Fuel Policy, Global Warming, and Uncertainty

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Many jurisdictions are implementing policies to reduce the greenhouse gas (GHG) intensity of transportation. These programs, which intend to force or encourage substitution of low-carbon fuels for fossil fuels, fall into two broad categories. First, GHG-intensity programs, like the California low carbon fuel standard (LCFS), oblige fuel sellers to ensure that the average GHG intensity (as measured by each fuel's global warming index, or GWI) of their annual sales does not surpass a legal limit. Second, quantity mandates like the US Renewable Fuel Standard require use of minimum quantities of specific categories of fuels, which are typically defined by GWI ranges.

Implementation of these programs requires that the regulating agency either assign a GWI value to each fuel (intensity programs) or determine that each fuel's GWI falls into one or another defining range (performance-based quantity mandates). When the policies were designed, it was implicitly assumed that a life cycle assessment (LCA) of greenhouse gas discharges would generate sufficiently unambiguous GWI values for fuels. However, uncertainty about the 'real' GWI of a fuel, especially of biofuels, has become a salient issue. This uncertainty is illustrated by the difficulty of quantifying so-called indirect land use (ILUC) discharges from land clearing induced by increased biofuel cultivation and by the variation in GWI values arrived at by different LCAs.

The present note frames the assignment of a GWI value to a fuel as a problem in decision analysis, and argues that properly choosing this value is more complicated than current policy recognizes. Attention must be paid not only to a full probability density function of the real value but also to (i) how the economy responds to the chosen value, (ii) the objectives of the policy, and (iii) a function giving the cost (relative to these objectives) of an assigned GWI being unequal to the unknown real value.

Decision Framework

We use an intensity policy as our example because it demands the same precision in GWI assignment for all fuels, whereas threshold-based policies demand less precision for fuels far from a threshold. A variety of fuels $i = 1,2,\ldots$ [2] may be blended in various proportions by

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[2] Here we mean i to index whatever categories of fuel the program differentiates; generally, these are not just chemical species (*eg*, ethanol) but fuels from specific feedstocks grown in specific locations and refined in specific ways.

the regulated party, typically a distributor who sells motor fuel. Each year, the distributor calculates his annual fuel carbon intensity (AFCI) as

$$\frac{\sum_i Q_i g_i}{\sum_i Q_i}$$

where Q_i is the quantity of fuel i sold and g_i is the GWI assigned to fuel i. If its AFCI is higher than the annual standard, the distributor must buy allowances from other distributors to cover the difference (or pay a fine); if its AFCI is below the annual standard, the distributor can sell its excess allowances.[3] In effect, the distributor is given a free allowance of AFCI, but this is not the same as an allowance of GHG as might characterize a "cap and trade" program because the distributor's total fuel sales are not capped.

The key action by the regulator is the assignment of GWIs via the choice of a vector $\{g_i\}$. One might think that each of these GWIs should represent the regulator's "most likely value" of γ_i, the unknown net amount of GHGs (in CO_2-equivalent units) released by producing and burning one megajoule of fuel i. For any two fuels, $(\gamma_i - \gamma_j)$ is the nominal amount of GHGs saved (or, if negative, emitted) by substituting energy-equivalent amounts of fuel j for fuel i. We will show that the best choice for g_i is in fact unlikely to be the best guess for γ_i: *assigning g_i is a regulatory action related to, but not the same as, the estimation of γ_i as though it were a physical property of fuel i.*

For each γ_i we have one or more estimates g^*_{ij}, because a variety of kinds of imperfect knowledge and error sources separate the value of each g^*_{ij} from each other and from the real value γ_i[4]. The correct statement of the regulator's knowledge of γ_i is a *probability density function* $f(\gamma_i) = f_i$ that describes the probability the regulator attaches to the proposition that the true value lies within any range.

