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Decision Support

Flexible waste management under uncertainty

Luca Di Corato [a,*], Natalia Montinari [b,c]

[a] Department of Economics, Swedish University of Agricultural Sciences, Box 7013, Johan Brauners väg 3, Uppsala 75007, Sweden
[b] Strategic Interaction Group, Max Planck Institute of Economics, Jena, Kahlaische Strasse 10, 07745, Germany
[c] Department of Economics, Lund University, Box 7082, Lund 22007, Sweden

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ABSTRACT

In this paper, we use stochastic dynamic programming to model the choice of a municipality which has to design an optimal waste management program under uncertainty about the price of recyclables in the secondary market. The municipality can, by undertaking an irreversible investment, adopt a flexible program which integrates the existing landfill strategy with recycling, keeping the option to switch back to landfilling, if profitable. We determine the optimal share of waste to be recycled and the optimal timing for the investment in such a flexible program. We find that adopting a flexible program rather than a non-flexible one, the municipality: (i) invests in recycling capacity under circumstances where it would not do so otherwise; (ii) invests earlier; and (iii) benefits from a higher expected net present value.

1. Introduction

The design of effective solid waste management strategies is a crucial issue for policy makers not only at the (inter)national level, where guidelines, targets, and strategies are set (US EPA, 2002; European Commission, 2010), but also at the local level, where waste is actually produced, collected, and treated.

In the last decades, the amount of municipal solid waste produced by industrialized societies has been increasing (Eurostat, 2011; EPA, 2011). This trend, together with growing attention on environmental pollution, human health, and resource recovery, has stimulated a wide debate on the strategies to be implemented to reduce the amount of waste produced and treat the waste collected in an effective and sustainable way (OECD, 2007; EC, 2008).[1] In particular, starting from the late 1970s, the US first, and later the EU, introduced a stricter regulation for the construction and operation of landfills[2] in order to promote recycling and incineration as alternative disposal methods (EEA, 2009; Kinnaman, 2006). Incinerators are expensive, however, and their effect on human health is controversial. As a consequence, citizens seem more willing to spend time sorting their waste for recycling than accepting the operation of an incinerator in their neighborhood (Giusti, 2009).[3] Thus, although their profitability is still debated, an increasing number of municipalities have introduced recycling programs (in order) to meet citizens' preferences (see, e.g., Kinnaman, 2006).

In this paper, we consider a municipality designing a new waste management program that integrates the preexistent landfilling with recycling as an alternative waste disposal method.[4] We assume that a price is paid to the municipality for recycled materials and that such a price follows a geometric Brownian motion. We also assume that recycling has higher operative costs than landfilling. The municipality can choose between a non-flexible and a flexible waste management program.

By investing in a non-flexible program (hereafter NFP), the municipality may partially or totally substitute landfilling with recycling. This decision is irreversible and implies that, irrespective of a change in the relative convenience of recycling with respect to landfilling, the purchased recycling capacity must always be fully used.

In contrast, by investing in a flexible program (hereafter FP), the municipality purchases recycling capacity but keeps the option to fully use the preexisting landfilling capacity whenever changes in the relative convenience make it profitable. By combining the

* Corresponding author. Tel.: +46 (0)18671758; fax: +46 (0)18673502.
E-mail addresses: luca.di.corato@slu.se (L. Di Corato), natalia.montinari@nek.lu.se (N. Montinari).

[1] Municipal solid waste can be disposed by essentially adopting four methods: landfilling, incineration, recycling, and composting. See Goddard (1995) for a discussion of these disposal methods.

[2] In the U.S., after the Resource Conservation and Recovery Act of 1976 providing federal guidelines for the operation of landfills, their number (of landfills) has significantly reduced (Kinnaman and Fullerton, 2000). In the EU, after the Directive 1999/31/EC, which fixed targets for the reduction of biodegradable municipal waste going to landfills, the quantity of waste landfilled has reduced from 68% in 1995 to 33% in 2009 (Eurostat, 2011).

[3] Even though landfilling has strongly reduced, it is still adopted as a residual method together with recycling. As for the EU countries, in 2009 shares of waste landfilled of 14% and 17% were reported by Norway and Luxembourg, respectively. France, Italy, Finland, and the UK reported shares in the range of 32–50%. Among the EU-12 member states, the highest shares in 2008 were reported by Greece (81%), Portugal (62%), Ireland (62%), and Spain (52%), (Eurostat, 2011).

[4] Note that considering incineration as an alternative disposal method would make no difference in our analysis.

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two disposal methods, the FP guarantees a certain degree of operational flexibility, which may be beneficial under uncertainty about the price for recycled materials. This flexibility, however, comes at a cost. More specifically, we assume that the FP setup requires a sunk investment cost which depends on the chosen recycling capacity, i.e., the chosen degree of flexibility.

The problem faced by the municipality is twofold, and we solve it in two steps. First, the municipality must determine the recycling capacity, taking into account its uncertain profitability and the option of landfilling whenever recycling becomes unprofitable. Second, the municipality must set the investment time threshold, triggering the adoption of the optimally designed FP.

Having designed the optimal FP, we compare the investment in such a program with the investment in an NFP where, as stated above, the option to switch back to landfilling is not available. We find that adopting an FP rather than an NFP gives the municipality two main advantages. First, we show that the municipality may be willing to invest in recycling capacity under circumstances where investment in an NFP would not be undertaken. Second, we show that an investment in an FP may be undertaken earlier than one in an NFP and also provide a higher expected net present value (hereafter NPV).

