A graduated transport fuel excise for metropolitan areas

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Summary

A graduated excise allows more spatial control of congestion and pollution. The cost of a detour to a cheaper gas station defines a gradient, and the integral gives an excise mountain with its top at the center of the metropolitan area. Consistency implies that the mountain with the maximal gradient is a cone. There are differential effects of fuel efficiency, tank size, speed and (virtual) wage costs. An increase in fuel efficiency e.g. reduces the maximal excise cone. Legislation and control would be required to prevent riding bombs and graduated smuggling.

Introduction

There are two major reasons for a fuel excise: the revenue and the economy effect. The revenue finances roads and general expenditure. The economy effect concerns both the reduction of air pollution with its subsequent health hazard, and the conservation of natural energy sources. The excise can be relatively high since fuel has a low price elasticity - i.e. the price of fuel must be very high before people abstain from its use. Typically, fuel excises are across the board, i.e. established for the whole area under jurisdiction as one constant amount of money per liter.

One effect of fuel - pollution - tends to be localized. Metropolitan areas suffer more from fuel pollution than rural areas. Thus one may question the adequacy of the constancy of the excise, and investigate whether the excise can be localized too. One can imagine an excise mountain with its top at the center of the metropolitan area, and the excise sloping down to the outer reaches.[2]

Our inspiration is the small country of Holland. The cities of Amsterdam, Rotterdam, The Hague and Utrecht together form a large metropolitan area along the shore of the

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[2] A colleague came up with a reverse suggestion: to have a valley. When road pricing or other measures drive up the cost of transport, then an excise valley could compensate for these costs. It may be remarked fuel use already is commensurate with road use, so that fuel excise is a form of road pricing in general. Thus it is a question whether graduated excise would achieve, in a general manner and efficiently, the same objective as road pricing tries to do in a very specific manner.

North Sea. There exists a distinct interest in reducing congestion and pollution. Raising the price of fuel in Holland by a constant excise will meet with problems at the borders with the countries of Belgium and Germany that are close to this metropole of Holland. Also, Belgium and Germany will not easily raise their excise too. The present solution is to raise the fixed cost of owning a car, but that solution implies relatively lower variable costs, even though it are the variable costs that mostly determine the actual use of a car. A new approach to restore the variable costs is a graduated fuel excise. In Holland, as a special case, the top of the excise mountain could be taken above the North Sea.
Below, we will abstract from actual policy making, and try to find the essential relations of a graduated fuel excise. We first state some general properties, derive the proper formula, plot graphs, discuss other behavioral reactions, and conclude.

General properties

If you are at a gas station, then it would take time and fuel to drive to another gas station that has a lower fuel price. It follows that the station has a hold on you. The hold on you depends on general transport costs, on how dear you value your time, and on the size of your gasoline tank, since this size multiplies with the gain in price that you want to achieve. This hold on you will be called the (threshold) gradient.
The main determinants are as follows. The traveling distance between two gas stations will be taken as twice the distance by air; the person has to travel up and down, and it will be too complicated to discuss other route patterns. We neglect other types of reroutings. The cost of the trip to another gas station depends upon fuel consumption, which depends on the fuel efficiency of the car. Fuel efficiency itself often depends upon the speed; the speed again may depend on the (virtual) wage, but is here at a maximum. The travel time depends upon the distance and speed, and the cost of time depends upon the (virtual) wage of a person. Other car usage costs, by definition of usage, depend upon time too, and thus can be included in the (virtual) wage. All costs of making the trip must be balanced by the savings made by filling up the tank at a lower price. It follows that the size of the tank is a key variable - as can be observed already at the Dutch border. In summary we get:

- *fe* = Fuel efficiency = on average 12.2 km / liter, but in general *fe*(speed)
- Time = traveling time cost = Wage * 2 * Distance between gas stations / Speed
- Cost of a trip = Gas price * 2 * Distance between gas stations / Fuel efficiency + Time
- Gradient = Cost of a trip / Tank contents
- *c* = Tank contents = 40 liter tank + 20 liter jerry can
- *p* = Gas price = Gas price at next station + Gradient
- Start condition = *p(0)* = the price of gas at the Dutch border is $1.25 / liter. (It really is.)

We require overall consistency of the system. The decision where to tank must be transitive. Regard three stations A, B and C, in order of distance, and suppose that you are in A. Prices and costs should be such that you decide to stay in A. You rather pay a little extra at this station A than drive to the nearest slightly cheaper one (B); and you will neither drive to C further away that is even more cheaper. If you were at B, you would remain at B instead of going to C, since the problem at B with respect to C is the same as at A with respect to B.