How a set of j estimates $\{g^*_{ij}\}$ of γ_i should be combined with each other and with any other knowledge to produce a density function f_i is beyond the scope of this note. In principle, it is no different from framing probability judgments on the basis of incomplete information in any other context, and challenging in practice because the mathematics of Bayesian inference do not rigorously accommodate multiple decisionmakers and stakeholders who do not share all the same data and prior beliefs. For the present discussion, we emphasize that it is not possible to rationally implement a fuel policy without doing this, whether implicitly or explicitly and whether by formal analytics or by some sort of heuristic. The question then is: given f_i, what should g_i be?

[3] Under the California LCFS, some fuel ratings are adjusted by an Energy Efficiency Ratio (EER) to reflect different drive-train efficiencies. We ignore this detail in the present example.

[4] For an examination of the uncertainty associated with GWI estimation, see (Plevin, O'Hare, et al. 2010).

Cost of Error and System Response

The word *should* requires attention to the goals of the program, which frame the objective function for the selection of the g_i's. The explicit goals of the LCFS, as expressed in its "Whereas" clauses, are quite broad, including energy security, development of the state economy, reduction of locally consequential "criteria pollutant" emissions, and climate stabilization; its actual operation, however, only counts something much more specific, namely reduction of the AFCI of transportation fuel.

The variety of goals that might have a place in implementation decision-making for the LCFS are illustrated by sketching its predictable consequences. After the regulator commits to $\{g_i\}$, the world responds by choosing particular fuel blends. The fuel blend choices are affected by the prices of the various possible fuel components i, by changes in motor fuel use within the jurisdiction due to the effects of blending choices and GHG intensity credits on prices, and by changes in motor fuel use outside the jurisdiction owing to effects on prices in other markets (Barker, Dagoumas et al. 2009; Stoft 2010). The fuel blend choices may then cause other effects such as changes in food consumption and changes in employment both within and beyond biofuel-cultivating regions, will follow as well.

We call the vector of measures of this response $\mathbf{R}\{g_i\}$. Note that these measures are random variables and are not known with certainty when $\{g_i\}$ is chosen. They have a multivariate distribution whose density function we label $h_{\mathbf{R}}$.

We begin the discussion from the perspective of 'society as a whole' which would presumably want the regulator to maximize expected utility, E(V):[5]

$$\mathrm{E}(V) = E_{f,h}\left[V\left(\{g_i\},\{\gamma_i\},\mathbf{R}\{g_i\}\right)\right]$$

where V is social utility, calculated generally and completely. In practice, a useful measure of social cost entails great simplification and approximation. For the moment, we will assume that the fuels program affects social utility only through the difference between g_i and γ_i, meaning that a "cost of being wrong" function can be constructed as $V(g_i - \gamma_i)$. If it is symmetrical around 0 so that $V(g_i - \gamma_i) = V(|g_i - \gamma_i|)$, we can refer to standard results from decision theory for an indication of the optimal regulatory action. (An intuitive justification for the simplified form relies on the approximate linearity of small changes.) If a given fuel's actual GWI γ_i is higher or lower than its operational value g_i, the immediate effect is that too little or too much of it will be used. If total discharge is all that matters to the decisionmaker and the range of outcomes is small with respect to other GHG discharges, then the result of a difference between g_i and γ_i will be a proportional (linear) effect on total carbon discharge and on social utility: $V = a\,|g_i - \gamma_i|$ where a is a constant.

[5] Other decision rules, such as minimax loss, or constraining the probability that the global release of GHGs from motor fuel could increase as a result of the LCFS, could be invoked. Much of the following analysis will still apply.

Figure 1 (symmetric cost function) illustrates the decision problem for this simplest case: we choose g to minimize

