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Recycling, Producer Responsibility and Centralized Waste Management

by

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Abstract:

This paper examines a Waste Management Organisation's (WMO) pricing options to implement the Pareto-efficient allocation in an economy where materials are first extracted, then used for producing a consumption good and finally recycled or landfilled. The WMO is established by the producers who are responsible for the proper disposal of consumption waste which consists of a mix of materials. That mix forms an aspect of the producers' (green) product design and affects the productivity of secondary material generation. The most favorable pricing strategies are shown to comprise (positive or negative) fees on producers based on residuals and material inputs.

JEL-code: H21, Q28

Keywords: recycling, waste, product design, producer responsibility

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1 Introduction

Recycling is an important means to economize on the use of primary materials and to reduce the flow of waste to landfills. But the rates of recycling turned out to be rather low and both theoretical considerations and empirical evidence suggested that markets lack incentives to allocate the waste flows efficiently. As a remedy, economists advocated institutional arrangements to bridge the gap of missing markets by appropriate price signals (charges, fees, administrative prices). It was understood, however, that the job cannot be done just by putting a single price tag on the total flow of waste when that waste consists of a mix of various waste materials. Recycling a material mix requires to recover each type of waste material which is - as we will assume in the present paper - the more expensive the smaller its share in the total mix.

Notwithstanding the consumers' increasing waste separation efforts household waste flows consist usually of mixed waste materials. Obvious examples are residues of durable consumption goods at the end of their useful economic life. Such residues consist of several different types of material whose composition is determined when the product is designed. Another case in point is packaging waste. Consumption goods are traded in a great variety of wrappings and/or containers made up of different materials. It is again up to the producer's package design which material or which material mix is used for packaging.

The present paper aims at reconsidering the economists' favorite idea of guiding household waste flows through prices by explicitly accounting for mixed materials waste. In practice, solid household waste used to be collected by centralized (municipal) waste agencies and the cost of these services was not covered, in general, by charging quantity-related or material-related rates to the households.[1] In fact, charging households for both the total quantity and the materials mix of their waste can hardly be considered a practical option, since the pertinent transaction costs are likely to be extremely high.[2]

Fortunately there is a way to avoid household charges altogether without giving up on price signals by adopting the principle of producer responsibility. Under this property rights arrangement consumers acquire nothing but the right to consume when 'buying' the consumption good, while the producer of the good is still the owner of the residuals left over

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[1] For example, in the U.K. households are not charged at all and in Germany they usually pay a fixed charge per person (for non-packaging waste).

[2] It may not be unreasonably costly to charge households uniform rates per unit of their total waste. But even this simplest scheme of quantity-related charges is rarely applied in practice owing to its strong incentives for illegal dumping. See e.g. Fullerton and Kinnaman (1995). Note also that even if illegal dumping is ruled out, uniform charges would be inadequate, as shown in proposition 3 below.

after consumption and hence is responsible for the future 'fate' of those residuals. It is interesting to observe that the principles of both household and producer responsibility conform to the 'polluter-pays principle' as established in the framework directive on waste of the European Community[3] which rules (among other things) that the cost of waste disposal [and recovery] must be borne by the holder who passes it to the waste collector [i.e. the household] *and/or* by the producer of the product which generated the waste.

The straightforward interpretation of the principle of producer responsibility is that the producer takes back the residuals for further (orderly) waste processing under her supervision. For some durable consumption goods, especially high-volume and brand products such as automobiles, this appears to be a viable low-cost procedure which is briefly discussed in section 4. However, for the bulk of consumption residuals, such as packaging waste, direct take back would be too expensive. But in these cases producer responsibility may still be institutionalized along the lines the so-called 'Green Dot' system of packaging waste processing works in Germany: About ten years ago, German producers of consumption goods, the packaging industry and/or the retail traders were threatened by a pending national legislation of mandatory take back. They responded to the legislator by promising to establish a private, centralized and all-encompassing Waste Management Organization (WMO) to avoid the expensive alternative of 'decentralized' direct take back. In fact, this arrangement entered the new German waste legislation[4] combined with some regulatory constraints and the (legal!) threat to impose mandatory direct take back unless the private WMO (called *Duales System Deutschland*) meets some minimum standards in service quality and participation.

In recent years nine other European countries reorganized their packaging waste sector along similar lines as the German 'Green Dot'. This institutional arrangement is based on contracts in which the producers delegate their responsibility for processing their residuals to the WMO. In return, the WMO is entitled to charge producers and recyclers with (positive or negative) administrative prices or fees that are contractually agreed upon.

Given the economists' conviction that efficient waste processing and recycling is best achieved by setting appropriate price incentives the pricing policy of the WMO is of utmost interest. In fact, the principal aim of the present paper is to investigate the WMO's pricing options and to assess the comparative performance of alternative pricing policies with the

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[3] Article 15 of the Directive 75/442/EEC of the Council about waste of 15.07.1975 (Abl. EC No. L 194 of 25.7.1975) as amended by the Directive 91/156/EEC (Abl. EC No. L 78 of 26.3.1991).

main emphasis on allocative efficiency of waste processing including both efficient product design and efficient recycling.

Recycling has been extensively studied since the 70s' in dynamic and static analysis. But it was only in recent years that the interdependence between product design and recycling was focused, e.g. by Holm-Müller (1997) and Fullerton and Wu (1998), who model 'recyclability' or the 'ease of separation or disassembly' as an aspect of product design. If improving 'recyclability' is costly for the producer but reduces recycling costs, at the same time, an issue of green product design arises. Fullerton and Wu (1998) show in a static general equilibrium model how the efficient 'recyclability' is achieved by suitable taxes and subsidies, if recycling is costless and 'recyclability' can be subsidized. Calcott and Walls (2000) extend that model by assuming costly recycling and investigate second-best policies needed when 'recyclability' cannot be used as a basis for subsidization. A different approach to the interdependence of product design and recycling (and waste treatment) is suggested by Eichner and Pethig (2000). In their model, a consumption good is made up of two different materials whose mix is an aspect of product design.[5] One of theses materials is recycled and the recycling costs are the smaller, the greater the 'material content, i.e. the share of this material per unit of (spent) output.

Eichner and Pethig (1999a) study how different systems of (possibly fictitious) markets bring about the efficient product design. In Eichner and Pethig (2000) various scenarios of failing markets are investigated along with efficiency restoring tax subsidy schemes all involve charging households for both the total quantity and the material mix of their waste (household responsibility). The present paper employs a simplified version of the model in Eichner and Pethig (2000) and focusses on waste management options that avoid charging households altogether through the arrangement of producer responsibility described above. It differs from Eichner and Pethig (2000) also in dealing with the *feasibility* of pricing policies by showing that the decentralization of Pareto-efficient allocations by prices does not necessarily constitute a competitive equilibrium supported by some tax-subsidy scheme. Moreover, our attention is restricted to the failure of markets to bring about the efficient product design and to a waste management organisation's options to use (combinations of) administrative prices and fees that replace the missing markets.

