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Non-linear production, abatement, pollution and materials balance reconsidered

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Abstract

In the environmental economics literature the standard approach of modeling non-linear production and abatement processes is to treat waste emissions "simply as another factor of production" [Cropper and Oates, J. Econ. Lit. 30 (1992) 675–740]. That approach does not map the materials flow involved completely and hides, moreover, the exact links between production, residuals generation and abatement. This paper shows that production functions with emissions treated as inputs can be reconstructed as a subsystem of a comprehensive production-cum-abatement technology that is in line with the materials-balance principle. In a simple economy with full regard of the materials flow it also explores the consequences for allocative efficiency and efficiency-restoring taxation of multiple and interdependent residuals generated in the transformation processes of production, abatement and consumption. Finally, the paper demonstrates that efficiency may require setting the emissions tax rate above or below *conventionally* defined marginal abatement cost if the residual subject to abatement is not the only residual causing pollution.

Keywords: Residuals; Abatement; Pollution; Materials balance

1. The problem

As is well-known from the law of mass conservation, the flow of materials taken from the environment for economic uses generates a flow of materials from the economy back into the

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environment that is of equal weight (after accounting for time delays). The economic activities of production and consumption are merely processes of transforming materials that only change the physical and chemical attributes and the composition of the materials flow. Quite obviously, the composition of the flow of residuals from the economy into the environment is of great significance because different kinds of residuals differ in their detrimental impact on the environment.[1]

As a consequence, a sensible strategy for alleviating the problem of environmental degradation is to control the process of materials transformation by reducing the emission of the most harmful pollutants through residuals abatement activities. Like production and consumption, this activity is a process of transforming materials subject to the materials-balance principle: the weight of all material outputs of that process equals the weight of all material inputs.

In their seminal paper on 'production, consumption and externalities', Ayres and Kneese [1] made a strong case for the need of a consistent and encompassing application of the materials-balance principle to *all* transformation processes. In their formalized materials-balance approach they employed linear technologies with fixed input–output coefficients, but since then the profession has revealed a preference for modeling non–linear rather than linear technologies. In fact, the notion and empirical evidence of strictly increasing (real) marginal abatement costs is at the core of many pollution control studies.

To be sure, it is possible to bring non–linear (abatement) technologies into line with materials-balance requirements, too. This has been demonstrated in various previous studies the most general and ambitious of which probably is Krysiak and Krysiak [8]. Yet fully regarding the materials-balance principle in theoretical analysis comes at the cost of enormous additional complexity which tends to prevent the derivation of informative results. To avoid such complexities many environmental economists became reluctant to explicitly and properly regard the materials-balance principle as the correct theoretical foundation of their analyses [11,12, p. 202]. Therefore Ayres and Kneese's [1,p. 283] verdict still applies to much of the present work that production processes are viewed "... in a manner that is somewhat at variance with the law of conservation of mass".

To be more specific, consider the simple production function $Y : \mathbb{R}^3_+ \to \mathbb{R}_+$ with

$$y = Y(e, \ell, m), \tag{1}$$

where two inputs, *labor* ℓ and *material* m, are employed to produce two outputs as joint products, a wanted *consumer good*, y, and an unwanted *production residual*, e (with e for *emissions*). This type of technology was already applied in the early 1970s, e.g. by Forster [5] and Klevorick and Cramer [7]. Varying grossly in its degree of generality, it became a widespread and accepted tool of analysis within few years (e.g. in [2,9,10]).

In their survey on environmental economics, Cropper and Oates [3] refer to the production function (1) as the standard approach in the environmental economics literature.[2] They observe

[1]A more detailed analysis would need to focus on further determinants such as the medium of discharge and the local environmental medium's assimilative capacity.

[2]As compared to our Eq. (1), Eq. (2) in Cropper and Oates [3, p. 678] is slightly more general in that they allow for an arbitrarily large vector of conventional inputs (which is reduced to the two-dimensional vector (ℓ,m) in (1)) and allow the level of pollution to be a negative productivity-reducing externality. This externality is omitted in the present paper to keep the analysis simple.