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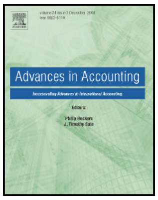

# A management control system to support corporate sustainability strategies

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ABSTRACT

This paper outlines a management accounting system, based upon cost variance analysis, which supports the pursuit of environmental and traditional financial goals within a decentralized organization. The framework decomposes inefficiencies into two parts. The first consists of what might be considered a natural outcome of pursuing the traditional economic goal of efficiency through cost-minimization, a “waste” variance. The second part consists of sustainability gains that produce societal benefit but may be incongruent with short-term economic goals, a “sustainability” variance. While elimination of waste variances can be encouraged using a traditional performance evaluation and reward structure, elimination of sustainability variances requires re-design of performance evaluation tools and reward structures. We demonstrate that differing production functions across operational units within organizations can impact the relative magnitude of the two variances. The failure to recognize and incorporate these differences can lead to inefficient allocation of resources and/or only partial fulfillment of the strategic environmental goals of the organization.

## 1. Introduction

As noted by Hartmann, Perego, and Young (2013), there has been insufficient work in the management accounting control literature focused on the development of corporate policy tools that address the misallocation of environmental resources within the firm. The delegation of tasks within a decentralized firm can make it difficult for top management to achieve its sustainability goals.

Recent experience at Diageo North America illustrates the difficulty in coming to grips with such organizational challenges. Diageo, one of the world's largest producers of spirits, wine, and beer, has become recognized as a global leader in environmental sustainability. Since 2007, Diageo North America, the company's largest division by volume, has reduced its greenhouse gas emissions by more than 75%, well ahead of its 50% reduction target for 2015, despite a significant increase in production volumes (Winston, 2013). The area of interest in the present paper is how a firm like Diageo communicates its environmental strategy internally, and what management accounting control tools are used to assure compliance throughout a complex decentralized organization.

An anecdote from the company's recent experience illustrates the involvement of various levels of management. By 2012, the company's North American division had already made substantial progress against its reduction target. At this point the division's sustainability manager proposed that the company's Canadian distillery enter into contracts to purchase natural gas harvested from a landfill, thereby reducing the carbon footprint for Diageo North America by another 30%. This would increase energy costs by more than $1 million per year, an incremental expense larger than the single plant could justify. A senior manager, the president of Global Supply and Procurement, realized that even though the landfill gas solution would increase operating costs for this one plant, it was actually a relatively cheap way to deliver a large reduction in emissions. He gave the go-ahead and some financial leeway to the plant manager who had to take an annual million-dollar-plus charge to his bottom line.

This anecdote has two interesting aspects. First, the management control system adapted to “allow the financial leeway” to the plant manager who was forced to internalize the million dollar cost. The system was required to identify the appropriate amount of leeway to be provided to the plant manager and communicate this information to him/her. Second, the decision process leading to the outcome involved at least three responsibility centers. If such decisions to internalize external costs are to become more widespread and routine, it is important to consider the design of responsibility accounting systems capable of achieving environmental goals at minimum costs.

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As with Diageo, when decisions affecting environmental performance are made at different levels within an organization, a management accounting information system that transmits information and organizational policy across various levels of management is required (Yakhou & Dorweiler, 2004). Epstein (1996) notes: "The success of an environmental strategy implementation depends on providing information related to corporate environmental impacts to various managers within the corporation. Thus, the development and improvement of these systems is critical." Dutta, Lawson and Marcinko (2013) develop a variance-based responsibility accounting system to facilitate such internal communication. In this paper we extend that framework to firms where operating divisions are subject to varying technological constraints. We demonstrate that the optimal response to the firm's strategic environmental goals can differ across divisions within a firm, and the information system and the incentive structure must take such differences into account. In doing so, we address the need to develop a single integrated accounting system to support traditional firm goals and environmental management goals (Hartmann et al., 2013).

Prior research has considered how the conflict between environmental and business goals has affected the design of management accounting system. Gabel and Gabel and Sinclair-Desgagné (1993) investigate the design of optimal wage contracts to alleviate the kind of environmental moral hazard problems encountered by Diageo. Lothe, Myrtveit, and Trapani (1999) envision a compensation system that features an earnings constraint with bonuses awarded for progress against environmental targets. Based on survey evidence, Lothe and Myrtveit (2003) recommend a compensation system that includes performance measures related to both environmental and earnings goals. Figge, Hahn, Schaltegger, and Wagner (2002) attempt an extension of Kaplan and Norton's (2006) balanced scorecard to assess and reward progress against both environmental and social goals.