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[4] Strictly speaking through the German Packaging Ordinance 1991.

[5] In Eichner and Pethig (1999a) products also consist of a material mix, but the focus is not on recycling but rather on waste treatment whose cost is assumed to depend on the material content of consumption residuals.

Section 2 introduces the model and section 3 characterizes an efficient allocation. Section 4 demonstrates the efficiency of the direct take back rule with integrated production and recycling, and zero collection costs. In approximation, this case may be considered realistic for durable high-volume brand products. The remaining paper presupposes that the cost of direct take back is prohibitive and hence focuses on centralized waste management by a WMO. A gallery of pricing policies for the WMO is suggested and discussed in section 5. Four policies are identified whose pertaining administrative prices mimick prices on potential but non-existent markets, whereas another four policies consist of fees that direct waste flows by different price signals on the demand and supply side of those flows. The former set of policies is scrutinized in section 6 and the latter in section 7. Section 8 summarizes the comparative performance of all policies and concludes.

2 The model

The complete model is given by:[6]

$$u \le U\left(\underset{-}{\ell^s}, \underset{+}{x^d}\right) \qquad \text{utility of the representative consumer} \tag{A1}$$

$$x^s = X\left(\underset{+}{\ell_x^d}, \underset{+}{m^d}\right) \qquad \text{production of the (only) consumption good} \tag{A2}$$

$$v^s = V\left(\underset{+}{\ell_v^d}\right) \qquad \text{primary material extraction} \tag{A3}$$

$$r^s = R\left(\underset{+}{\ell_r^d}, \underset{+}{q^d}, \underset{+}{z^d}\right) \qquad \text{recycling of material from residuals} \tag{A4}$$

$$\ell_f^d = C\left(\underset{+}{f^d}\right) \qquad \text{landfilling costs of recycling waste} \tag{A5}$$

$$q^s := \frac{m^d}{x^s} \qquad \text{material content of the consumption good} \tag{A6}$$

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[6] Upper-case letters are reserved to denote functions and subscript attached to them indicate first derivatives. A plus or minus sign underneath an argument of a function denotes the sign of the respective partial derivative. The superscripts *d* and *s* reflect quantities demanded and supplied. They are consistently applied to all economic variables to indicate material flows (transactions) from extraction all the way down to final waste disposal.

$z^s = z^d$ all residuals become recycling input (A7)

$f^d = f^s \equiv z^d - r^s$ all recycling waste is landfilled (A8)

$x^s = x^d$, $x^s = z^s$, $\ell^s = \ell_x^d + \ell_r^d + \ell_f^d + \ell_v^d$,

$q^s = q^d$, $v^s + r^s = m^d$ resource constraints (A9)

The amount x^s of a single *consumption good*, called good *X*, is produced using *labor*, ℓ_x^d, and *two types of material* which are both embodied in the output. For simplicity, one of these materials is assumed to be costless and (therefore) not explicitly introduced into the formal model. The other type of material referred to as *material,* for short, is an explicit productive input in production function (A2); its quantity is m^d. Each unit of the consumption good is of constant weight but the production process (A2) allows for varying the material input mix as measured by the material-output ratio, q^s, defined in (A6) as the embodied (explicitly modeled) material input per unit of output.[7] q^s is denoted the *material content of good X.* It is an attribute of good *X* that is produced along with the quantity of good *X* without being itself an explicit argument of the production function[8] (A2). Our focus on material content is motivated by its positive impact on the productivity of recycling, (A4) (which we consider a realistic hypothesis (see below)). Hence the producer's choice of material content (product design) affects recycling, and therefore the material flow through the economy will be inefficient if the producer designs her product without accounting for the impact of material content on recycling.

After consumption, good *X* is turned into *consumption residuals*, *z.* With the help of labor, ℓ_r^d, material is reclaimed from these residuals according to technology (A4). The recycling process generates two outputs: *recovered material*, r^s, that is (re)used as a perfect substitute of primary material in producing good *X* (see (A9)), and *recycling waste*, $f^s = z^d - r^s$, (see (A8)) that is landfilled. In (A4) the marginal productivity of material content in recycling is assumed to be positive ($R_q > 0$) which is both plausible and called for by material balance

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[7] To rule out the case that good *X* does not contain any costless material we assume $q^s \in [0, \bar{q}]$ with $\bar{q} \in (0,1)$.

[8] In this important aspect our specification of product design differs from that suggested by Fullerton and Wu (1998) and Choe and Fraser (1999). In both papers a variable for 'recyclability' is introduced into the production function which is not specifically linked to materials flows.

considerations. To see this, suppose for a moment that $R_q = 0$ for all ℓ_r^d and for all z^d (as assumed e.g. by Pethig (1977), Miedema (1983), Dinan (1993) and Kohn (1995)) and consider some positive amounts ℓ_0, q_0 and z_0 of inputs that yield the recycled material $r_0 := R(\ell_0, q_0, z_0) > 0$. Clearly, material balance then implies $r_0 < m_0 := q_0 \cdot z_0$. Now keep the inputs ℓ_0 and z_0 constant, whereas q is successively reduced to zero. Then $m = q \cdot z_0$ shrinks to zero, too, but the output of the recycling activity is maintained at the level $r = r_0$, since $r = r_0 = R(\ell_0, q, z_0)$ for all $q < q_0$ in view of $R_q = 0$. With q tending to zero we will eventually have $r_0 > q \cdot z_0$ which obviously violates the law of material balance: it is infeasible to recover more material from residuals than is embodied in them.

According to the *utility* function (A1), the representative household consumes x^d of good X and has the endogenous labor supply ℓ^s. Labor is demanded to produce good X, $X_\ell > 0$, to extract primary material, $V_\ell > 0$, to recycle material, $R_\ell > 0$, and to landfill the waste generated in the recycling process, $1 / C_f > 0$.

In our economy, recycling and landfilling are mandatory activities of waste processing ((A7) (A8)) that are costlessly and effectively enforced. Thus illegal dumping[9] is excluded which serves primarily to simplify the analysis. But it does not appear to be unduely restrictive, either, since under the concept of producer responsibility to be studied here no quantity related fees are levied on consumers who are usually considered the hardest-to-monitor culprits of illegal dumping.

