Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Incentivizing secondary raw material markets for sustainable waste management

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ARTICLE INFO

Article history:
Received 19 January 2017
Revised 18 April 2017
Accepted 23 May 2017
Available online xxxx

Keywords:
Landfill
Municipal solid waste
Secondary raw material
Sustainable waste management
Waste management

ABSTRACT

Notwithstanding several policy initiatives in many countries over a number of years, there remains a general sense that too much municipal solid waste is generated and that too much of the waste that is generated is landfilled. There is an emerging consensus that a sustainable approach to waste management requires further development of secondary raw material markets. The purpose of this paper is to propose a theoretical economic model that focuses upon this stage of a sustainable waste management program and explores policy options that could motivate efficiency in secondary raw material markets. In particular, we show how firm profit and social welfare optimizing objectives can be reconciled in a two-product market of waste management processes: landfilling and material reclamation. Our results provide theoretical support for building out recent Circular Economy initiatives as well as for the relatively recent emergence of landfill mining as a means for procuring secondary raw materials.

1. Introduction and literature review

Notwithstanding several policy initiatives in many countries over a number of years, there is still a general sense that too much municipal solid waste is generated and that too much of the waste that is generated is landfilled.[1] Both engineers and economists have theoretically modeled and empirically estimated various aspects of material usage from cradle-to-grave stages. Indeed, there is an emerging consensus that a sustainable approach to waste management requires further development of landfill diversion strategies and of secondary raw material (SRM) markets. One manifestation of this consensus is the EEA's (2016, 17) emphasis upon promoting a Circular Economy in Europe, including waste-as-a-resource business models.

Amongst the academic literature on this topic, several previous papers address the development of policies designed to reduce the creation of waste to socially optimal rates. Those strategies include appropriate taxes, subsidies, regulations, and legal liability on the extraction of virgin materials, household and firm-level recycling efforts, and pricing of waste disposal on a full (that is, social) marginal cost basis. See, for instance, Fullerton and Kinnaman (1996), Palmer et al. (1997), Walls and Palmer (2001), Massarutto (2007), Longo and Wagner (2011), and Nicolli and Mazzanti (2013) on the economic theory, practice, and results along these lines. There is relatively less—but growing—attention in the literature to incentivizing the development and management of SRM markets within sustainable waste management systems. That is, once materials arrive at the landfill, how should they be optimally managed? Questions to answer include whether and how waste should be landfilled as opposed to being more actively managed; whether energy should be captured at the landfill as part of active management; whether waste should be incinerated or otherwise treated to generate energy and/or to alter its physical state for volume reduction or materials mining purposes; whether landfilled waste should be mined for SRMs at a future point in time; and the extent to which the waste should be sorted prior to treatment in order to achieve desirable/marketable properties of SRMs like compost or raw critical materials.[2] The economics literature related to these questions includes Keeler and Renkow (1994), Dijkgraaf and Vollebergh (2004), Wagner (2011), and Massarutto (2015).

Finally, there are a few papers in the literature that address economic aspects of market incompleteness in the waste management context. Calcott and Walls (2005) focus upon motivating upstream green design of products to improve recyclability of waste residuals downstream via consumer sorting. Hence, the market imperfec-

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[1] See, e.g., Allen (2001), Mazzanti and Zoboli (2009), EEA (2009), and Brunner and Rechberger (2015).

[2] There is another branch of literature that examines questions of optimal landfill siting processes; the optimal number of landfills; and the optimal depletion of landfills. Pioneering references in this literature include Ready and Ready (1995) and Gaudet et al. (2001).

http://dx.doi.org/10.1016/j.wasman.2017.05.036
0956-053X/

tion of their focus is the imperfect sorting of recyclables by consumers/households and how policy instruments can be bundled in order to work around the resulting gaps in recyclable materials markets.[3] Nicolli et al. (2012), citing Calcott and Walls (2005), focus on how technological change can reduce "…information asymmetries by, for instance, facilitating market participants' assessment of the characteristics of different materials." They discuss the merits of promoting research and development in this market, and stress the development of intellectual property in particular as a way of addressing resulting missing or weak markets for waste residuals. Massarutto (2014), also citing Calcott and Walls (2005), describes how the extended producer responsibility principle has been effective for correcting market imperfections in waste management, including the formation of SRM markets. Our paper contributes to this stream of literature by developing a theoretical model within which the important conceptual and empirical contributions of Massarutto (2014), Nicolli et al. (2012), Calcott and Walls (2005), and others can be arranged for additional analysis. In particular, our model provides some economic theory justification for policymakers helping to build out SRM markets, in light of the market incompleteness/imperfection that these authors describe. The key take-away from our analysis is that a bit of regulatory flexibility on SRM utilization, such as that called for recently by Johansson et al. (2017, 425–26) in the context of advanced landfill mining, can raise social welfare while preserving firm profit (necessary for incentive-compatibility).

Our paper is organized as follows. Section 2 presents our baseline economic model, wherein a private waste management firm seeks to maximize profit from receiving some waste types that can be landfilled but other waste types that can be routed to SRM markets. The private profit optimization is compared to social welfare maximization; the baseline model concludes with isosurplus and isoprofit function analysis that enables both an analytical and a visual framework in which to investigate competing policy approaches for ameliorating SRM market incompleteness in Section 3. Our conclusions and directions for future research follow in Section 4.

