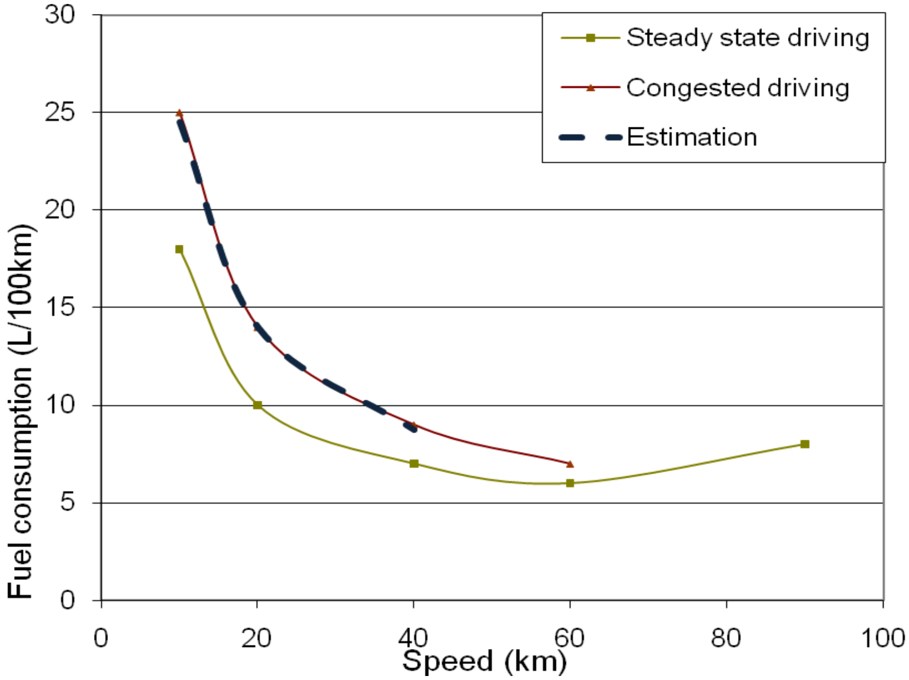

Figure1. Gas consumption at different speeds (average car)

In fact, users choose routes (links) based on both travel time and this cost, g_{ij}. The idea is obtaining this information, g_{ij}'s, will lead users to change their route to avoid extra expenditure on fuel. However, this information might be effective only in the case of high gasoline prices and if users perceive these costs explicitly when driving. The next section will analyze this strategy using a hypothetical example.

Apparently, relaxing the assumption of similarity of users adds to the complexity of the problem but leads to a more realistic model. This difference is due to different perceived costs as a result of different income levels. For example, a richer user may be ready to pay more to save time. Based on different utility functions, groups of people behave differently in response to any change, changing to different paths or modes of travel when this information becomes available. But for simplicity, the heterogeneity of users is not considered here.

5. A HYPOTHETICAL EXAMPLE

A numerical example can show the outcomes of this strategy. The solved problems show many interesting facts that can encourage planners to pursue this scheme. The test network is shown in figure 2 (the link parameters and OD matrices are shown in the appendix).

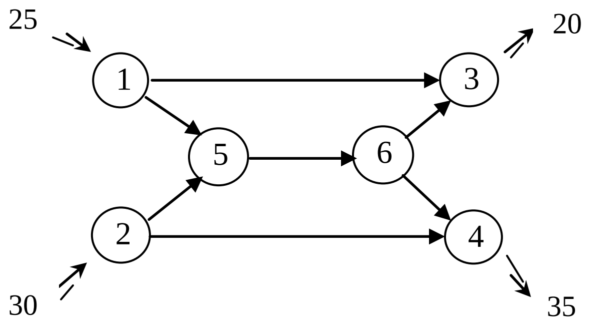

Figure2. Test network with the initial demand (Low demand scenario)

The links' travel time functions are considered BPR functions with distinct parameters. A simple network is considered, which tries to model real-life conditions. The link 5-6 acts like a freeway that has high capacity and high free flow speed. Other links represent arterials, which have low free flow speed (high free flow travel time compared to their length). Links 1-3 and 1-4 are alternative paths, like arterials, to the freeway for users commuting to their destinations. But they can act as passive paths; users do not use them because their free flow speeds are lower than the used paths. Without any outside intervention like congestion pricing, people are willing to use the freeway, link 5-6, and intermediate links like 1-5 and 6-4, to reach their destination (for O/D 1-4).

To solve the problem, two different demands are considered (high and low in the appendix). The problem is solved using fixed demand assumption; the demand for travel does not change when supply changes. These two different demands can help to analyze the effects of fuel consumption information facing different conditions.

Three different levels of gasoline prices are considered: \$0.6, \$1.2, \$1.8. These different prices can also contribute to the analysis of the result. It should be added that the elasticity of 0.1 for gas demand is considered. This means when gas price becomes \$1.2, which compared to its base price '\$0.6' is doubled, travel demand (Tables 2 and 3 in Appendix) will decrease by 10 percent.