As outlined in the introduction we think of producer responsibility *in the strict sense* as a regime in which the producer still owns her product when it has turned into consumption residuals and hence has the legal obligation to take all those residuals back. Therefore the physical flow of material would not be, as usual, from extraction, (A3), via production, consumption and residuals collection to recycling and then either to landfilling or back to production but would rather lead from the consumers back to the producer and then to the recycler etc. However, as argued above for many types of consumption residuals such an arrangement would be too expensive so that *indirect* ways of applying the principle of producer responsibility promise to be more efficient. In any case, the important point about producer responsibility is that the producers are held responsible for delivering all residuals to the recycler. This is formalized by the constraint $x^s = z^s$ in (A9). As an implication, any price or charge on the supply of residuals, z^s, will be directly paid (or received) by the producer.

Bevor we proceed with the analysis of the economy (A1) - (A9) it is worthwile to briefly outline an *alternative* interpretation of the material flows involved. Recall that output x^s from (A2) is measured in weight which is assumed to be constant per unit of output x^s. Hence the weight x^s is proportional to the units of good *X*. In contrast suppose now there is only one type of material, namely the explicitly modeled one, and assume also that $x^s = X(\ell_x^d, m^d)$ measures *units* of output *X*, and that the production function *X* from (A2) is linear homogeneous. Then q^s from (A6) is clearly reinterpreted as the *weight per unit of output X*. Whenever the producer chooses a factor combination (ℓ_x^d, m^d) she uniquely determines the 'labor intensity' ℓ_x^d / m^d and, owing to linear homogenity, the weight per unit of output, q^s. To make the model (A1) - (A9) consistent with this reinterpretation two further modifications are necessary.

(i) The recycling function *R* from (A4) takes on the special form[10] $R(\ell_r^d, q^d, z^d) = \tilde{R}(\ell_r^d, q^d \cdot z^d)$.

(ii) The definition f^s in (A8) is replaced by $f^s \equiv q^d \cdot z^d - r^s$.

With these changes the variable *q* has a markedly different meaning which turns out to also reflect an important aspect of green product design.[11] However, to reduce the complexity of the analysis, we refrain, in what follows, from discussing the implications of our model when *q* is interpreted as weight per unit of output.

3 Allocative efficiency

In the absence of institution-specific costs we can investigate allocative efficiency in the model (A1) - (A9) by solving the Lagrangean:

$$L = U(\ell^s, x^d) + \lambda_{xx}\left[X(\ell_x^d, m^d) - x^s\right] + \lambda_v\left[V(\ell_v^d) - v^s\right] + \lambda_x(x^s - x^d) + \lambda_m(v^s + r^s - m^d) +$$

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[9] See e.g. Fullerton and Kinnaman (1995) and Choe and Frazer (1999).

[10] This form of recycling function is dealt with in proposition 6 below as special case.

$$+\lambda_\ell\left[\ell^s-\ell_x^d-\ell_r^d-\ell_v^d-C\left(f^d\right)\right]+\lambda_r\left[R\left(\ell_r^d,q^d,z^d\right)-r^s\right]+\lambda_f\left(f^d-z^d+r^s\right)+\lambda_{zx}\left(x^s-z^s\right)+$$

$$+\lambda_z\left(z^s-z^d\right)+\lambda_q\left(\frac{m^d}{x^s}-q^s\right)+\lambda_{qr}\left(q^s-q^d\right). \tag{1}$$

We restrict our analysis to the case of an interior solution in which the Lagrange multipliers λ_z and λ_{zx} turn out to be ambiguous in sign while all other multipliers are positive. The solution is characterized by the FOCs listed in the first column of table I in the appendix.

Proposition 1. *(Properties of an efficient allocation)*

(i) If the functions U and V are concave and C is convex, there is a class of concave recycling functions, R, for which a solution to (1) exists.

(ii) An efficient allocation of the economy (A1) - (A9) is characterized by

$$\frac{R_q}{R_\ell}=-\frac{xA}{X_\ell}>0 \qquad \textit{where } A:=\left(X_m-\frac{X_\ell}{V_\ell}\right), \tag{2}$$

$$-\frac{U_x}{U_\ell}=\frac{1}{X_\ell}-\frac{qA}{X_\ell}-\frac{R_z}{R_\ell}+C_f. \tag{3}$$

(iii) If the production function X is linear homogeneous and the function V is linear, the assumption $R_q > 0$ implies that the efficient material content is greater than it would be if R were independent of q.

The proof of proposition 1 and of all following propositions is provided in the appendix. Proposition 1i is rather technical - though not trivial in light of the results provided in the next sections. According to equation (2) the material content is efficient if the marginal benefit from material content in the recycling process (LHS) equals its marginal 'production cost' (RHS). Due to $R_q > 0$ the efficient material content creates a 'distortion' in production, since $A < 0$ implies $X_m V_\ell < X_\ell$, whereas in the absence of any recycling (as well as in case of $R_q = 0$) efficiency would require the equality of the direct (X_ℓ) and the indirect ($X_m V_\ell$) marginal productivity of labor.

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[11] Calcott and Walls (2000) investigate waste management issues not only regarding 'recyclability' but also with respect to the efficient choice of the weight per unit of output.

Equation (3) characterizes the efficient allocation of good *X*: The consumer's marginal willingness-to-pay (LHS) equals total marginal costs (RHS) consisting of post-consumption marginal net cost $(C_f - R_z / R_\ell)$ and marginal production cost $\left(1-qA\right)/X_\ell$. The former marginal cost, $(C_f - R_z / R_\ell)$, is the difference between marginal landfilling cost and marginal recycling benefit and hence is indeterminate in sign. Since $R_q > 0$ implies $A < 0$, the marginal production cost of good *X* in terms of labor, $\left(1-qA\right)/X_\ell$, is greater than the direct marginal labor cost of production, $1/X_\ell$, when the choice of product design is efficient. It pays to increase the 'distortion' $A < 0$ in the production of good *X* so long as, at the margin, it matches the recycling benefit R_z / R_ℓ.

The insight of proposition 1iii conforms to one's intuition[12]: Since raising the material content increases, ceteris paribus, the output of recovered material, green product design requires to choose a level of material content higher than in the absence of that productivity effect (or in the absence of recycling). This is why we expect producers of consumption goods to choose an inefficiently low level of material content unless they perceive monetary incentives (prices, fees or charges) inducing them to directly or indirectly take post production recycling benefits of their product design into account in their profit maximization calculus[13]. The issue of efficient pricing will be the focal point of the remainder of the paper.