The intuition behind these results is that the municipality that adopts the FP, by holding the option to switch back to landfilling, may, if needed, adjust the waste disposal operations and so optimally hedge against uncertainty about the profit from recycling. This hedging policy may prove particularly valuable when net revenues from recycling remain low and/or are volatile. In contrast, when net revenues are high and stable, the exercise of the option to switch back to landfilling becomes unlikely and the value of the hedging policy vanishes. Hence, the municipality may, by investing in an FP that guarantees operational flexibility, start recycling when the relative net revenues are too low to justify the investment in an NFP instead. Moreover, this may also occur with a higher payoff in terms of NPV.

Several papers have studied the design of waste management programs in the presence of alternative disposal strategies. In a deterministic frame, some pioneer investigations have been conducted by Huhtala (1997) and Highfill and McAsey (1997, 2001b). Huhtala uses an optimal control model to determine the optimal recycling rate for municipal solid waste. He shows that landfilling is more costly than other disposal alternatives, once the monetary costs of recycling, the social costs of landfilling, and consumers' environmental preferences have been accounted for. Under endogenous waste stream, Highfill and McAsey (1997) study a municipality which must choose between using an (existing and exhaustible) landfill or recycling at higher cost. The authors show that a municipality that recycles will always simultaneously use its landfill. This will last for some time when since landfill use is declining while recycling is increasing. Highfill and McAsey (2001b) extend previous works by including in their analysis a growing income stream. Income is optimally split between consumption and expenditures for waste disposal. Waste disposal must be optimally allocated between recycling, which is considered (as) a backstop technology, and landfilling. The authors show that landfill capacity and initial income have a considerable impact on the optimal recycling program and recommend considering these factors when designing a waste management program. Recently, Lavee et al. (2009) have analyzed the choice of a municipality that can switch forward and backward between landfilling and recycling but cannot combine them. The choice is determined by taking into account a sunk switching cost and uncertainty about prices for recycled materials. Their main finding is that recycling, due to its uncertain profitability, may not be adopted even when it is less expensive than landfilling. Hence, their analysis advises policy intervention in favor of price stabilization as a tool for enhancing recycling. Finally, it is worth noticing that an alternative approach for tackling waste management decision problems under uncertainty and multiplicity of objectives is represented by fuzzy mathematical programming[5] (see Zadeh, 1965). As shown by,[6] for instance, Koo et al. (1991) and Chang and Wang (1996a, 1997), the practical implementation of this approach to real-world cases may provide valuable support to policy makers when comparing waste disposal alternatives characterized by different economic and environmental impacts.

Our paper contributes to the literature adopting a stochastic programming approach in two respects. First, under uncertainty about profit from recycling, we study the optimal design of a program where the simultaneous combination of two disposal strategies, i.e., landfilling and recycling, is feasible. Second, we consider how the presence of landfilling as a preexisting and residual method affects (i) the degree of operational flexibility in the waste management program and (ii) the timing of its adoption.[7]

The remainder of the paper is organized as follows. In Section 2, we present the basic setup of our model. In Section 3, we determine the optimal recycling capacity. In Section 4, we study investment value and timing. In Section 5, we use some numerical examples to illustrate our findings. Section 6 concludes. All proofs are available in Appendix A.

2. The basic setup

Consider a municipality currently using landfilling as a waste disposal method and contemplating the opportunity of integrating it with recycling. Following Highfill and McAsey (2001b), we restrict our analysis to the recycling programs offered by the municipality and do not consider any recycling activity undertaken by individuals on their own initiative. By integrating these two disposal methods, the collected waste may be partially or totally recycled, with the municipality still holding the option of landfilling.[8] Both disposal methods are costly. Denote by c^L and c^R the operating costs of landfilling[9] and recycling waste, respectively. We assume that $c^R - c^L > 0$.[10] Compared to landfilling, recycling involves additional costs for collection, selection of different types of waste

[5] The main difference between fuzzy and stochastic programming is given by the assumption that uncertain information in waste management processes may not be fully represented by using traditional probability theory.

[6] See also Lee et al. (1991) and Chang et al. (1996b).

[7] In the real option literature, the value of operational flexibility has been deeply investigated. See, e.g., Kulatilaka (1988, 1993),Triantis and Hodder (1990), He and Pindyck (1992),Fontes (2008), Li and Wang (2010), and Benaroch et al. (2012). In this literature, our paper belongs to a recent family of papers studying investment in flexible systems where the degree of flexibility is optimally chosen. See, e.g., Di Corato and Moretto (2011) on investment in a biogas digester under flexible diet composition and Moretto and Rossini (2012) on partial outsourcing and flexible vertical arrangements.

[8] In our paper, we implicitly assume that the landfill space capacity is not binding over the considered time horizon. The reason for this is that we want to abstract from capacity considerations and focus on the benefit of implementing, through a combination of waste disposal technologies, operational hedging policies against uncertain recycling profit. Note that at no loss our frame is sufficiently general to consider an alternative technology such as incineration.

[9] It is worth noticing that the cost of landfilling, c^L, may also include the cost associated to externalities generated by the landfill when still in use (see Huhtala, 1997; Kinnaman, 2006). Note also that potential external effects (e.g. damages due to methane gas explosions, toxic leakages, etc.) may also be associated to the landfill once abandoned. In our decision problem, however, we consider negligible the impact of the abandonment decision in that: (a) we assume that landfill capacity is not binding over a sufficiently long time period. This would in fact imply that abandonment would likely occur far in the future and consequently, due to the effect of discounting, shut-down costs and the benefit from postponing abandonment (by introducing recycling) would have limited impact on the investment decision and (b) in modern lined landfills, due to stricter regulations, the probability of accidents and, consequently, expected damages have sensibly lowered (see Eshet et al., 2006).

[10] This assumption is in line with Kinnaman (2006, pp. 220), reporting that "*On a per-ton basis, recycling is roughly twice as costly as landfill disposal.*".