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Characterizing regulation and negligence rule uncertainty in solid waste management

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Abstract

We propose a model of municipal waste management that combines waste quality monitoring with leachate control. These inputs modulate two types of uncertainty. First, waste quality is uncertain, as it arrives from several nonpoint sources and may contain hazardous waste. Second, while U.S. federal law requires landfill operators to employ these specific inputs, the rates at which they should be employed to avoid culpable negligence for environmental damages are uncertain. We extend the economic literature regarding the management of these types of uncertainty to this municipal waste context.

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1. Introduction

Although much progress has been made in municipal solid waste (MSW) management, it is evident from continued policy discussions that the economic aspects of MSW management are not yet fully resolved. For example, there are ongoing discussions regarding the number of MSW disposal facilities in various countries and the siting of new facilities; the quality of the groundwater surrounding MSW disposal facilities; and long-standing tensions regarding interstate and international trade in MSW. The economic literature regarding MSW addresses several aspects, including household waste generation rates, recycling and disposal choice/behavior, sustainable/green product design issues, negative externalities surrounding landfills, optimal pricing of land disposal of MSW (tipping fees), waste-to-energy plant possibilities, and the degree of economic inefficiency introduced by flow-control statutes.[1] One aspect that has not yet received attention is the optimal employment of key inputs necessary for managing the uncertain engineering and legal aspects of MSW management. The purpose of this paper is to propose a microeconomic model of MSW management that takes this aspect into account. Such a model would be a more comprehensive one than has heretofore appeared in the literature.

In the abstract, a MSW landfill is a production process that receives waste of imperfectly known quality, and by monitoring the waste quality in-flow and restricting the out-flow of leachate, isolates such waste for an indefinite period of time. There are two key problems that MSW managers face. First, a small percentage of municipal waste is relatively hazardous waste—such as batteries, motor oil, prescription medication, medical sharps, paint, computer parts and other electronics such as television sets—and should not have entered the municipal waste stream, despite current laws and guidelines to households/firms. This small but potent flow of relatively hazardous waste combines with the great mass of relatively benign—but degrading—waste to create a leachate that threatens the biosphere surrounding the landfill.[2] The problem is that this "small but potent flow" originates in households and firms on a nonpoint source basis. That is to say, once individuals contribute their MSW to neighborhood pickup trucks, the landfill manager cannot discern ownership of any problematic wastes that arrive for disposal and contribute to the potentially toxic leachate.

As Millock *et al*. (2002) indicate, the extent to which pollution is nonpoint source is a function of monitoring technology. Reminiscent of the history of other nonpoint source problems, the lack of technology that would enable better monitoring of disposal decisions by households and firms, as well as the lack of leachate control systems in first-generation landfills, resulted in the fouling of groundwater surrounding multiple landfills. The U. S. federal government responded to this growing problem by first passing the Resource Conservation and Recovery Act (RCRA) in 1976, and then in 1991, by creating the dual federal requirements that MSW managers must monitor the quality of the waste presented for disposal and monitor the quality of the leachate created that may migrate to

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[1] See, for instance, in the order of these aspects, Jenkins *et al.* (2003), Choe and Fraser (1999), Fullerton and Kinnaman (1996), Dijkgraaf and Gradus (2004), Calcott and Walls (2000), Eichner and Pethig (2001), Walls and Palmer (2001), Nelson *et al.* (1992), Ready and Ready (1995), Palmer *et al.* (1997), Palmer and Walls (1997), Keeler and Renkow (1994), Tawil (1999) and Ley *et al.* (2002).

[2] See Hamer (2003, 78-79) and Kjeldsen *et al.* (2002, 320).

nearby groundwater.[3] Secondly, the landfill management may be held responsible for leachate that migrates to the groundwater, particularly if the groundwater is—or is expected to be—utilized as drinking water.[4] Thirdly, state and federal governments imposed source-reduction strategies that have reduced the initial flow of problematic forms of waste, with the effect of modulating the nonpoint source pollution problem before it can be created by households and firms, and therefore before it arrives at MSW disposal facilities. For instance, the State of New York began limiting the mercury contents of batteries in 1992.[5] Fourthly, as scholars such as Choe and Fraser (1999) and Jenkins *et al.* (2003) point out, it is possible to structure economic incentives at the household level that encourage more attention to legal MSW disposal as well as to recycling. While Choe and Fraser (1999) emphasize the importance of effective monitoring to obtaining efficiency, Millock *et al.* (2002) propose a voluntary monitoring program in the presence of nonpoint source pollution that may be quite useful in this context. We shall discuss this possibility further below.