4 Vertically integrated production and recycling

Following the usual welfare economic reasoning we now proceed by investigating if and how the efficient allocation can be 'decentralized by prices'. We assume that there are competitive markets for labor (price p_ℓ), material (price p_m) and good *X* (price p_x). As a consequence, two of the five agents in our economy, namely the consumer and the producer of primary material, carry out all their transactions on competitive markets. Their optimizing calculus is to solve the Lagrangeans, respectively,

$$L^H = U\left(\ell^s, x^d\right) + \gamma_c (p_\ell \ell^s + \phi - p_x x^d), \tag{4}$$

$$L^V = p_m v^s - p_\ell \ell_v^d + \gamma_v \left[V\left(\ell_v^d\right) - v^s\right], \tag{5}$$

where ϕ denotes a lumpsum transfer of profit shares to consumers.

As a (highly) stylized approximation for the disposal of recycling waste in practice we consider landfilling as being managed by a (public) enterprise that sets a disposal fee, p_f, equal to marginal cost and adjusts that fee until the recycler's supply of recycling waste matches the landfiller's demand: $f^s = f^d$, (A8). In formal terms, the landfilling firm maximizes

$$-p_f f^d - p_\ell C(f^d). \tag{6}$$

This specification secures landfilling not to be a source of allocative inefficiency thus allowing us to draw our attention exclusively on product design and recycling. Note that (4), (5) and (6) remain unchanged throughout the paper while the constraints under which the producer and the recycler maximize their profits will vary with the specific features of the waste management regime under consideration.

In the present section we think of good *X* as a durable consumption good that can be easily recognized by its brand, like e.g. the automobiles of a specific manufacturer. Each unit of such products typically consists of a material mix and can be easily kept separate from total household waste and collected at the end of its useful economic life. These are favorable preconditions for take back. In addition to the take back rule we assume that the producer of the consumption good observes her responsibility for recycling by carrying out production and recycling in a single vertically integrated firm. To see the implications of this set-up, we 'endow' the producer of good *X* not only with the production function (A2) but also with the recycling technology (A4). In an effort to maximize (joint) profit as a price taker she then solves

$$L^{P+R} = p_x x^s + p_m(r - m^d) + p_f(z - r) - p_\ell(\ell_x^d + \ell_r^d) + \gamma_z(x^s - z) + \gamma_q\left(\frac{m^d}{x^s} - q\right) +$$

$$+ \gamma_x\left[X\left(\ell_x^d, m^d\right) - x^s\right] + \gamma_r\left[R\left(\ell_r^d, q, z\right) - r\right]. \tag{7}$$

Observe that the decision variables ℓ_x^d, ℓ_r^d, m^d, f^s and x^s of the integrated firm are related to external transactions while the other decision variables q, r, and z are internal. The latter

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[12] The (sufficient) conditions on technology used to attain proposition 1iii are quite restrictive. Our conjecture is, however, that this result is robust under more general assumptions. But its proof would be very involved.

three variables clearly create an interdependence between production and recycling which is appropriately taken care of by joint profit maximization:

Proposition 2. *(Efficiency of integrated recycling)*

Suppose the consumption residuals are taken back and recycled by the producer of the consumption good. Setting $p_\ell = \mu_\ell = 1$, $p_m = \mu_m$, *and* $p_x = \mu_x$ *clears all competitive markets and* $p_f = -\mu_f$ *is a landfilling fee that equalizes demand for and supply of recycling waste. The associated competitive equilibrium is efficient.*

Proposition 2 shows that the competitive prices p_ℓ, p_m, p_x are all positive, as expected. The landfilling charge for recycling waste, p_f, is negative and thus provides for a positive revenue, $(-p_f f^d)$, of the landfilling firm. $p_f < 0$ is a consequence of our implicit assumption that 'free disposal' or 'illegal dumping' of recycling waste is effectively and costlessly ruled out.

5 A gallery of pricing policies for a Waste Management Organization

In view of proposition 2 direct take back and recycling of residuals by the producer secures an efficient flow of materials and the efficient product design. It is tempting to conclude that this institutional arrangement should be adopted in solid waste management at large. But implicitly proposition 2 presupposes zero collection costs while in many relevant practical cases the cost of collecting producer-specific residuals is very high or even prohibitive. These costs are likely to be the higher, the smaller is the weight of a unit of consumption good and the more differentiated are the consumption goods - both of individual producers and across producers. A particularly important example of high producer-specific collection cost is waste from packaging consumption goods which our model (A1) - (A9) is capable to accommodate for following some minor modifications in notation and interpretation.

Since direct take back is not a practical solution in many cases of waste processing one might want to use competitive markets for efficient waste processing. But there is ample empirical evidence that waste material flows are not guided effectively by competitive prices

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[13] This conjecture is confirmed in proposition 2 below.

and therefore other private or public institutional arrangements are called for. Many countries have set up regimes in which a more or less centralized *waste management organization* (WMO) operates as an intermediary. But it was only recently that in some countries these arrangements have adopted the principle of producer responsibility with the German 'Green Dot' system as one of the pioneering approaches.

For the purpose of our stylized analysis it suffices to describe the basic institutional arrangement of recycling through the intermediation of such a WMO as follows: The producer of good X delegates her responsibility for the processing of consumption residuals to the WMO and this organization obtains the right to impose administrative prices or fees on both the producer of the consumption good and on the recycling firm. WMO and this organization obtains the right to impose administrative prices or fees on both the producer of the consumption good and on the recycling firm. Both take these administrative prices as given, and the WMO adjusts them in a trial and error procedure so long as supply matches demand (like the landfilling enterprise does regarding the fee p_f).[14] Our main focus are WMO's alternative pricing options rather than the comparison of the WMO as an institution with alternative arrangements. It seems acceptable, therefore, to neglect the WMO's costs of set up and operation.[15]

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[14] Note that in terms of the formal model the WMO as well as the landfilling enterprise assume the role of the Walrasian auctioneer in their respective domains of waste processing.

[15] It should be mentioned, though, that high administrative costs and lack of competition are major criticisms against the German WMO in the area of packaging waste: See, e.g. Staudt et al. (1997) or Sachverständigenrat (1998, p. 174ff).

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policy of administrative pricing				base of administrative price
A	B	C	D	
pricing residuals only	pricing residuals and their material content	pricing residuals depending on their material content	pricing material embodied in residuals	
π_z	π_z	$\Pi^z(q)$	-	z^s, z^d
-	π_q	-	-	q^s, q^d
-	-	-	π_b	$q^s z^s,\ q^s z^d$

fee policy				fee base
E	F	G	H	
pricing material	pricing material,	pricing material and	pricing material,	

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[16] Note that in terms of the formal model the WMO as well as the landfilling enterprise assume the role of the Walrasian auctioneer in their respective domains of waste processing.