This paper takes a different approach. We provide a management accounting control mechanism based on traditional responsibility accounting systems to direct attention at appropriate levels of the organization. Using a standard cost system, we demonstrate that variances capable of distinguishing between departures from optimality along both financial and environmental dimensions are sensitive to the technology employed by an operating unit. This approach is beneficial to firms with multiple operating units, each characterized by its own production technology. The cost system also has the capability of assigning responsibility for inefficiencies across various management levels within an organization. Perego and Hartmann (2009) found that the relationship between environmental strategy and the use of environmental performance measures for decision-influencing purposes operated indirectly through systems focused on environmental information quantified in financial terms, which this model provides.

The remainder of this paper is organized as follows. In the next section we develop a management control system that can be used to achieve alignment between environmental strategy and performance measurement. Next, the model is illustrated with numerical examples. We then discuss its implications. Finally, we conclude with observations regarding its implementation and significance.

## 2. Input choice model

The model of the firm assumes three levels of management: top management, upper level management and the cost center. In traditional management accounting literature these are referred to as the investment center, profit center and the cost center. The objective of the firm is to minimize the cost of producing a budgeted level of a single output Y sold in a competitive market at price $p_Y$. The budgeted level of output is determined by top management and communicated through the organization. Production requires a number of inputs subject to the technological constraint of a production function, known with certainty throughout the organization. The inputs are substitutable at rates specified by the production function. That is,

$$Y = f(x_1, x_2, \ldots, x_n) \tag{1}$$

Where:

$Y$ = output of the cost center
$x_i$ = quantity of the $i^{th}$ input

The function f is assumed to be single valued. The first partial derivatives with respect to the inputs $x_i$, are assumed to be positive, i.e., additional amounts of each input would result in higher output:

$$f'_i > 0 \text{ for all i}$$

The profit center manager is aware of the prices of the inputs and uses these prices to determine the optimal input mix that will be used to produce the budgeted level of output. The profit center manager's decision process can be represented by the following constrained optimization problem:

$$\begin{array}{l}\text{Minimize} \sum_{i=1}^{n} p_i x_i \\ \text{Subject to}: \ Y_0 = f(x_1, x_2, \ldots, x_n)\end{array} \tag{2}$$

where $Y_0$ equals the budgeted level of output. The problem is solved by introducing a Lagrange multiplier λ and constructing the function:

$$\sum_{i=1}^{n} p_i x_i - \lambda[f(x_1, x_2, \ldots, x_n) - Y_0] \tag{3}$$

The familiar first order minimization conditions require the manager to choose the vector $\boldsymbol{X}$, $(x_1, x_2, \ldots x_i, \ldots x_n)$ as the solution to:

$$\frac{p_i}{p_j} = \frac{f_j}{f_i} \text{ for all } i, j = 1, \ldots, n \tag{4}$$

The first-order conditions [4] imply that a reduction in the price of $x_i$ will require a substitution of $x_i$ for one or more other inputs in order to minimize cost.

This familiar neoclassical model of the firm can be generalized to include the costs of negative externalities resulting from input consumption. Managers are usually unaware and therefore indifferent to the costs borne by society and consequently do not include these in their decision-making process. Private production activities consume resources, the costs of which are not all internalized and paid for by the producer. The costs not borne by the firm are instead borne by society. Shadow prices communicate the social cost of emission, as measured by the decrease in social welfare caused by the emission of one more unit of pollutant. Theoretical development of estimated shadow prices has generally occurred in a mathematical programming context for a variety of pollutants.[1]

The incorporation of shadow prices in the model is accomplished by partitioning the vector of inputs into two subsets: $x_1$ through $x_j$, are inputs whose use either cause zero environmental discharges or discharges whose cost is completely captured in the market prices of those inputs; and the remaining inputs, $x_{j+1}$ through $x_n$, whose use causes negative externalities through environmental discharges, the costs of which are not fully captured in the market prices of those inputs. Thus, $p_i$ for $i = 1, \ldots, j$ measures the full social opportunity cost of consuming one unit of that input, while $p_i$ for $i = j + 1, \ldots, n$ understate the full

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[1] Shadow prices for sulfur oxide(s) and nitrogen oxide(s) emissions have been computed for the Korean electrical power industry (Lee, Park, & Kim, 2002). Similarly, a linear programming approach was used to determine shadow prices for sulfur dioxide emissions in thirty regions of China (Ke, Hu, Li, & Chiu, 2008). Underscoring the versatility of a programming approach, shadow prices of runoff and leaching of pesticides was calculated in U.S. agriculture industry (Fare, Grosskopf, & Weber, 2006).