In this paper, we abstract from the latter two forces that affect landfill health—waste source reduction and household/firm level monitoring—and focus entirely upon the former two forces that are entirely within the control of the landfill operator—waste quality monitoring at the landfill gate and leachate control. The microeconomic aspect we find most intriguing regards the ambiguity in U.S. federal law regarding the legally-binding threshold levels of waste quality monitoring and leachate control. Indeed, while some aspects of landfill health are clearly specified in federal law (such as Table 1 of RCRA Subpart D, 40 CFR Part 258.40, which specifies concentration limits for various chemicals in the groundwater surrounding the landfill) landfill managers should view their compliance with current federal statutes as statistically uncertain on multiple counts. First, groundwater tests are subject to statistical error, so that a sequence of tests must be taken, and an analysis of variance test performed, before management knows whether the standard has been violated from a legal point of view.[6] Second, the statutes recognize that it may be uncertain which local party's contamination is responsible for the degradation of a particular water supply. Lastly, the language of the U.S. federal law should leave the manager uncertain of the legal consequences of her disposal facility being found culpable—and then being found negligent—for a violation of the statistical health standards.[7] In summary, we maintain that MSW management is most appropriately modeled as selecting optimal rates of precautionary strategies subject to ex ante regulations and an uncertain negligence rule.

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[3] See Resource Conservation and Recovery Act (RCRA) Subtitle C, 40 CFR Part 258.20 regarding waste input monitoring requirements and Subtitle D, 40 CFR Part 258.40 regarding leachate management requirements. This regulation was signed into law in 1991, after studies such as State of New York (1986) revealed weaknesses in on-site waste quality monitoring procedures.

[4] See 40 CFR Part 258.57 (Selection of Remedy), particularly section (e).

[5] New York Statute S-27-0719(3).

[6] See 40 CFR Part 258.53 (Groundwater Sampling and Analysis Requirements). This would seem to be increasingly problematic as the landfill ages, for Mendes *et al.* (2004, 53) state: "As widely described in the literature, it is generally accepted that most landfill liners will eventually develop leaks; hence, some of the leachate will leak out. The assumption adopted is that over the life of the landfill, 70% of leachate will be collected and treated, and 30% will leak out without any treatment."

[7] See in particular 40 CFR Part 258.57(e).

We are not aware of MSW research that formalizes this type of problem; however, these types and apparent magnitudes of uncertainty in MSW disposal practice have been addressed in multiple strands of law and economics literature by researchers such as Beavis and Dobbs (1987), Shavell (1987), Kolstad *et al.* (1990), Bartsch (1997), Dyar and Wagner (2003), and Hutchinson and van't Veld (2005). Our model, presented in Section 2, shows how aspects of this literature can be combined in new ways to yield insights in the MSW context. The model is sufficiently abstract to enable focus upon what we view as the key aspects of landfill environmental/financial health; yet, the model is sufficiently flexible to accommodate aspects of the landfill manager's concern that occur off-site (such as the relatively unobservable waste sorting decisions of households). The model provides a foundation to which complicating factors discussed in Section 3 may be added. As well, the framework suggests multiple testable hypotheses and directions for future research, also discussed in Section 3.

2. The Model

As we described above, landfill operators produce a service comprising acceptance of nonpoint source generated waste. Since the waste is generated on a nonpoint source basis, the flow of municipal solid waste Q that the landfill operator receives is of uncertain quality and can cause environmental damage for which the landfill operator may or may not be found culpably negligent. Let the flow of Q (again, of uncertain quality) that a landfill operator chooses to accept be a function of two inputs: waste quality in-flow monitoring resources M and waste out-flow (leachate) control resources L. The landfill operator employs technology $Q(L,M)$, which we assume is a continuous and differentiable function that characterizes M and L as weak substitutes in managing MSW. Even if the waste is expected to be perfectly benign—such as yard clippings—we propose that positive amounts of both waste quality monitoring and leachate control are necessary in order to distinguish a waste management facility from a "dump". We assume that inputs M and L can be obtained at perfectly competitive prices w_M and w_L. Suppose further that the landfill operator offers disposal services in a perfectly competitive market at price p.