[17] It should be mentioned, though, that high administrative costs and lack of competition are major criticisms against the German WMO in the area of packaging waste: See, e.g. Staudt et al. (1997) or Sachverständigenrat (1998, p. 174ff).

[18] It should be mentioned, though, that high administrative costs and lack of competition are major criticisms against the German WMO in the area of packaging waste: See, e.g. Staudt et al. (1997) or Rat von Sachverständigen für Umweltfragen (1998, p. 174ff).

and residuals	residuals and material content	residuals depending partly on material content	residuals and embodied material	
π_m	π_m	π_m	π_m	m^d
π_z	π_z	π_z	π_z	z^s
$\hat{\pi}_z$	$\hat{\pi}_z$	$\Pi^z(q)$	-	z^d
-	-	-	π_b	$q^s z^d$
-	π_q	-	-	q^d

Table I: *The WMO's options of administrative pricing and fees*

In table I eight different pricing strategies A - H are specified that are at the WMO's disposal. A distinction is made between policies involving *administrative prices* (A - D) and policies involving *fees* (E - H). A 'price' charged or paid by the WMO is said to be an administrative price if it is the same for both the supply and the demand side of the respective material flow: The suppliers are paid the administrative price (which may be positive or negative) and the demanders have to pay for it. Hence the WMO is a pure intermediator acting as a substitute for missing markets. In contrast, fees are defined as (positive or negative) 'prices' of the WMO which 'tax' or 'subsidize' each side of a material flow in a different way (including the case that one side remains completely 'unpriced').

Policy A prices the total flow of consumption residuals, z, implying that both types of waste materials embodied in consumption residuals are uniformly priced. All other policies price material content in a direct or indirect way. Policy B prices the total flow of consumption residuals, as does policy A, but also the material content of residuals, q. In policy C the flow of consumption residuals is priced as in policies A and B, but the price is a function of material content (hedonic pricing); hence policy C accounts for the material mix of the residuals in an indirect way. Policy D is the only strategy which does not price the flow of consumption residuals but rather the (explicitly modeled) material embodied in consumption residuals, $q \cdot z$.

The common characteristics of the policies E to H are that producers pay fees for material demanded, $\pi_m \cdot m^d$, and for residuals supplied, $\pi_z \cdot z^s$, and that no fee at all is charged for both the material content supplied, q^s, and the supply of material embodied in residuals, $q^s z^s$. The distinctive features of policies E to H are fees levied on the recycling sector: Policy

E employs a fee on the demand for residuals, $\hat{\pi}_z z^d$, which is complemented by a fee on material content demanded, $\pi_q q^d$, in policy F. Policy G is like policy E except that the fee on residuals demanded depends on material content. Finally, policy H places a fee on the demand for material embodied in residuals, $\pi_b q^s z^d$.

Before we discuss each of these policies successively, a few remarks are in order on the criteria of assessment. The main focus of our following investigation will be on the (comparative) efficiency of the pricing policies. But a basic precondition for dealing with the efficiency issue is, of course, that a policy is *feasible* in the sense that in a situation where all competitive markets clear there are values for the administrative prices or fees constituting the policy such that demand matches supply for all those waste flows to which the respective administrative prices or fees refer. We will not elaborate on the feasibility issue in those cases where feasibility (or existence of equilibrium) can be established by standard arguments as, e.g., in all results reported in the subsequent propositions 3 - 7 except proposition 4i. For some pricing strategies feasibility will turn out to remain an open question under well-behaved assumptions on technology. It is also of some interest to know whether an efficient pricing policy allows the WMO to ballance its budget, since the balanced-budget (or cost-covering) rule is a mandatory requirement for many public waste management agencies, e.g. in the German 'Green Dot' system. For the policies A - D the balanced budget property holds trivially (because the WMO's purely intermediating role), but this is not so obvious with regard to the other policies.

6 The policies A - D of administrative pricing

(1) *Uniform pricing of waste materials (policy A)*

When policy A is applied, the profit maximizing problems of the producer and the recycler, respectively, are described by the Lagrangeans[19]

$$L^P = p_x x^s + \pi_z z^s - p_\ell \ell_x^d - p_m m^d + \gamma_z (x^s - z^s) + \gamma_x \left[X\left(\ell_x^d, m^d\right) - x^s \right], \tag{8}$$

$$L^R = p_m r^s - \pi_z z^d - p_\ell \ell_r^d + p_f (z^d - r^s) + \gamma_r \left[R\left(\ell_r^d, q^s, z^d\right) - r^s \right]. \tag{9}$$

Observe first that (8) and (9) specify the WMO's role as an intermediator. It 'purchases' the consumption residuals, z^s, from the producer spending the (positive or negative) amount $\pi_z z^s$ and then 'sells' the residuals to the recycler receiving the (positive or negative) revenue $\pi_z z^d$. By way of trial and error the WMO sets its administrative price π_z such that $z^s = z^d$ implying that its budget is balanced.[20]

Observe that in case of strategy A the producer's profit maximizing calculus (8) does not contain material content as a decision variable. This is so because policy A does not provide the producer with a price signal relating to the material content of her product. Hence it is rational for her to ignore any impact the design of her product may have after it is sold to the consumers. There is, however, such an impact because the variable q^s as defined in (A6) enters the recycler's optimization problem (9). Since the level of q^s is determined by the producer without any regard of the recycler's needs or wants, q^s represents a positive externality for the recycler. Hence pricing policy A must be expected to be inefficient.

Proposition 3. *(feasibility and inefficiency of policy A)*

(i) Policy A is feasible but it fails to induce the efficient product design.

(ii) If the production function X is linear homogeneous and the function V is linear, the material content of good X is inefficiently low.

Solving (4) - (6), (8) and (9) provides us with some interesting information about the sign of the administrative price π_z:

$$\pi_z = -\left(C_f - \frac{R_z}{R_\ell} \right). \tag{10}$$

In absolute terms, π_z equals the post-consumption marginal net cost of the consumption good, as identified in (3). π_z is negative, if and only if the marginal labor cost of landfilling is greater than the value of labor saved by substituting, at the margin, residuals for labor in recycling. If $\pi_z > 0$, the producer receives a positive revenue from 'selling' consumption residuals whereas the recycler has to spend money for 'purchasing' it. Such a situation begs

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[19] The other agents' optimization problems are invariably given by (4), (5) and (6).

immediately the question as to why a (competitive) market for residuals fails to exist in the first place. Casual empirical evidence shows that some markets for waste material are indeed active, e.g. for glass, aluminum or waste paper. Other waste materials may have a positive shadow price but the respective market may fail to work due to high transactions costs (not included in the present model). At any rate, our model also generates the result which we consider typical for many types of solid waste: If marginal landfilling costs are sufficiently high, the administrative price π_z is *negative*, meaning that the supplier of consumption residuals (the producer) is 'taxed' by the WMO while the demander (the recycler) is 'subsidized' by the WMO.

