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“Messy” marginal costs: Internal pricing of environmental aspects on the firm level

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ABSTRACT

Internal pricing of environmental aspects is usually not embedded in management accounting systems. Therefore, we first show that pricing from a corporative perspective is possible and applicable. Contrary to common belief, we also show that marginal costs curves of environmental aspects are often not monotonic and price changes are highly context-specific. We introduce a model that addresses different environmental aspects that translate into constraints or change direct cost factors in the objective function. Environmental constraints originate from different types of limit values concerning emissions and production processes as well as restraining the potential environmental damage as the outcome of ecological valuation methods. Direct cost factors include the taxation of emissions and costs stemming from being involved in the emissions trading market. Our model allows for calculating the marginal (indirect) costs of these environmental aspects as the constraints might enforce factor and product substitutions. We show that the marginal costs differ substantially from the direct costs and do not follow a predictable pattern. Sensitivity analysis and parametric programming are applied to set up an internal pricing and cost allocation scheme for environmental aspects, specifically focusing on the pricing of emissions, resources and processes, of production and recycling. The model's implications on corporate decision making are illustrated by a numerical example that draws on the opportunity of process substitution, e.g. producing a product on different machines. Even though we cannot use original data for proprietary reasons, such settings are highly relevant in industry and the energy sector.

1. Introduction

Although there is a substantial amount of literature covering different aspects of sustainable operations (Jaehn, 2016), deep insights into the consequences of environmental constraints, e.g. originating from different types of limit values, and direct cost factors, e.g. taxation of emissions and costs stemming from being involved in the emissions trading market, are still under-researched. More specifically, we formulate a production planning problem that includes these typical environmental constraints and relevant cost factors. Then, illustrated by a numerical example, the variation of the overall production volumes (the product system's capacity utilization) allows for deriving cost curves of emissions, production factors and products. The results show that these cost curves are not only difficult to calculate without using operations research methods but that they are also more complex than often assumed in the literature, i.e. the cost curves are neither monotone nor concave or convex. Applying the model and its results in practice can increase environmental and financial performance of firms substantially (Zhu et al., 2007).

Production planning approaches which cover a broader range of environmental aspects are still scarce (Hong et al., 2016). Our model incorporates different types of regulatory and societal environmental aspects and show that we can identify price schemes which reflect corporate environmental costs suitable for corporate decision making. Contrary to assumed cost behavior in economics textbooks assuming that firms can easily calculate marginal costs of emissions or emission abatement technologies (McKitrick, 1999; Kesicki and Ekins, 2012) or just adopt marginal cost rates from available analyses on the industry level (Zhou et al., 2015; Lee and Zhou, 2015), we also show that marginal costs curves of environmental aspects are often not monotonically increasing and price changes are highly context-specific (and difficult to predict). Our model can be applied to allocate flows of material and energy as well as their related costs to input factors, processes, and products and provides a sound basis for integrating environmental

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aspects into planning and corporate decision making. Even when simply varying the firm's overall production volumes – as illustrated in our example – marginal costs are influenced by interdependencies between environmental aspects, the structure of the production program, and the overall capacity utilization (Delarue et al., 2010). Anticipation of all these interdependencies is highly complex and only feasible when all relevant planning parameters are available.

Our contribution is to provide an overall approach to price environmental aspects within an activity-based approach. We aim for consistent price schemes which provide information for both cost allocation and corporate decision making. We show that interdependencies between environmental aspects and instruments (environmental taxes, emissions trading, emission limit values, recycling, environmental impacts in different environmental categories) exist and can be embedded in internal price schemes. Note that we use the term emissions for all solid, fluid and gaseous emissions whereas the term environmental impacts refer to the consequences of these emissions for the natural environment and human beings. These environmental impacts may take – depending on the assessment method – for example the ecologic and human toxicity and/or the Global Warming Potential (GWP) and other impact categories into account. To our best knowledge, this is the first approach which generates consistent pricing for a broad variety of environmental aspects applicable for decision making and cost allocation. The highly varying marginal cost levels illustrate why firms often argue that environmental policy instruments create uncertainty when planning daily operations and making (environmentally-conscious) investment decisions (Saltari and Travaglini, 2011).

The remainder of this paper is organized as follows. Section 2 reviews previous work in the related fields of environmental accounting. Section 3 describes the basic model and section 4 provides a numerical example for our model which enables us to demonstrate the calculation of (marginal) environmental costs. Section 5 summarizes our main results, discusses limitations and future research opportunities.

2. Related literature

Environmental aspects relevant for corporate decision making can influence firm competitiveness in many ways. We can distinguish between aspects which directly increase cost, which reduce available decision alternatives and which influence the quality of relationships with corporate stakeholders. Additionally, closed-loop cycles to decrease waste and to preserve resources can reduce the firm's overall environmental impact. As we will see in our model, the following aspects are highly interdependent and models concentrating on singular environmental constraints are often suboptimal.