The final aspect to capture in the model regards the expected environmental damages (in dollars) that could arise if there is a breach of the landfill's leachate control technology *and* the landfill operator is judged to be culpably negligent in her management practice. Suppose that the probability π of damage occurring is a continuous, differentiable function of M and L, so that we have $\pi(L,M)$. Moreover, assume that the dollar estimate of the environmental (including possible punitive) damages D a breach could cause is likewise a continuous and differentiable function of monitoring effort M and leachate control effort L, so that we have $D(L,M)$. Then, as in literature such as Kolstad *et al.* (1990, 890), the expected damages can be represented by an accident function, $A(L,M) = \pi(L,M) * D(L,M)$, with $\frac{\partial A}{\partial M}, \frac{\partial A}{\partial L} < 0$. That is, expected damages fall with the employment of more M and/or L. L and M therefore constitute the two key types of precaution exercisable by landfill operators, and the landfill operator is willing to undertake some cost of precaution in order to modulate expected damages.

To complete the characterization of potential environmental damages surrounding landfills, we turn now to what we view as a most intriguing aspect of the landfill operator's economic problem: the uncertainty over the threshold levels of monitoring and of leachate control required by federal law. That is, while US federal law requires some degree of waste quality monitoring and leachate control—and while there are specific thresholds for heavy metal counts in local groundwater samples that cannot be statistically exceeded—the threshold levels of monitoring and leachate control that would counteract charges of culpable negligence are, in our view, ambiguous. We raise this issue because Kolstad *et al.* (1990), Bartsch (1997) and Dyar and Wagner (2003) each found that this type of uncertainty can lead to socially inefficient rates of precaution being taken. We here show how their methodologies can be extended to the case of MSW management.

We propose that the landfill operator is uncertain over the negligence-nullifying levels of both *M* and *L*. Assume the landfill operator has conducted a mean assessment of the most likely thresholds of each, $\overline{M}$ and $\overline{L}$, and assume that the operator has formed probability distribution functions $f_M(M)$ and $f_L(L)$ for inputs *M* and *L*, based upon the legal histories with which it is familiar. Following Kolstad *et al.* (1990) and Dyar and Wagner (2003), we can represent the probability that the operator's *actual* choice of monitoring, $\hat{M}$, fails to ward off charges of negligence and liability as $R_M(\hat{M}) = \int_{\hat{M}}^{\infty} f_M(M)dM$ (the area under the probability density function from the operator's choice of *M* to infinity). We may likewise represent the probability that the operator's *actual* choice of leachate control, $\hat{L}$, fails to ward off charges of negligence and liability as $R_L(\hat{L}) = \int_{\hat{L}}^{\infty} f_L(L)dL$. This being the case, we may write the risk-neutral landfill operator's economic problem as one of choosing L and M to maximize the following expected profit function:[8]

$$E\Pi(p, w_M, w_L) = pQ(L,M) - w_M M - w_L L - R_L(L)A(L,M) - R_M(M)A(L,M) \qquad (1)$$

The corresponding first-order conditions, when rearranged and when suppressing some notation for clarity, are:

$$p\frac{\partial Q}{\partial L} - \left[\frac{dR_L}{dL}A + \frac{\partial A}{\partial L}\{R_L(L) + R_M(M)\}\right] = w_L \qquad (2)$$

$$p\frac{\partial Q}{\partial M} - \left[\frac{dR_M}{dM}A + \frac{\partial A}{\partial M}\{R_L(L) + R_M(M)\}\right] = w_M \qquad (3)$$

The interpretation of (2) and (3) is that the profit maximizing firm seeks to hire each input such that its marginal revenue product equals its expected marginal cost. In this case of facing an uncertain negligence rule, the marginal revenue products pick up an additional positive term, in comparison to a case in which the landfill operator faces a strict liability policy. Note that since $\frac{dR_L}{dL}, \frac{dR_M}{dM}, \frac{\partial A}{\partial L}, \frac{\partial A}{\partial M} < 0$, each square-bracketed

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[8] Note that our specification has much in common with the approach favored by Beavis and Dobbs (1987, 119, Eq. 15).

term in (2) and (3) is negative. Combining these facts with the negative signs in front of each square-bracketed term confirms that each input's marginal revenue product is increased by the extent to which it wards off culpable negligence.