According to proposition 3i policy A does not bring about the appropriate product design. In general, it is not possible to specify how it deviates from the efficient one, but introducing more restrictive assumptions on technology in proposition 3ii, the same used already in proposition 1iii, enables us to conclude that the material content is too low under policy A. Material content is underprovided because the producer ignores the positive externality associated to it. In other words, uniform pricing of residuals fails to internalize that externality.

The obvious conclusion is that the WMO ought to apply other pricing policies which provide the producer with incentives for green product design. Table I shows that the policies B, C and D consist of administrative prices that are related to the material content of good *X* in some way or another. We will now answer the question whether these policies do better than policy A.

(2) *The policy of two-part pricing (policy B).*

Like policy A this strategy consists of an administrative price placed on consumption residuals, and it provides, in addition, a price signal for green design by pricing the material content directly. The pertinent profit maximization problems of the producer and the recycler, respectively, are described by the Lagrangeans

$$L^P = p_x x^s + \pi_z z^s + \pi_q q^s - p_\ell \ell_x^d - p_m m^d + \gamma_z (x^s - z^s) + \gamma_q \left(\frac{m^d}{x^s} - q^s \right) + \\ + \gamma_x \left[X\left(\ell_x^d, m^d\right) - x^s \right], \qquad (11)$$

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[20] In a similar obvious way the balanced budget property can be shown to hold for the policies B, C and D.

$$L^R = p_m r^s - \pi_z z^d - \pi_q q^d - p_\ell \ell_r^d + p_f (z^d - r^s) + \gamma_r \left[R\left(\ell_r^d, q^d, z^d\right) - r^s \right]. \tag{12}$$

In principle, the WMO's intermediating role is as in case of strategy A. But this time, *z* and *q* are decision variables of both the producer and the recycler. Hence the WMO must seek to fix its prices (π_z, π_q) in such a way that $z^s = z^d$ and $q^s = q^d$ are simultanously satisfied (in which case the WMO's budget is balanced).

Proposition 4. *((In)efficiency conditions for policy B)*

Suppose the production function is linear homogeneous.

(i) If the Pareto-efficient material content of good X is smaller than $\overline{q}$ *and if policy B is feasible, then it is inefficient.*

(ii) If the Pareto-efficient material content is $\overline{q}$*, then policy B is (feasible and) efficient.*

The proof of proposition 4 (appendix) reveals that for policy B the producer's decision variable q^s as defined in (A6) renders her profit maximization problem non-concave. For linear homogeneous production functions policy B induces the producer to supply the material content $q^s = \overline{q}$ for all those administrative prices (π_z, π_q) and market prices $\left(p_\ell, p_x, p_m, p_f\right)$ for which a non-zero profit-maximizing production plan exists. Figure 1 shows that for given *x* the profit is increasing in *q* whereas for given *q* the profit is the same for all values of *x*. Consequently the producer is indifferent with respect to all values of *x*, and since *q* is bounded from above by $\overline{q}$, the profit-maximizing material content is always $\overline{q}$.

- Insert **figure 1** about here -

This is why policy B is efficient [inefficient] if the efficient material content is equal to $\overline{q}$ [smaller than $\overline{q}$]. Even though the possibility of $\overline{q}$ being Pareto-efficient cannot be ruled out it seems to be an atypical special case. Hence in its essence, proposition 4 should be considered as a negative result. It is, in fact, an intriguing if not disturbing prospect that policy B might not work, in general, under the assumption of linear homogeneous production which economists apply routinely both in their theoretic and applied work. Note also that since proposition 4 has been restricted to the case of linear homogeneous production functions, we did not answer the question what happens in economies with production technologies that are concave (and considered 'well-behaved' in neoclassical economies) but not linear homogeneous. The reason for that reserve is plainly that we just do not know whether policy B is feasible in such an environment because the administrative prices constituting policy B render the producer's profit function non-concave, in general, when the production function is concave but not linear homogeneous. As a consequence, the producer's excess supply cannot be shown to exhibit the continuity properties in prices and administrative prices necessary to apply an appropriate fix point theorem. Our conjecture is that policy B is not feasible in case of concave but non-linear homogeneous production technologies. However, for the sake of completeness and at the risk to further complicate the argument it must be added that if policy B is feasible in such a technological setting it is also efficient (Eichner and Pethig (1999a)).

(3) The policy of hedonic pricing (policy C).

With this pricing strategy, the profit maximizing problems of the producer and the recycler, respectively, are described by the Lagrangeans

$$L^P = p_x x^s + \Pi^z(q^s) z^s - p_\ell \ell_x^d - p_m m^d + \gamma_z (x^s - z^s) + \gamma_q \left(\frac{m^d}{x^s} - q^s \right) + \gamma_x \left[X\left(\ell_x^d, m^d\right) - x^s \right], \tag{13}$$

$$L^R = p_m r^s - \Pi^z(q^d) z^d - p_\ell \ell_r^d + p_f (z^d - r^s) \;+\; \gamma_r \left[R\left(\ell_r^d, q^d, z^d\right) - r^s \right]. \tag{14}$$

Comparing (13) and (14) to (8) and (9) shows that π_z is replaced by $\Pi^z(q^s)$ in (13) and by $\Pi^z(q^d)$ in (14). Moreover q^s from (9) is replaced by q^d in (14). Hence policy C does not create an externality anymore as did policy A. It rather implies, like policy B, that *z* and *q* are decision variables of both the producer and the recycler. The difference between the policies B and C is also worth noting: In policy B the WMO has at its disposal two price instuments to bring about the equalities $z^s = z^d$ and $q^s = q^d$. With policy C the same equalities have to be secured by the WMO by means of pricing residuals only. This can be achieved, since now the price for residuals depends on material content, and therefore the WMO's choice of $\Pi^z(q)$ has a simultanous impact on the supply and demand of both residuals and their material content.

Proposition 5. *(Efficiency of policy C)*

Policy C is feasible and efficient.

As shown in the proof of proposition 5 (appendix) the profit is strictly concave in *m* and ℓ_x attaining an unique interior maximum for any positive *x*.

As in case of policy A the competitive prices p_ℓ, p_m, p_x are positive and the landfilling charge for recycling waste, p_f, is negative. Regarding the hedonic price function we find $\Pi_q^z(q) = \mu_q / z > 0$ and $\Pi^z(q) = \mu_z = -\left(C_f - \frac{R_z}{R_\ell} \right)$. Hence $\Pi^z(q)$ is determined in the same way[21] as π_z in (10) in the context of policy A.