$$E(V) = \int_{\gamma} |g - \gamma| f \ .$$

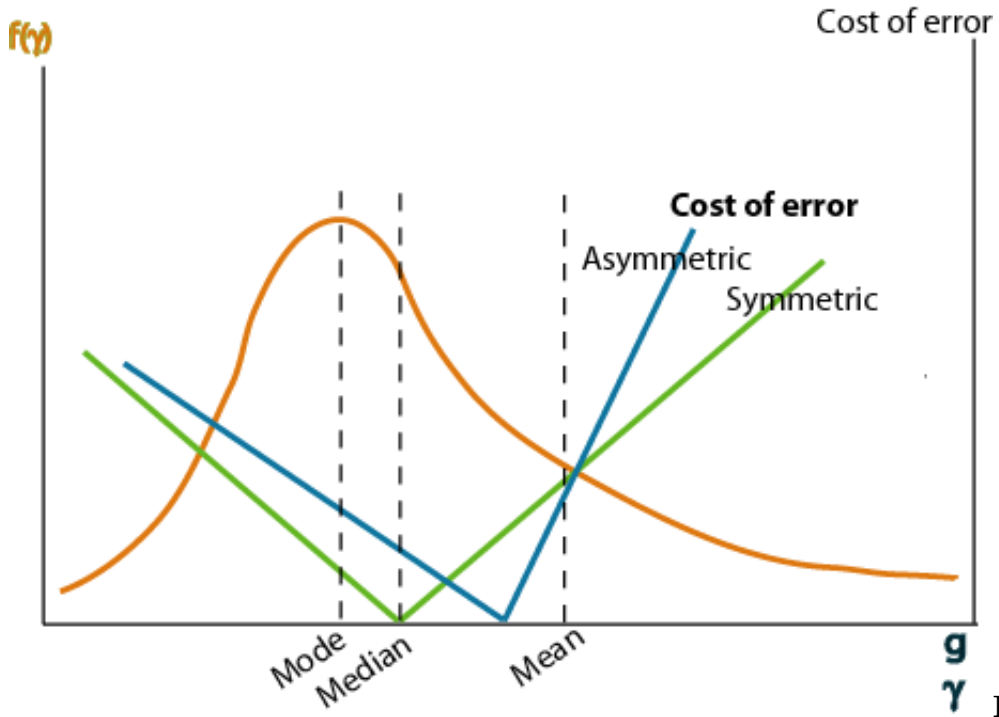

Fig ure 1: Optimal choice of *g* for a biofuel given a probability density function for γ (the real GWI of the fuel) and cost of error functions.

For any linear cost function, this minimum is at the median of f (Raiffa and Schlaifer 2008). We also note that if f is not symmetrical, its median is not equal to its mode (which is its most likely value). As f has a longer tail to the right (higher values of γ) for at least one important biofuel (Plevin, O'Hare et al. 2010), as Figure 1 shows,the expected error under a linear cost assumption is minimized at a g value (the median of f) higher than the mode.

The shape of V is important: for example, if the cost of error increases with the square of the error, the optimal value is the mean of f, which is still higher than the median in the case of a distribution with a long right tail. Even if the cost in linear in the error, it may have different slopes on either side of γ. If it is more costly (for example) to underestimate γ for a given fuel than to overestimate it by the same amount, the optimal g is higher than if V is symmetrical.

Up to this point we have implicitly treated fuel substitution as though it will occur on a MJ-for-MJ basis. However, as suggested above, cross-elasticities in fuel markets and non-fuel responses complicate the total system response. It is entirely possible for an LCFS to cause more rather than less GHG discharge even though AFCI is reduced, or to achieve GHG reductions only at very high cost compared to other options (Holland, Hughes et al. 2009). It is accordingly very important to characterize V in a way that captures at least some of the elements of **R**.

Conclusion

Uncertainty about the global warming intensity of many fuels that may be important compliance options for low-carbon transportation is refractory: it is unlikely to be reduced to triviality by further analysis. The key policy implementation step of assigning operational GWI values must explicitly recognize the nature of this uncertainty, especially including moments of f above the second (skewness) for even a very simplified objective structure. Even if a narrow goal like GHG reduction is sought, let alone if policy is directed to a broader accounting of social cost minimization, the assignment of these values also needs to incorporate an explicit cost function describing the consequences of assigning values that do not equal the unknown real values. Just as the operational yield strengths of construction materials–the strengths building codes require designers to use in design-differ from their most likely values by a safety factor, this analysis will almost certainly indicate operational $\{g_i\}$ values for GWI that differ from the estimated most-likely values of $\{\gamma_i\}$.

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