As Bartsch (1997, 142) and others have shown in other law and economics contexts, it is useful to think in our MSW context of the two (bracketed and unbracketed) pieces of each marginal revenue product (MRP) function as the contributions each input makes to the management of "good" waste and "bad" waste, respectively. That is, each unit of waste Q admitted to the landfill has uncertain quality. There is a relatively benign element that requires input to manage but which has a negligible effect upon expected damages. The first term in each MRP function reflects the value of the input toward the management of this relatively benign waste. The second term in each MRP function represents the value of each input in reducing the expected damages from the troublesome elements of waste inadvertently or intentionally sent to the MSW landfill by households and firms. If the legal standards are certain and are set at the socially efficient rates, the M^* and L^* implicitly defined by equations (2) and (3) represent both the privately and socially optimal rates of input utilization. If the disposal facility operator is not culpable for $A(L,M)$, and therefore ignores $\frac{\partial A}{\partial M}$ and $\frac{\partial A}{\partial L}$, the privately optimal input usage will be less than the socially optimal input usage. We must note that the positive flows of pollution from the landfill at the social optimum define the socially optimal environmental standards to which the firm should be held. As Viscusi and Hamilton (1999) and others have shown, statutory pollution standards are not necessarily established at economically efficient levels (that is, where the marginal social benefit of abating health risks from the landfill just equal the marginal social cost of abatement). We return to this aspect of the model later when we discuss the possibility that current environmental standards are not set at these socially efficient levels.

3. Discussion of Results and Directions for Future Research

Several extensions of this baseline model suggest themselves. An examination of Equation (1) and the first-order conditions (2) and (3) shows that there are three areas of comparative statics to consider. They are (a) changes in the legal framework (or the firm's perceptions of the legal framework), as expressed by $R_L(L)$ and $R_M(M)$; (b) changes in the price of waste quality monitoring M; and (c) changes in the price of leachate control L.

3.1. Changes in the Legal Framework, or Perceptions Thereof

With respect to changes in the actual or perceived legal framework, Kolstad *et al.* (1990) showed that when faced with ex ante regulation and a negligence rule—as we have here in this MSW landfill context—harming parties may not implement the socially efficient rate of precaution. Building upon Kolstad *et al.* (1990), and inspired by Doremus (1999), Dyar and Wagner (2003) considered how a harming party's private actions would be affected by an impression that the court looks relatively more favorably upon one abatement strategy versus another. Dyar and Wagner (2003) were especially interested in whether a wildlife manager's choice of certain inputs may provoke a court to ratchet upward its assessment of the manager's culpability for damages done by the species under its management (wolves). They showed that indeed this can have a countervailing effect upon the efficient selection of inputs, as firms should be expected to shy away from actions that may be interpreted as admissions of culpability. Bartsch (1997) and Hutchinson and van't Veld (2005) explore a related possibility in which some inputs that modulate environmental damages are observable to outside parties while other inputs are not; they show that the relative observability of the firm's precautionary efforts can cause the firm to choose socially inefficient combinations of such inputs.[9] In our MSW model that features multiple precautionary strategies, it may be the case that the court would view the landfill operator as more culpable for leachate control failures than for waste quality monitoring failures, given the relatively unobservable waste quality monitoring efforts by households and the consequent nonpoint nature of the waste received by landfills. If this is the case, the landfill manager could be expected to shade his or her management strategy to favor leachate control; such a strategy may not be socially efficient, however.

Another type of uncertainty to take into account is the evolution of environmental standards and the expectation that they will become stricter over time. Practices that were viewed approvingly in the past may tomorrow be viewed as negligent practice. For instance, as a result of the 1984 Hazardous and Solid Waste Amendments to RCRA, in 1990 the U.S. Environmental Protection Agency added 25 organic chemicals to the list of regulated toxic wastes and mandated replacement of the Extraction Procedure Toxicity Test (EP) with the Toxicity Characteristic Leaching Procedure (TCLP).[10] One could expect that future regulations will expand in scope to deal with waste constituents not presently addressed.