The finding that Π_q^z is positive deserves to be emphasized. $\Pi_q^z > 0$ is necessary to provide the producer with an incentive to extend the material content beyond the level which she would have chosen in case of $\Pi_q^z = 0$. Therefore $\Pi_q^z > 0$ leads the producer to correctly account for the positive productivity of the material content in recycling at the (early) stage of designing her product.

While the efficiency result of proposition 5 sheds a more favorable light on policy C than on policy B the overall appraisal of policy C is hardly much better than that of policy B for the following reason: Eichner and Pethig (1999a) show that the efficiency property of proposition 5 does not carry over, in general, to an economy with more than one producer of the consumption good and more than one recycling firm.

(4) The policy of pricing embodied material (policy D)

This pricing policy is characterized by the Lagrangeans

$$L^P = p_x x^s + \pi_b b^s - p_\ell \ell_x^d - p_m m^d + \gamma_{bx}(b^s - q^s x^s) + \gamma_q\left(\frac{m^d}{x^s} - q^s \right) + \gamma_x\left[X\left(\ell_x^d, m^d\right) - x^s \right], \quad (15)$$

$$L^R = p_m r^s - \pi_b b^d - p_\ell \ell_r^d + p_f (z^d - r^s) + \gamma_{br}(b^d - q^s z^d) + \gamma_r\left[R\left(\ell_r^d, q^s, z^d\right) - r^s \right]. \quad (16)$$

The common feature of the policies A and D is that with her choice of material content, q^s, the producer imposes an externality on the recycler. But there is an important difference. The pricing base is not *z* as in policy A but the *embodied material*, $q^s z$. Hence the value of

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[21] But since strategy A is inefficient and strategy C is efficient the administrative prices π_z and $\Pi^z(q)$ are different, in general, even though the expression of partial derivatives determining them is the same for both.

q^s must be known not only to the recycler (as in policy A) but also to the WMO that would otherwise not be able to price embodied material. In policy D the WMO has to fix its price π_b so that $b^s = b^d$ which is equivalent to $z^s = z^d$ for any given q^s. In this aspect policy D resembles policy A more than the policies B and C because policy A also required the WMO to set $z^s = z^d$ while in policies B and C administrative prices had to be set so that the equalities $z^s = z^d$ and $q^s = q^d$ are satisfied simultaneously.

Proposition 6. *((In)efficiency conditions for policy D)*

(i) Policy D is inefficient, in general.

(ii) Policy D is efficient, if landfilling is costless $\left(C(f^d) = 0 \text{ for all } f^d \geq 0\right)$ *and if the recycling technology is of the special form* $R\left(\ell_r^d, q^s, z^d\right) = \widetilde{R}\left(\ell_r^d, q^s \cdot z^d\right)$.

Proposition 6 is easily understood by observing that, from the producer's perspective, policy D is a special case of policy C. To see that we rewrite (15):

$$L^P = p_x x^s + \pi_b b^s - p_\ell \ell_x^d - p_m m^d + \gamma_{bx}(b^s - m^d) + \gamma_x\left[X\left(\ell_x^d, m^d\right) - x^s\right]. \tag{15'}$$

Equation (15') shows that using the equations $b^s = q^s x^s$ and $z^s = x^s$ and defining $\hat{\Pi}^z(q) := \pi_b q^s$ it is possible to replace $\pi_b b^s$ in (15) by $\pi_b q^s z^s = \hat{\Pi}^z(q) z^s$. Hence in policy D the producer faces the same profit maximizing problem as in policy C with a specific linear price function $\hat{\Pi}^z$. Therefore the feasibility of policy D is proved along the same lines as the feasibility of policy C.

Since policy D involves the same externality as policy A, the inefficiency result of proposition 6i does not come as a surprise. The intriguing part of proposition 6 is, in fact, the efficiency result of proposition 6ii that holds under fairly restrictive conditions, though. To see how the 'internalization of the externality' is achieved under the conditions of proposition 6ii, observe first that by setting $R\left(\ell_r^d, q^s, z^d\right) = \widetilde{R}\left(\ell_r^d, q^s \cdot z^d\right)$ equation (16) turns into:

$$L^R = p_m r^s - \pi_b b^d - p_\ell \ell_r^d + p_f(z^d - r^s) + \gamma_r\left[\widetilde{R}\left(\ell_r^d, b^d\right) - r^s\right]. \tag{16'}$$

Comparing (16) and (16') reveals that in (16') material content, q^s, is eliminated and the recycler's demand for consumption residuals also vanishes except in the term $p_f(z^d - r^s)$. But this term is zero since landfilling is assumed to be costless in proposition 6ii (and hence $p_f = 0$). In this way the externality has been removed which explains the achievement of allocative efficiency.

However, the price paid for the efficiency result is high in terms of severely restrictive assumptions. In our view the recycling problem at hand is not adequately captured by assuming zero landfilling costs and by setting[22] $R = \widetilde{R}$. We conclude, therefore, that one cannot make a strong case for policy D.

Summing up the appraisal of the four policies A - D under review, we learnt that pricing nothing but consumption residuals on the supply and demand side (policy A) is sufficient for inefficiency. In other words, efficiency cannot be achieved unless additional price signals are introduced that somehow affect the material content. The policies B, C and D satisfy that requirement, but the performance of these policies is hardly much better than that of policy A although for different reasons.

7 The fee policies E - H

We now turn to policies E - H as characterized in section 5. Each of these pricing strategies consists of levying fees on the supply of residuals and on the demand of material as specified in the Lagrangean

$$L^P = p_x x^s + \pi_z z^s - p_\ell \ell_x^d - (p_m + \pi_m) m^d + \gamma_z (x^s - z^s) + \gamma_x \left[X\left(\ell_x^d, m^d\right) - x^s \right]. \tag{17}$$

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[22] To see the inadequacy of $R = \widetilde{R}$ imagine a large container filled with n_o white and b_o black balls where $n_o + b_o$ represents the total amount of consumption residuals. Suppose further that with given labor effort ℓ_o it is technicologically feasible to pick $r_o := \widetilde{R}(\ell_o, b_o)$ black balls from the container. If the number of white balls is successively increased the technology $\widetilde{R}$ still allows to pick r_o black balls so long as ℓ_o and b_o remain unchanged even though the share of black balls is successively reduced towards zero.