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social opportunity cost of these inputs by ignoring the effects of negative externalities. The vector of input prices may be written as follows:

$$\mathbf{P} = [p_1 + \Delta p_1, \ldots, p_n + \Delta p_n]$$

where.

$$\begin{aligned} & \Delta p_i = 0 \text{ for } i = 1, \ldots, j, \\ \text{and} \quad & \Delta p_i > 0 \text{ for } i = j+1, \ldots, n. \end{aligned}$$

The term $\Delta p_i$ measures the costs of negative externalities. The negative externalities such as those caused by environmental discharges and not captured by market price of the inputs are denoted by $\Delta p_i > 0$ i.e., the shadow prices. The first-order conditions in [4] can now be rewritten as:

$$\frac{p_i + \Delta p_i}{p_j + \Delta p_j} = \frac{f_j}{f_i} \text{ for } i, j = 1, \ldots, n \tag{5}$$

Since the market prices, $p_{i,}$ of inputs $x_{j+1}$ through $x_n$ will be less than their full social costs (or $\Delta p_i > 0$), from the point of view of society the cost center will overuse these inputs. This is the familiar negative externality problem.

In practice, attempts have been made to quantify shadow prices for various pollutants. The Clean Air Act of 1990 established a cap and trade program for emissions of sulfur dioxide in the United States and featured an auction market (Stavins, 2005). New Zealand has similarly adopted a cap and trade system for carbon emissions (Carlson 2011). United Kingdom requires that shadow price be used as part of the impact assessment for any proposed government policy (Stern, 2007). In addition to its incorporation in public policy, firms have started considering the cost of a pollutant and incorporating this price in their operational decision-making.[2]

### 2.1. Formulae for waste and sustainability variance

The solutions to Eq. (5) can be viewed as providing the standards for producing the budgeted level of output $Y_{0.}$ Those standards in turn are the basis of a system of variances that can be used to evaluate and reward the performance of both the profit and cost center managers. For any level of budgeted output, the production function can be depicted by an isoquant specifying all technically efficient input combinations that yield the given level of output. The equation of an isoquant is given as follows:

$$\begin{aligned} & Y_0 = f(x_1, x_2, \ldots, x_n) = K \\ & \text{thus, } dY_0 = f_1 dx_1 + f_2 dx_2 + \ldots + f_n dx_n = 0 \end{aligned}$$

The slope of this isoquant in any direction is:

$$\frac{dx_i}{dx_j} = -\frac{f_j}{f_i} \text{ for all } i \neq j \tag{6}$$

This slope is negative since the partial derivatives $f_i$ are all positive, assuming that increased use of any input results in higher output.

A similar construction yields an isocost construct, which is a locus of $x_i$ combinations resulting in the same level of total cost. Mathematically,

$$\begin{aligned} & C_{0\cdot} = (p_{1+}\Delta p_1)x_1 + (p_{2+}\Delta p_2)x_2 + \ldots + (p_{n+}\Delta p_n)x_n = K' \\ & \text{thus, } dC_0 = (p_{1+}\Delta p_1)dx_1 + (p_{2+}\Delta p_2)dx_2 + \ldots + (p_{n+}\Delta p_n)dx_n = 0 \end{aligned}$$

The slope of the isocost in any direction is thus.

$$\frac{dx_i}{dx_j} = -\frac{p_j + \Delta p_j}{p_i + \Delta p_i} \text{ for all } i \neq j \tag{7}$$

The first order minimization conditions [5] amount to requiring that the $x_i$ be chosen at a point of tangency between the isoquant and isocost. Thus, the socially optimal levels of input use are given by the vector

$$\mathbf{X}^* = [x_1^*,\ x_2^*, \ldots,\ x_n^*]$$

which satisfies the conditions set forth in [5] and the point of tangency described by [6] and [7]. On the other hand, the levels of input use chosen by the cost center manager will satisfy [4] and are given by the vector.