6. RESULTS

Table1 shows the summary results of different problems solved. The first observation is that when travel demand is relatively low, gas consumption information does not change anything even for higher gas prices (cases 3, 6, and 9 compared to their similar UE problems). On the other hand, when travel demand is higher (more congested conditions), this information can change the flow pattern toward a more socially efficient solution. In the most effective case, case 15, gas information and congestion pricing result in nearly the same total travel time result which reduces the total gas consumption by near 2% from do nothing, UE, pattern.

It should be noted that the prices for congestion pricing problems are considered flexible, they can be changed to obtain better solutions, while the prices for gas information problem are considered constant because of fixed gasoline prices. On the other hand, the congestion pricing problems solved are based on the most efficient prices which lead to minimized travel time in a network. These optimized solutions may not be practical. This fact closes the gap between gas information cases and their congestion pricing counterparts.

Table1 Summary of results

		Type of problem	Gas price ($/lit)	Total travel time	% time change from UE (DO nothing)	Total gas consumption (Time)	% gas consumption change from UE (DO nothing)
Low Demand	1	UE	$0.6	27.125	-	2.583	-
	2	SE- congestion pricing	$0.6	24.692	-8.969	2.406	-6.862
	3	Gas Information	$0.6	27.087	-0.141	2.581	-0.082
	4	UE	$1.2	22.826	-	4.516	-
	5	SE- congestion pricing	$1.2	21.798	-4.504	4.316	-4.432
	6	Gas Information	$1.2	22.826	0.000	4.516	0.000
	7	UE	$1.8	19.799	-	6.031	-
	8	SE- congestion pricing	$1.8	19.422	-1.907	5.871	-2.643
	9	Gas Information	$1.8	19.799	0.000	6.031	0.000
High Demand	10	UE	$0.6	46.667	-	4.068	-
	11	SE- congestion pricing	$0.6	45.823	-1.809	4.011	-1.394
	12	Gas Information	$0.6	46.514	-0.329	4.059	-0.210
	13	UE	$1.2	39.639	-	7.152	-
	14	SE- congestion pricing	$1.2	38.427	-3.058	6.988	-2.283
	15	Gas Information	$1.2	38.516	-2.834	7.010	-1.987
	16	UE	$1.8	34.424	-	9.514	-
	17	SE- congestion pricing	$1.8	32.344	-6.043	9.101	-4.344
	18	Gas Information	$1.8	33.620	-2.335	9.379	-1.429

Table2 shows the flow pattern for some of the problems solved, cases13 through 15. Not only for this case but also for other cases, traffic volumes for gas information problems are between the UE and congestion pricing volumes. These volumes are close to the UE volumes and far from congestion pricing volumes. As shown in Table2, the highest change from UE flows is 8%. This means that fuel consumption information systems only slightly change the flow pattern from the UE pattern but their effects can be significant as shown in the Table1.

Table2 Flow pattern in cases 13-15

Link No.	UE volumes	SE volumes	Gas info Volumes	% change gas info vols from UE
1-3	11.9	14.35	12.1	0.02
2-4	6.6	10	7.1	0.08
1-5	24.1	21.65	23.9	-0.01
2-5	33.9	30.5	33.4	-0.01
6-3	24.1	21.65	23.9	-0.01
6-4	33.9	30.5	33.4	-0.01
5-6	58	52.15	57.3	-0.01

Finally, it should be noted that although the results are encouraging in terms of the potential effects of the gas consumption information on people's behavior, congestion pricing is still a superior policy unless it requires a more complicated system and an initial investment to charge people. The flexibility of congestion pricing, different prices for different demand levels, makes it a more efficient solution unless installing the tracking devices are very expensive or tolling procedures are complicated and politically hard to apply.

7. CONCLUSIONS

The results from a simple network showed that providing gas consumption information can change people's behavior, route change, at least theoretically. Although the result is encouraging, especially for the congested networks, congestion pricing, if available, still might be superior because of the flexibility of prices. However, introducing any new scheme of pricing, to replace or add to gasoline tax, requires political acceptance along with cost-benefit suitability.

Based on the results of the hypothetical example, a one or two percent decrease in gas consumption for a big city will save huge amounts of money. Although the result shows that presenting the policy leads to people changing their routes, changes in gas demand elasticity are still vague. Further work models the effect of this policy on different income groups of users.

8. ACKNOWLEDGMENTS

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Appendix

TableA1 The network parameters

Link no.	t_0	X	C	Length (km)
1-3	0.5	0.15	15	25
1-5	0.1	0.15	25	5
2-4	0.5	0.15	11	25
2-5	0.1	0.15	35	5
5-6	0.2	0.15	45	15
6-3	0.1	0.15	20	5
6-4	0.1	0.15	35	5

$T=t_0*(2+x*(V/C)^4)$: BPR function

TableA2 O/D matrix for the test network (Low demand)

		Destination	
		3	4
Origin	1	10	15
	2	10	20

TableA3 O/D matrix for the test network (High demand)

		Destination	
		3	4
Origin	1	20	20
	2	20	25