The fees π_z and π_m have two favorable consequences. First, by varying π_z and π_m the WMO 'controls' the producer's choice of material content $q^{s,} = m^d / z^s$ effectively. This is what good fees are supposed to do. Second, the fees π_z and π_m do not render the producer's profit function non-concave for any concave production function, thus assuring feasibility for all policies E - H. That puts them at a great advantage over the policies B - D whose unresolved feasibility issue raises serious doubts about their suitability.

Different types of fees can be set to provide the recycler with incentives to expand her activity. They are specified in the following Lagrangeans:

$$L^R = p_m r^s - \hat{\pi}_z z^d - p_\ell \ell_r^d + p_f (z^d - r^s) + \gamma_r \left[R\left(\ell_r^d, q^s, z^d\right) - r^s \right], \tag{18}$$

$$L^R = p_m r^s - \hat{\pi}_z z^d - \pi_q q^d - p_\ell \ell_r^d + p_f (z^d - r^s) + \gamma_r \left[R\left(\ell_r^d, q^d, z^d\right) - r^s \right], \tag{19}$$

$$L^R = p_m r^s - \Pi^z(q^d) z^d - p_\ell \ell_r^d + p_f (z^d - r^s) + \gamma_r \left[R\left(\ell_r^d, q^d, z^d\right) - r^s \right], \tag{20}$$

$$L^R = p_m r^s - \pi_b b^d - p_\ell \ell_r^d + p_f (z^d - r^s) + \gamma_{br} (b^d - q^s z^d) + \gamma_r \left[R\left(\ell_r^d, q^s, z^d\right) - r^s \right]. \tag{21}$$

When combined with (17) the Lagrangeans (18), (19), (20) and (21) represent the fee policies E, F, G and H, respectively, as defined in table I. Observe that the common feature of the policies E and H is that q^s is an externality in recycling like in policies B and D. In contrast, in case of policies E and F the recycler optimizes over q^d as she did in policies B and C. Using (17) - (21) we now proceed to investigate the efficiency property of the policies E - H.

Proposition 7. *(Efficiency of policies E - H)*

All policies E - H are efficient. Policy F generates a budget surplus while the budget is balanced in case of policies E, G and H.

Proposition 7 gives rise to a number of interesting observations:

(a) For policies E - H the efficient producer fees are:

$$\pi_z = -\left(C_f - \frac{R_z}{R_\ell} \right) - \frac{R_q q}{R_\ell z}, \quad \pi_m = -\frac{R_q}{R_\ell z}. \tag{21}$$

The fee π_z is set equal to the difference between the post-consumption marginal net cost of good X (which is indeterminate in sign, see (10)) and the (labor) value of material content in recycling per unit of residuals. $\pi_z > 0$ cannot be ruled out but with only one positive and two negative components π_z is likely to be negative in which case producers are 'taxed'. π_m is a 'subsidy' ($\pi_m < 0$) set equal to the (labor) value in recycling of material content per unit of residuals or, equivalently, the (labor) value in recycling of material embodied in residuals. In combination, both fees induce the producer to raise the material content of the consumption good up to its efficient value.

(b) According to proposition 7 policy F is efficient in the absence of a budgetary constraint. This efficient policy F can be shown to generate a budget surplus. Consequently, if - for whatever reason - an unbalanced budget is not allowed for policy F is bound to be inefficient. In contrast, the policies E, G and H yield a balanced budget even without imposing a zero-budget requirement. There is a sense in which policy F can be considered redundant since it differs from policy E only by the 'extra' fee π_q. Dropping this fee is equivalent to switching from policy F to E and to settle, at the same time, the balanced-budget issue.

(c) Recall that under policies E and H material content q is an externality for the recycler who has no leverage to promote green product design. Nevertheless, the efficient product design is achieved through attaching appropriate values to the fees π_z and π_m. Therefore (π_z, π_m) can be viewed as a 'Pigouvian' tax-subsidy scheme internalizing the material-content externality in recycling.

(d) The policies F and G induce the producer to provide the efficient material content, like the policies E and H, but the fees $(\hat{\pi}_z, \pi_q)$ and $\Pi^z(q)$, respectively, contain direct or indirect price signals for the recycler's choice of material content. The purpose of these signals is to make the efficient product design (as supplied by the producer) also the recycler's best choice.

(e) As in case of policy C (section 6) the positive performance of policy G is subject to the reservation that policy G is not efficient anymore in an economy with more than one producer of the consumption good and with more than one recycling firm.

8 Concluding remarks

The starting point of our analysis was the empirical insight that using price signals for achieving efficient waste management under the principle of household responsibility does not work, since quantity-dependent charges on households differentiated with respect to types of material are too costly to implement. On the other hand, the regime of producer responsibility has been shown to work efficiently without any government interference or cooperative effort of the parties involved, if the direct take back rule can be applied at reasonable transactions cost. For the mayor part of solid household waste including packaging waste the cost of take back appears to be extremely high, however. Therefore, a (private or public) regime of centralized waste management with a WMO - as e.g. the German 'Green Dot' system - might be considered a better alternative. Our main focus was to investigate the feasibility and efficiency properties of eight alternative pricing policies which a WMO may want to adopt. The first set of four policies, denoted policies A - D, was designed to mimick missing markets. One could hope that such policies are capable to restore efficiency based on the (usual) proposition that it is the failure of those markets that caused the inefficiencies in the first place. Closer inspection revealed, however, that none of the policies A - D did fared particularly well.

The other four policies under consideration, denoted policies E - H, consist of a set of fees which are not the same for the supply and demand side of the waste flow (and hence do not replace missing market prices). One would refer to them as tax-subsidy schemes, in fact, if the WMO is a government agency. It is rather surprising that the performance of these policies is much better than that of policies A - D. For one thing, there is no feasibility problem at all. Moreover, all these policies are capable to achieve efficiency (including efficient product design and efficient recycling) even though some reservations have to be made regarding the policies F and G. It follows that the policies E and H can be recommended for WMOs in practice provided that monitoring the fee bases is possible without excessive cost and provided that setting the correct 'Pigouvian fees' (π_z, π_m) is informationally feasible.

Our appraisal of various pricing policies was based exclusively on theoretical arguments. Since the 'Green Dot' system is now applied in Germany since almost ten years, it is possible to assess the actual pricing policy of the pertinent German WMO on the background of our theoretical findings. Eichner and Pethig (1999b) show that the pricing policy presently applied by the German WMO is not efficient but that it has major elements of policy H and that it is hence recommendable to adopt policy H consistently. It is beyond the scope of the present paper to offer an appropriate and detailed account of practical pricing policies but our brief reference to Eichner and Pethig (1999b) indicates the potential of our theoretical investigation to serve as a system of reference for future applied work on the pricing strategies of existing centralized waste management systems that are based on the principle of producer responsibility.

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