2. The baseline model

There are two general approaches one can take in building a theoretical economic model of sustainable waste management. While Wagner (2011), for instance, sets forth an *input* selection model—managers choose units of landfill monitoring, landfill engineering, and the landfill's natural endowment—Keeler and Renkow (1994) present an *output* selection model, wherein the total flow of waste generated is optimally allocated to recycling, landfilling, and incineration. In what follows, we set up an output selection model so that we can focus upon the interaction between selling landfill services and the possibilities for selling SRMs such as fly/bottom ash via waste-to-energy engineering for use in secondary construction materials, leachate derivatives (e.g. compost), and rare earth minerals that can be retrieved via landfill mining operations. Our abstract model poses landfills as receiving a flow of waste W and offering two distinct services. On one hand, landfills sell space as a sanitary location for residuals with no known alternative uses. Let W_L denote the flow of this type of service of landfilling waste products so as to modulate its impact upon ambient environmental quality. On the other hand, the landfills have the opportunity to identify some of the waste stream W to process and sell to SRM markets. Let W_M denote the flow of this different type of service. In this formulation, $W = W_L + W_M$: the rate at which the firm can sell waste residuals into the SRM markets will be constrained by the rate of waste that is landfilled instead. We envision two parallel processes occurring within a multi-product firm that receives two streams of raw material of rubbish and services those streams of rubbish to either be safely landfilled with no further use in mind or to be processed into SRMs that have further value. While physical units of municipal solid waste are exchanging hands (sometimes across state lines), the economics and legal literatures emphasize that the "article of commerce" in waste management markets is not the municipal solid waste itself (which is indeed a "bad" rather than a "good") but rather waste management *service* (either units of airspace in a sanitary landfill or units of waste processed into new goods that have value in aftermarkets).[4]

Before we formalize the waste management firm's profit maximization problem, we first consider the social planner's problem in this context. The social planner's problem in each time period is to manage these two waste management services to maximize the net social benefits:

$$S = B(W_L, W_M) - C_P(W_L) - C_P(W_M) - C_E(W_L) - C_E(W_M) \tag{1}$$

where benefits B accrue from both effectively landfilling waste W_L and mining residuals W_M for SRMs. In other words, while consumers do not benefit from units of waste, consumers do benefit from the sanitary disposal of household waste for which there is no other use, and from the reformulation of some household waste into other useful purposes (like compost produced by landfills for sale as SRM). C_P and C_E denote private and external costs related to the provision of each type of service. The first-order conditions are straightforward:

$$\frac{\partial S}{\partial W_L} = \frac{\partial B}{\partial W_L} - \frac{\partial C_P}{\partial W_L} - \frac{\partial C_E}{\partial W_L} \text{ or choose } W_L^* \text{ where } \frac{\partial B}{\partial W_L} = \frac{\partial C_P}{\partial W_L} + \frac{\partial C_E}{\partial W_L} \tag{2}$$

$$\frac{\partial S}{\partial W_M} = \frac{\partial B}{\partial W_M} - \frac{\partial C_P}{\partial W_M} - \frac{\partial C_E}{\partial W_M} \text{ or choose } W_M^* \text{ where } \frac{\partial B}{\partial W_M} = \frac{\partial C_P}{\partial W_M} + \frac{\partial C_E}{\partial W_M} \tag{3}$$

The first-best outcome involves managing and utilizing waste residuals so that their respective external costs are taken into account. Also, in the first-best outcome, waste residuals are not all necessarily landfilled; some may be allocated back into the economy for further use in SRM markets that in a first-best world are complete. Since such markets heretofore do not appear to be complete, we draw upon this baseline model in what follows to explore some of the consequences of market incompleteness and some possible remedies. To facilitate doing so, we consider the private firm's profit maximization problem first in an abstract world in which there are no regulations on sanitary landfilling or reformulation of waste residuals for SRM markets. There are two basic changes to the social surplus maximization in (1). First, the social benefit functions are replaced by total revenue functions, the struc-

[3] By imperfect sorting, we are referring to situations in which one part of a consumer product at end-of-life (such as a computer printer toner cartridge or packing materials around fragile electronic equipment) has SRM use/value but another part does not, such that sorting may not occur and the entire product may be inefficiently landfilled.

[4] See, for instance, Gaudet et al. (2001, 1149) and Longo and Wagner (2011, 149). Note that our set-up is also inspired by the multi-product frameworks in Liu and Helfand (2009, 757–759) and Holland et al. (2009, 111). Liu and Helfand feature one firm that produces both conventional cars and alternative-fuel cars with additively separable costs assumed for simplicity, while Holland et al. feature one firm that produces both high-carbon fuel and low-carbon fuel with additively separable costs. This assumption means that the cost of producing each product/service depends only on the quantity of that product/service produced and not upon the quantity of the other product/service produced, i. e., that there are not economies of scope in production. As Holland et al. (2009, 111, fn. 21) note, this assumption can be relaxed at the cost of more notation.

Please cite this article in press as: Schreck, M., Wagner, J. Incentivizing secondary raw material markets for sustainable waste management. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.05.036