Solutions to part 1: Pollution in LICs

Most of this is straightforward. I will assume that the VSL and QALY concepts are known, so I will not elaborate too much here.

Valuation using VSL = value of statistical life is based on standard loss values per person dying as a result of the project. VSL values are usually found from either a) original valuation studies using either revealed preferences or stated preferences, or b) value transfer from other studies done with the same objective.

Valuation using QALY = quality-adjusted life years implies that a standard value is set to extending life in full health by one year, and that the annual value is adjusted down by specific factors for persons with particular types of sickness or inhibitions.

The most specific and perhaps tricky problem here is to distinguish between air pollution and water pollution projects in LICs. The most important distinction, in terms of value, is that while projects to reduce air pollution mostly save persons who are already relatively old and/or sick, projects to reduce water pollution would mostly save children. For a given number of lives saved from each of these projects, the VSL value would be the same for both projects. The QALY value would however be much higher for the project reducing water pollution (since children, mostly saved by the water pollution project, have much longer remaining lifetime than old people, mostly saved by the air pollution project).

Solutions to part 2: Urban traffic in LICs

1. The most important types of externality costs in road transport are carbon emissions; local tailpipe pollution emissions and emissions due to particles constituting worsened air quality; noise; road congestion; road accidents; road wear. All these types of externalities are consequential for all types of vehicles. Exceptions are road wear for smaller vehicles (insignificant for vehicles other than large trucks); and local tailpipe emissions and possibly noise (and carbon emissions when the electricity is not produced from fossil fuels) for electric vehicles.

2. Fuel-related externalities: Carbon emissions; and local tailpipe emissions. Distance-related externalities: Congestion; accidents; and road wear. A fuel tax is a good instrument to correct for the first type of externality. A distance-related tax (thus, a tax on the amount of driving) is a better instrument to control for the second type. This tax must ideally be variable to be able to correct for the large temporal variation in congestion externalities, which tend to dominate at times when congestion is high.

3. Here, I have been using a note by Ian Parry which is given at the end of this document. I do not expect students to know precisely the formulas in this document, only the basic argument, that he marginal congestion cost when congestion is serious, is generally adds a multiple of the average congestion cost (the cost for the vehicle we consider), due to congestion imposed on other vehicles. This multiple is usually, according to Parry, between 2.5 and 5. I have discussed this note very recently, and it is included in the published lecture notes.

4. Costs of road accidents are in terms of a) mortality; b) morbidity, hospital time, related lost work time etc.; c) material costs including damaged vehicles and other property that may be hit, etc. Estimation of mortality and morbidity costs would be done in basically the same way as for pollution damages. One difference is however that persons dying or being injured from road accidents are usually younger and healthier than persons dying from air pollution. This implies that, at least when using a QALY measure of mortality damage cost (which I have also talked about at the lectures), the damage would be relatively greater from road accidents relative to pollution damage, for a given mortality (and morbidity) impact. What should be considered as externality costs will also vary with type of accident. For accidents of type a), it is standard to not consider the costs as external but in principle internalized by the driver (although one should be able to count externality costs when a driver has passengers who may be harmed and who have no direct influence on the driving activity; or costs on oneself that will be borne by society, such as hospital or disability costs borne by the social security system). For accidents of type b), given one person in each vehicle, a standard calculation is to consider half the damages as internalized, and half as external (with the same caveat as for single-person accidents above). For accidents of type c), costs are usually all counted as external. In principle (part or all of) the latter costs might be internalized when a driver is held (fully or partly) responsible for such accidents.

Solutions to part 3: Saving rainforests

To point 1, it seems clear that a private firm will tend to set or have $\alpha = 0$; an environmental NGO will also have a low value of α; while a government or international development institution will tend to set α higher. The case of $\alpha = 1$ is a limit case that perhaps no development institution will maintain. Here in this problem, however, as α is assumed to take two possible values: either 0 or 1. It is then natural, as part of this problem, to identify the latter institutions with setting $\alpha = 1$; while identifying private firms and NGOs with setting $\alpha = 0$.

Point 2: This is straightforward as the buyer can here always implement an efficient solution by setting H = B. The forest will then never be saved in case a); it will be saved with probability β_1 in case b); with probability $\beta_1 + \beta_2$ in case c), and with probability 1 in case d).

Point 3: With $\alpha = 1$, the buyer has a range for implementing the optimal solution in all the cases b) – d). In case b) this range is $[V_1, V_2]$, in case c) it is $[V_2, V_3]$, and in case d) it is $[V_3, \infty]$.

Point 4: In case b), this buyer will buy only in the case of $V = V_1$, occurring with probability β, and pay the minimum amount to implement this solution, which is V_1. This solution is socially efficient.

Point 5: In this case, the buyer has a choice between implementing a payment only with probability β, and pay V_1, or implementing a payment with probability 1, and pay V_2. The condition for the latter solution to be chosen is then

(1) $$(\beta_1+\beta_2)(B-V_2)>\beta_1(B-V_1)\Leftrightarrow \mathrm{V}_2<\frac{\beta_1}{\beta_1+\beta_2}V_1+\frac{\beta_2}{\beta_1+\beta_2}B\,.$$

Alternatively, this condition can be expressed as:

(2) $$\beta_2>\beta_1\frac{V_2-\mathrm{V}_1}{B-V_2}$$

We see that when either V_2 is relatively small, and/or β_2 relatively large, the buyer will prefer to offer H = V_2, in which case the forest will be saved in both cases V = V_1, and V = V_2, which is efficient. In other cases the forest will be saved only in state V = V_1, which foregoes socially efficient saving in state V = V_2, occurring with ex ante probability β_2.