Formulas

We first naively take above relations and derive a major relation. This we test on consistency, and find it to be erroneous. Then we derive the proper relation, which generates a cone.
Let *p(x)* be the gas price at *x* kilometers from the border, then *p(x-d)* is the price at *d* kilometers closer to the border (and hence lower). Using *s* for speed:

$$p(x) = p(x-d) + (p(x-d)\ 2\ d / fe(s) + wage\ \ 2\ d / s) / c \tag{1}$$

Bringing *p(x-d)* to the left, dividing by *d* and isolating 2 gives:

$$(p(x) - p(x-d)) / d = 2\ (p(x-d) / fe(s) + wage / s) / c \tag{2}$$

And taking the limit of $d \rightarrow 0$ gives the differential equation:

$$p'(x) = 2\ (p(x) / fe(s) + wage / s) / c \tag{3}$$

Equation (3) and the start condition solve as:

$$p(x) = p(0)\ e^{2x/(c\, fe(s))} + \frac{wage\ fe(s)}{s} (e^{2x/(c\, fe(s))} - 1) \tag{4}$$

Note that *p(x) - p(0)* will be the graduated excise. The result gives the price as an exponential function of the distance from the border. The important parameters of tank content and fuel efficiency have an exponential effect too, while the price at the border and the (virtual) wage have a linear effect only.
The important effect within (3) is, that the higher excise also raises the local cost of a detour, enhancing the gradient. Therefor, regrettably, the exponential relation does not satisfy the consistency requirement. It pays to drive to a much cheaper station. If we have three gas stations A, B and C, then, due to the exponential rise of the excise, it would pay to make a larger detour from A to C. It follows that (3) is not the proper equation to start with.
We can find the proper relation by applying the minimal gradient to the whole range; the minimum of (3) is the maximum of the real problem. Thus in the right hand side of (3) we replace *p(x)* with *p(0)*. Directly solving:

$$p'(x) = 2\ (p(0) / fe(s) + wage / s) / c \tag{3'}$$

$$p(x) = p(0) + 2\ (\frac{p(0)}{fe(s)} + \frac{wage}{s})\ x\ /\ c \tag{5}$$

The threshold gradient generates a linear relation. It gives the maximum by which the fuel price can rise, if consistency is to be warranted. Thus, the maximal mountain is a cone. We first consider some graphs and then look again at this consistency.

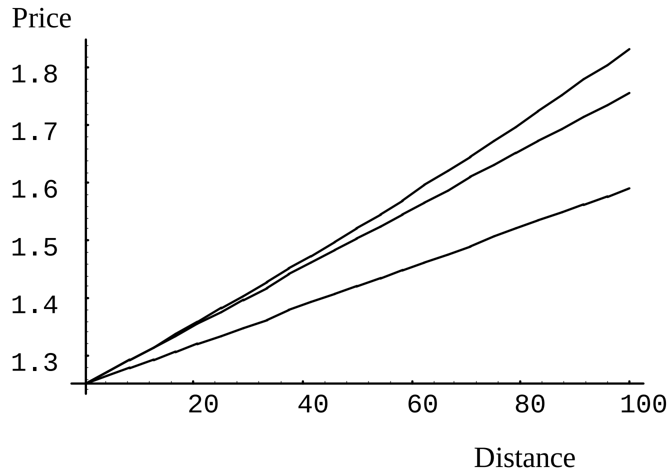
Graphs

Amsterdam is 100 km from the closest border. Default parameter values are *p(0)* = \$1.25,
s = 100 km/hour, and fuel efficiency *fe(s)* = 12.2 km/liter.
With these parameter values, and a 40 liter tank and \$10 wage, the fuel price in Amsterdam could be \$2.18 per liter. With a 40 liter tank and a \$5 wage it could be \$2.01. The wage has no large effect, and this is caused by the fact that the current Dutch fuel price is high, relative to the (virtual) minimum wage. [3]
Let us take two precautions:

- The Dutch net minimum wage actually is higher than \$5, and studies on border behavior have shown a virtual wage of \$10. However, \$5 stays on the safe side. Thus *wage* = \$5/hour.
- Current tanks are 40 liter ones. However, it is useful to take account of 'jerry can behavior', and then target for 60 liter contents. Thus *c* = 60 liter.

With these parameter values, the fuel price in Amsterdam can be \$1.76. When we put (virtual) wage costs to zero, it still can be \$1.59. Figure 1 gives the plot of the price as a function of the distance from the border, with Amsterdam located at 100. We plot the erroneous exponential relation too (with its Amsterdam value of \$1.83), so that we can better see the error.

Figure A: Price as a function of the distance to the border, exponential and linear with and without (virtual) wage

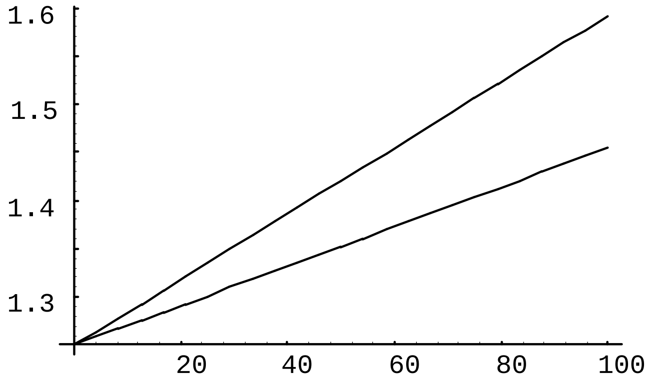


Let us check on the consistency. Someone driving from Amsterdam to the border to get some cheap gasoline, drives 200 km and uses 16.4 liters of gasoline, with a border value of \$20.5. Two hours driving at a net minimum wage costs \$10. The savings on the tank are
60 (\$1.76 - \$1.25) = \$30.5. Thus, it's no use to make the 'detour'.
If Amsterdam had been priced exponentially, savings would have been (\$1.83 - \$1.25) = \$34.8 and there would be a small gain of \$4.3. So the exponential function is not consistent.