- Environmental instruments which directly influence the company's cost structure are taxation of inputs and emissions (Christ and Burritt, 2013). Market-based instruments like emissions trading create prices for emissions (e.g. carbon dioxide, sulfur dioxide, methane) which have previously been “free goods” from the company perspective (Baumol, 1972).
- Environmental constraints (Absi et al., 2013) impose emission limit values on resources, e.g. the average amount of some emissions per machine hour, or by setting an overall limit for other emissions. Here, the cost can only be calculated if the firm context is taken into account. While some emission limit values might not impact decision alternatives in some firms, they can yield high emission abatement or opportunity costs in others (Gungor and Gupta, 1999).
- Societal claims: As traditional environmental regulations require achieving legal compliance, active stakeholder management goes further and analyzes the relationships to important internal and external stakeholder groups (Post et al., 2002). Several companies respond to stakeholder demands by setting environmental goals which exceed legal requirements (Murillo-Luna et al., 2008). They also employ methods to quantify and limit their overall environmental impact (damage) (Kosugi et al., 2009), for example with regard to their impact on climate change (Pandey et al., 2011). Although such evaluation methods are often discussed controversially (Schaltegger and Csutory, 2012; Franks et al., 2014) they can be seen as an effort to incorporate traditionally neglected aspects into management accounting and make them (more) visible in corporate planning and decision making processes (Figge and Hahn, 2013).
- Internal recycling efforts are often driven by various motivations. While companies are required to recycle process waste and products after their useful lifetime in several countries,[1] internal recycling activities can lead to significant cost savings when recycling costs are lower than purchasing new materials plus the cost savings due to waste reduction (Spengler et al., 1997; Fröhling et al., 2013). Although we focus on internal recycling in our model, we want to point out that companies can reduce material costs by working together with specialized external recycling firms or by participating in recycling networks (Souza, 2013; Jafari et al., 2017; Kadambala et al., 2017). With the understanding of waste as solid emissions, we also want to point out that recycling processes can be seen as emission mitigation processes when the main purpose is to mitigate or even eliminate negative environmental impacts of production systems. As we continue to use the term recycling processes for the sake of simplicity, in some cases they might also reflect emission mitigation that does not primarily target the reprocessing of non-product production outputs (Murphy and McKeogh, 2006).

Nearly all environmental impacts can be traced back to material and energy flows which build the quantitative basis for both environmental cost accounting and environmental impact assessment (Glasson et al., 2013; Müller et al., 2013). For cost allocation purposes, it is necessary to correctly attribute these environmentally relevant material and energy flows to input factors, processes (activities) and products (Henri et al., 2014). As first published by Steven and Letmathe (1996), we apply the concept of bills of environmental impacts (see also Letmathe and Doost, 2000; Melnyk et al., 2001) which distinguishes between input-based, process-based and product-based allocation of environmental impacts. Such bills of environmental impacts which allow emissions to be allocated to their causing factors are applied in a variety of firms, e.g. some major chemical companies have started the integration with traditional bills of materials in the 1990s. In consequence, adopting environmental bills allows modeling the firm's production capabilities through a set of input-output activities (Bonney and Jaber, 2013) based on Leontief technologies (Leontief, 1970). For this purpose, we distinguish production and recycling activities with the opportunity to (partially) substitute these activities for each other to obtain an optimal production plan (Koopmans, 1951).

A part of the complexity of the underlying decision situation is related to the fact that each emission, input factor, process, and product might be subject to different regulatory, societal and internal constraints. Therefore, several literature contributions discuss interactions between operational research and environmental management (Bloemhof-Ruwaard et al., 1995; Daniel et al., 1997; Yang et al., 2011; Brandenburg et al., 2014; Jaehn, 2016) and have claimed that integrating environmental aspects into planning models can significantly improve corporate decision making. Several models focus on single environmental issues like waste management (Spengler et al., 1997; Williams et al., 2007; Golzarpoor et al., 2017), water (Walsh et al., 2017) and emissions trading (Rong and Lahdelma, 2007; Zhang and Xu, 2013; Chang et al., 2015). More comprehensive models (e.g. Penkuhn et al., 1997; Letmathe and Balakrishnan, 2005; Rădulescu et al., 2009; Wellington et al., 2014; Nouira et al., 2014) include several of these aspects simultaneously. Wu and Chang (2003, 2004) consider parameter uncertainties (especially

[1] Such take-back obligations apply to cars, household devices, batteries and several other product types in the European Union (Cannella et al., 2016).