3.2. Changes in the Price of Waste Quality Monitoring *M*

Thus far we have assumed that monitoring of waste quality can only be accomplished at the gates of the landfill. In reality, of course, households that send waste for disposal exercise some amount of monitoring. Depending upon the incentive structure households face—and depending upon the information households have regarding recycling, MSW and hazardous wastes—households could exercise more waste quality monitoring than is presently undertaken. Turning now to consideration (b) noted above, our framework could accommodate the addition of the household sector (such as presented by Choe and Fraser (1999)). In such a model, an improvement in household monitoring of waste quality can yield Pareto-improving trades between households and landfill operators. Specifically, a Pareto-improvement can occur if households obtain a decrease in the legal waste disposal cost and the waste disposal operator obtains verifiable waste quality monitoring from households more cheaply than its own waste quality monitoring cost. Millock *et al.* (2002) propose a monitoring mechanism for counteracting nonpoint source pollution that in our view could be useful in this waste quality monitoring situation. Millock *et al.* (2002) emphasize that the efficiency of the mechanism requires nonpoint source polluters to *volunteer* to be monitored, and to pay for their own monitoring equipment. This could occur here if the discounted total cost of

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[9] Hutchinson and van't Veld (2005) introduce the additional innovation that unobservable efforts modulate the probability of an accident occurring while the observable efforts modulate the size of damage, should an accident occur. Specifying the accident function *A* in our model in this manner could well enable additional useful insights for MSW management.

[10] See U.S.DOE (2000).

household compliance over some period of time is less than the discounted stream of disposal fee savings (i.e., this defines each household's incentive-compatibility constraint). Likewise, the landfill operator's per-unit revenue p would fall by some increment while the waste quality monitoring cost w_M would fall by some increment; if the landfill operator's profit rises, the operator's incentive-compatibility constraint is also met. We can imagine that households may very well have lower marginal costs for monitoring waste quality than does the landfill operator. This is reasonable, given the scale difference in monitoring one item at a time in one's kitchen versus sorting through truckloads of refuse at the gates of the landfill. In order for the above voluntary program to take shape, technologies must exist that enable households to verifiably monitor waste quality. A relatively simple example of "verifiable monitoring equipment" would be clear plastic bags coupled with random auditing of the contents of such bags by the landfill operator as the bags are picked up at the household; Kasperson (2000) describes such a mechanism that is currently employed in Nantucket, Massachusetts.

3.3. Changes in the Price of Leachate Control *L*

One interesting aspect of industrial organization is the extent to which firms will adopt improved technologies as they become available. The evidence is that some technologies are not adopted as quickly as one would have forecasted. Even though there may exist opportunities to reduce marginal costs of production via new technology, a significant motivation for technology adoption delay regards the various forms of fixed costs the firm faces when choosing to adopt. One form of fixed cost would be a licensing fee that the firm must pay in order to employ the new technology. Another form of fixed cost could be refitting costs necessary in order to make initial design features mesh with the new technology. In either case, adopting the improved technology involves a reduction in the firm's variable costs and an increase in the firm's fixed costs.

Our model can be generalized to take this aspect of MSW into account. The disposal operator's leachate control cost $w_L L$ in Equation (1) can be replaced with the total cost function $F_L + w'_L L$, where F_L is the fixed cost of obtaining the new leachate control technology and $w'_L < w_L$. The landfill operator compares the fixed cost with the marginal cost savings; if the fixed cost is relatively high, technology adoption is postponed, even though the new technology is clearly more efficient and cheaper to utilize on a per-unit basis. Assuming functional forms and model parameters, one could solve for the threshold fixed cost F_L that the landfill manager would be willing to pay for any new leachate control technology adoption.

Interestingly, note that in the context of our model that any Pareto-improvement accomplished by greater household monitoring of waste quality (described in the previous section of our paper) could be used to overcome the fixed costs described in this section. Thinking about these two features of the landfill manager's problem in a dual manner enables us to see how difficulties with cooperation on waste quality monitoring can have the effect of restricting the implementation of new technologies. This insight from our model is consistent with Stranlund's (1997) argument regarding the utilization of public aid to motivate greater environmental compliance by firms.

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