[3] We might take a higher wage, if that is relevant for car users.

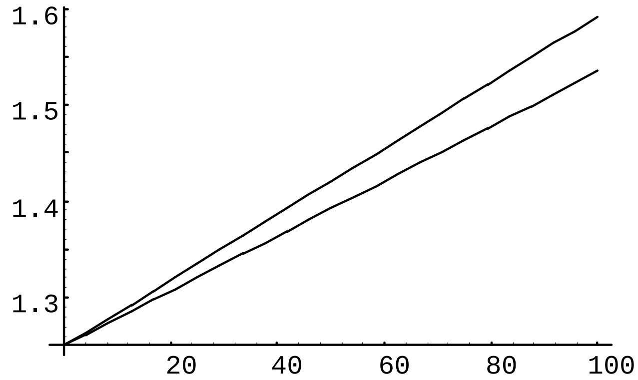
Someone living between Amsterdam and the border to Germany, e.g. at 60 km from the border and 40 km to Amsterdam, will not make a trip to Germany, and neither to a gas station at 59 km from the border, since it will not pay to travel that distance.
If a substantial number of people adjust the tank size to 100 liter, the price must drop. Let us regard the worst case, i.e. that people do not take account of wage costs. Then the price in Amsterdam can only be $1.45. Figure 2 compares the no-wage case for 60 and 100 liter tanks.

Figure B: Price as a function of the distance to the border, without (virtual) wage: 60 and 100 liter tanks



Now let fuel efficiency increase. If our default 12.2 km/liter is increased by 20% to 14.64 km/liter, then the price in Amsterdam, in the no-wage and 60 liter tank case, must drop to $1.53, which is almost 4% below the earlier value of $1.59.

Figure C: Price as a function of the distance to the border, without (virtual) wage, 60 liter tank: 12.2 and 14.64 km/liter



Another avenue of inquiry is to regard fuel efficiency as a function of speed *fe(s)*. The default speed taken here is 100 km/hour and fuel efficiency likely is optimal at lower speeds. If wages are zero, then there is only the normal increase in efficiency, as in figure 3. If wages are nonzero, then the fuel savings may well be offset by the time lost due to the slower speed. This indeed happens when wages are $5 and an efficiency of 14.64 km/liter is reached at 70 km/hour.

Other effects on behavior

Obviously, regional commuters to Amsterdam, and especially someone at the border driving to Amsterdam, will fill up the tank at home, and have a relatively cheap trip. It is advisable to accept this; the ‘marking’ of fuel will not be needed. A general effect will be that people tank at the lowest point of their trajectory along the excise mountain. The gas stations at the top will go broke, but others will draw customers from uphill. The overall effect still will be an increase in variable costs, since the average excise can rise. There will be a tendency to expand the tank and to load the car with jerry cans, and this will generate ‘riding bombs’, with a great risk to road safety. The use of jerry cans around the home garage is dangerous itself too, also considering the effect of vapors on health. One solution is to legislate the size of tanks and the use of jerry cans for passenger cars. One might target a 30 liter tank and a 2 liter emergency jerry can. Legislation of course comes with control.

Another possible danger is that tank trucks start delivering huge quantities from the cheap area to personal home tanks uphill. This requires legislation on what constitutes a gas station. If it can be established that home deliveries are at the going price of the area, then such deliveries are not likely to be generated.

The graduated system requires a closer control of gas stations. The treasury can easily determine geographic co-ordinates and the associated excise, and inform the gas stations. It may be more difficult to measure actual sales at each station, though this should not be a technical problem.

Fuel companies do not vary their base prices much. It seems that whatever their policy is, that it need not interfere with the graduated excise.

Likely, the existence of more variation in prices will make people more conscious of the cost of transport in itself. Interestingly, the discussion of the instrument of graduation itself, long before its possible implementation, might already raise cost consciousness.

A point of inquiry is whether the time spent driving really is a cost. For tourists it is entertainment.

Conclusion

To me the greatest surprise was that consistency requires us to abandon the exponential relation - precisely the relation that I enjoyed finding. The linear case has the maximal gradient, but is rather dull. The gradient can be less, i.e. the price relation can curve downwards but cannot curve upwards. Well, that is a strong result again.

A number of factors have been identified. It is interesting to see the differential effects of (virtual) wage costs, fuel efficiency and tank contents. The official government policy to increase fuel efficiency may force a reduction of the size of the excise cone.

Legislation and control would be required to prevent riding bombs, and to prevent the new phenomenon of graduated smuggling.

As said, our discussion has been abstract, and concerns only a few key aspects. Practical implementation would require an altogether different study.