$$\mathbf{X}' = \left[x_1',\ x_2', \ldots,\ x_n'\right].$$

Since not all $\Delta p_i = 0$, $\mathbf{X}^* \neq \mathbf{X}'$. The vector $\mathbf{X}'$ lies at a different point of tangency between the isoquant and an isocost for which all $\Delta p_i = 0$. The total cost associated with $\mathbf{X}'$ exceeds the total cost associated with $\mathbf{X}^*$ because the profit center manager has planned to overuse the inputs $x_{j+1}$ through $x_n$. This difference in cost between $\mathbf{X}^*$ and $\mathbf{X}'$ will be labeled the sustainability variance. Mathematically,

$$\text{Sustainability Variance} = (\mathbf{X'})\left(\mathbf{P}^{\mathrm{T}}\right) - (\mathbf{X}*)\left(\mathbf{P}^{\mathrm{T}}\right) \tag{8}$$

Because $\mathbf{X'}$ is suboptimal from a social perspective given $\mathbf{P}$ this variance must be positive or unfavorable. The sustainability variance is shared between the firm and society. It can be decomposed as follows: First, form the vector sum $[\mathbf{X'} - \mathbf{X}^*]$. By vector addition it follows that the price vector $\mathbf{P}$ can be written as $\tilde{\mathbf{P}} + \Delta\mathbf{P}$ where,

$$\tilde{\mathbf{P}} = [p_1,\ p_2, \ldots, p_n] \qquad \text{and} \quad \Delta\mathbf{P} = \Delta p_1, \Delta p_2, \ldots, \Delta p_n].$$

The sustainability variance can thus be written,

$$\text{Sustainability Variance} = [\mathbf{X}'\text{-}\mathbf{X}*]\ \tilde{\mathbf{P}}^{\mathrm{T}} + [\mathbf{X}'\text{-}\mathbf{X}*]\Delta\mathbf{P}^{\mathrm{T}}. \tag{9}$$

Since the profit center incurs the input prices, $\tilde{\mathbf{P}}$, its share of the sustainability variance is $[\mathbf{X'} - \mathbf{X}^*]\,\tilde{\mathbf{P}}^{\mathrm{T}}$. Because $\mathbf{X'}$ is optimal given $\tilde{\mathbf{P}}$, $\mathbf{X'}\tilde{\mathbf{P}}^{\mathrm{T}} < \mathbf{X}^*\tilde{\mathbf{P}}^{\mathrm{T}}$, and the profit center's share of the variance must be favorable. Further, because the total sustainability variance is unfavorable, it follows that the share borne by society, $[\mathbf{X'} - \mathbf{X}^*]\,\Delta\mathbf{P}^{\mathrm{T}}$ is unfavorable.

[Note that $\mathbf{X'}$ and $\mathbf{P}$ are row vectors, thus transposing $\mathbf{P}$ and multiplying by $\mathbf{X'}$ yields a scalar.]

We also recognize the possibility that the actual use of the inputs will differ from that planned, $\mathbf{X'}$, due to inefficiency or waste. Let the vector

$$\mathbf{X^a} = [x_1^a,\ x_2^a, \ldots,\ x_n^a]$$

which denotes the actual usage of inputs contain at least one element $x_i^a > x_i'$. The difference in cost between $\mathbf{X^a}$ and $\mathbf{X}'$ will be referred to as the efficiency or waste variance. Mathematically,

$$\text{Waste Variance} = (\mathbf{X}^{\mathrm{a}})\left(\mathbf{P}^{\mathrm{T}}\right) - (\mathbf{X}')\left(\mathbf{P}^{\mathrm{T}}\right) \tag{10}$$

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[2] Microsoft imposes a significant fee on each of its divisions for carbon emissions that they produce. Additionally, the U.K.-based energy company National Grid has developed an internal budget for carbon which ties CEO and other executive compensation to greenhouse gas reduction goals (Lubber, 2010). Google also employs a cost for carbon emissions when deciding on new infrastructure. Wal-Mart's U.K. operation embeds a carbon shadow price in all of its carbon mitigating investment decisions. Woolworths (Australia), a supermarket chain, factors a similar price into all areas of its business and all potential investments.

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By development similar to that leading to [9] above, the waste variance may be written as:

$$\text{Waste Variance} = \left[\mathbf{X}^{a}\text{-}\mathbf{X}'\right]\tilde{\mathbf{P}}^{T} + \left[\mathbf{X}^{a}\text{-}\mathbf{X}'\right]\Delta\mathbf{P}^{T}. \tag{11}$$

The portion of the variance borne by the cost center, $[\mathbf{X^a} - \mathbf{X'}]\,\tilde{\mathbf{P}}^T$, is unfavorable since $\mathbf{X^a}$ is not optimal given the price vector $\tilde{\mathbf{P}}$. Likewise, the share of the waste variance borne by society, $[\mathbf{X^a} - \mathbf{X'}]\,\Delta\mathbf{P}^T$, is also unfavorable.