Point 6: Here the situation is made slightly more complicated as it is now also socially efficient to save the forest when V = V_3. Disregarding for the moment that state, the conclusions from point 5 still hold. We must now check whether saving the forest in state V_3 can be an equilibrium for the buyer, in two different situations: First, when condition (1) (as well as (2)) holds and the buyer would save the forest in both states V_1 and V_2 (when the option to save the forest for V_3) is not available. Secondly, when condition (1) does not hold, so that the buyer would save the forest only in case V_1 when the option V_3 is not available.
In the first case, the condition for saving the forest when V = V_3 is (then the forest will be saved with probability 1):

(3) $$B-V_3>(\beta_1+\beta_2)(B-V_2)\Leftrightarrow V_3<(1-\beta_1-\beta_2)B+(\beta_1+\beta_2)\mathrm{V}_2\,.$$

In the second case, the similar condition is:

(4) $$B-V_3>\beta_1(\mathrm{B}-V_1)\Leftrightarrow \mathrm{V}_3<(1-\beta_1)B+\beta_1V_1\,.$$

When both conditions (3) and (4) hold, the forest will be saved in all states. This occurs, generally, when the probability of occurrence of V_3 ($1-\beta_1-\beta_2$) is relatively large, the probability of V_1 (β_1) is small, and V_3 is not much larger than V_2.
We see that we can have cases where the forests would not be saved in state 2 given that the option 3 is not available (consequently, when $V_3 > B$), but that the forest would be saved in all stated when option 3 is available (when $V_3 < B$). This happens when V_3 is not much greater than V_2, the probability of V_2 is relatively small, and the probability of V_3 is relatively large. Then the buyer would not increase the price from V_1 to V_2 to capture a small number of additional sellers (probability β_2 relatively

small), but would increase the price slightly further to V_3 if it thereby captures many potential sellers. Adding the third option then leads to an efficiency gain.

Box 4.1. Measuring Congestion Costs: Some Technicalities

The total costs (*TC*) per hour of congestion to passengers in vehicles driving along a one-km lane segment of a highway can be expressed:

$$TC = V \cdot (T(V) - T^f) \cdot o \cdot VOT$$

Here *V* denotes traffic volume or flow—the number of cars that pass along the km-long stretch per hour (the implications of other vehicles on the road is discussed later). T^f is travel time per km when traffic is free-flowing and *T* (which exceeds T^f) is the actual travel time, is an increasing function of the traffic volume (because speeds fall with less road space between vehicles). *o* is vehicle occupancy (average number of passengers per vehicle). Total travel delay from congestion for all passengers is therefore $\cdot AD \cdot o$, where $AD = T - T^f$ is the average delay time per vehicle km. Multiplying total travel delay by the value of travel time (VOT) expresses delays as a monetary cost.

Dividing *TC* by traffic volume gives the average cost of congestion (*AC*) per vehicle km:

$$AC = AD \cdot o \cdot VOT$$

This is the cost borne by individual motorists which (on average) they should take into account when deciding how much to drive.

Differentiating *TC* with respect to *V* gives the added congestion cost to all road users from an extra vehicle km:

$$dTC/dV = (AD + D^{other}) \cdot o \cdot VOT$$

This includes the average cost (taken into account by the driver), as just described. It also includes the cost to occupants of other vehicles (which is not). The latter is the delay to other vehicles, denoted D^{other}, times the average number of people in other vehicles, times the VOT to express costs in money units. In turn $D^{other} = (dT/dV) \cdot V$, the increase in travel time per vehicle times the number of vehicles.

Suppose, as discussed in the text, that travel delay can be approximated by a power function of traffic volume, that is:

$$AD = T - T^f = \alpha V^{\beta}$$

where α and β are constants. α reflects factors like road capacity while β reflects the rate at which additional traffic slows travel speeds. Differentiating this expression by *V* gives $dT/dV = \alpha\beta V^{\beta-1}$. With a bit of manipulation, we end up with:

$$D^{other} = AD \cdot \beta$$

That is, the delay to other vehicles is simply the product of average delay and the scalar β. As discussed below, empirical studies suggest a value for β of between about 2.5 and 5 for congested roads.

If speed data is available, average delay can be estimated using:

$$T = \frac{1}{S}, \quad T^f = \frac{1}{S^f}$$

where *S* and S^f are the actual and the free-flow travel speeds (km/hour).

Another way to write the condition for marginal congestion costs:

$$TC = V \cdot AD \cdot \sigma \cdot VOT = \alpha V^{\beta+1} \cdot \sigma \cdot VOT \Leftrightarrow \frac{dTC}{dV} = \alpha(1+\beta)V^{\beta} \cdot \sigma \cdot VOT = (1+\beta)\frac{TC}{V}$$