The total variance is the sum of sustainability and waste variance, or.

$$\text{Total Variance} = \left(\mathbf{X}^{a}\right)\left(\mathbf{P}^{T}\right)-\left(\mathbf{X}^{*}\right)\left(\mathbf{P}^{T}\right). \tag{12}$$

When simplifying to the case of two inputs, these variances can be demonstrated graphically as shown in Fig. 1. Here the isoquant YY′ contains all technically efficient combinations of the inputs $x_1$ and $x_2$ capable of producing the budgeted level of output $Y_0$. Input $x_1$ causes zero environmental discharges, i.e., $\Delta p_1 = 0$, while input $x_2$ causes discharges with costs not captured by its market price $p_2$, i.e. $\Delta p_2 > 0$. Once the prices of the inputs $[(p_1)_, (p_2 + \Delta p_2)]$ are known, the optimal combination of $x_1$ and $x_2$ can be identified as the tangency between YY′ and the isocost line $C_0 = p_1x_1 + (p_2 + \Delta p_2)x_2$. This point has been labeled $\mathbf{X}^*$ in the exhibit. The firm can depart from this optimal point in two ways: First, if the profit center manager regards $\Delta p_2$ as zero, $x_2$ will be substituted for $x_1$ in production. The input proportions chosen will lie at the tangency between the isoquant YY′ and the isocost line $C_0' = p_1x_1 + p_2x_2$. This point has been labeled $\mathbf{X'}$ in the exhibit. Second, the actual amounts of $x_1$ and $x_2$ used by the cost center to produce the budgeted level of output may exceed those required by the production function due to wastage. Assume that the actual usage of the inputs is indicated by point $\mathbf{X^a}$ in Exhibit 1.

In Fig. 2, the waste and sustainability variances are graphically illustrated. The difference between total cost at point $\mathbf{X^a}$ and total cost at point $\mathbf{X'}$ is identified as a waste or efficiency variance. In addition to the waste variance, the difference in total cost between points $\mathbf{X}'$ and $\mathbf{X}^*$ represents an unfavorable variance that has arisen because the proportions or mix in which the inputs were used is not optimal given their full prices. This is the sustainability variance.

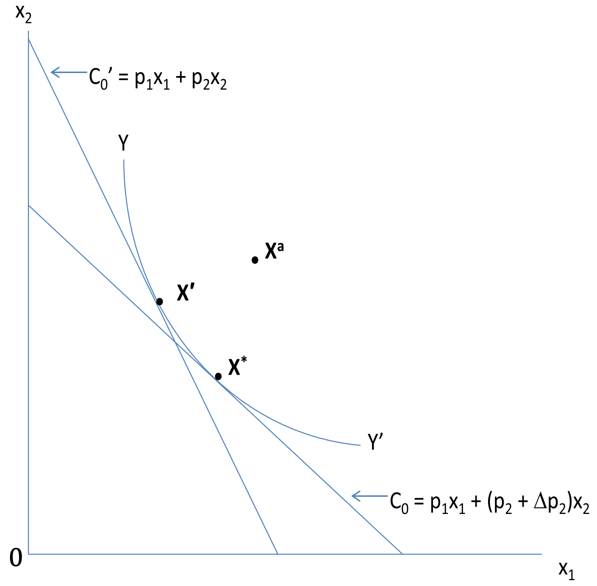

**Fig. 1.** A comparison of optimal combination of inputs with and without consideration of the cost of environmental externalities. Xa represents the actual usage of inputs, **X′** the optimal level of inputs *without* consideration of externalities, and **X*** the optimal level of inputs *with* consideration of externalities.

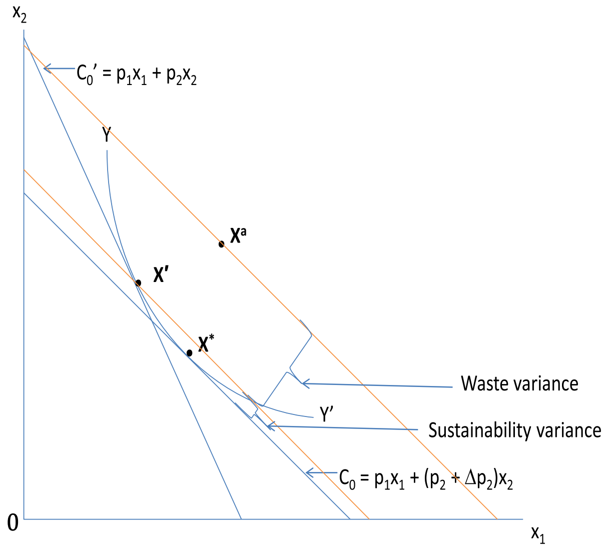

**Fig. 2.** Graphical representation of waste and sustainability variance. The waste variance is the difference in cost incurred at Xa as compared to those incurred at **X'**; the sustainability variance the difference in cost incurred at **X'** as compared to those incurred at **X***. Xa represents the actual usage of inputs, **X'** the optimal level of inputs *without* consideration of externalities, and **X*** the optimal level of inputs *with* consideration of externalities.

To the extent that the waste errors resulted in the over consumption of $x_2$, there will be excess discharges into the environment. Control of the waste variance will therefore reduce such excess discharges. Such control corresponds to the low hanging fruit of sustainability efforts. This is a win-win situation as cost to the firm falls and environmental discharges are reduced. Since the price of $x_2$ captures only the private cost of its usage and there are important external (social) costs of discharges that are not borne by the firm, i.e. $\Delta p_2 > 0$, the profit center manager will systematically overuse $x_2$ (from a social cost standpoint) and cause excess discharges to the environment. The sustainability variance informs top management as to the social cost of ignoring the discharges resulting from such over consumption of $x_2$.

## 3. Numerical example

In this section we illustrate the computation of variances, developed above, with the aid of numerical examples. For ease of illustration, we restrict the production function to two-inputs. Three examples are presented in which the degree of substitutability between the inputs vary. It is shown that as the degree of substitutability between the inputs increases, the sustainability variance becomes relatively larger.

In each example the firm is constrained by a production function of the constant elasticity of substitution (CES) type. The choice of the CES production function allows us to vary the ease with which the firm may substitute one input for another in production as measured by the elasticity of substitution. Such variation can affect efforts to implement strategic sustainability goals. The elasticity of substitution may vary across cost centers within a single firm due to a number of factors including: local regulatory constraints; resource availability; and, technical knowledge (Johansen, 1972). Econometricians have estimated the parameters of the CES function in numerous studies since the 1960s (Arrow, Chenery, Minhas, & Solow, 1961; Johansen, 1972; Nerlove, 1967). Recent studies (Dissou, Karnizova, & Sun, 2014; Kemfert, 1998; Van der Werf, 2008), have estimated elasticites of substitution using capital, labor, and energy inputs to address sustainability issues.

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For a two input production function, assume that the budgeted level of output is $Y_0$ units and that the production function can be represented as:

$$Y_0=A\left[\alpha x_1^{-\rho}+(1-\alpha)x_2^{-\rho}\right]^{-1/\rho}$$

where:

A, α, and ρ are the suitable exponents and coefficients defined by the technical process.

The extent of substitution possibilities between $x_1$ and $x_2$ is determined by the parameter ρ with the elasticity of substitution given by $\sigma = 1/(1+\rho)$. As ρ approaches −1, the elasticity of substitution approaches infinity, the inputs become perfect substitutes, and the isoquants of the production function become linear. As ρ approaches ∞, the elasticity of substitution approaches zero, substitution becomes impossible and the curvature of the isoquants approaches a right angle. In this section we illustrate three examples by varying the degree of elasticity by changing ρ from −0.8, to zero to 4. In Fig. 3 three representative isoquants are shown for various values of ρ.

The profit center manager is assumed to know the prices $p_1$ and $p_2$ for inputs $x_1$ and $x_2$, respectively. The manager chooses $x_1$ and $x_2$ by solving the constrained minimization problem below:

$$\begin{array}{ll}\text{Minimize} & TC = p_1x_1 + p_2x_2 \\ \text{Subject to} & Y_0 = A\left[\alpha x_1^{-\rho} + (1-\alpha)x_2^{-\rho}\right]^{-1/\rho}\end{array}$$

The problem is most easily solved by means of the Lagrange multiplier method. Thus, we seek to minimize:

$$Z=p_1x_1+p_2x_2+\lambda\{A[\alpha x_1^{-\rho}+(1-\alpha)x_2^{-\rho}]^{-1/\rho}-Y_0\}$$

The first-order minimization conditions are:

$$\begin{aligned} Z_1 &= p_1\text{-}\lambda\frac{\alpha}{A^\rho}\left(\frac{Y_0}{x_1}\right)^{\rho+1}=0 \\ Z_2 &= p_2\text{-}\lambda\frac{(1-\alpha)}{A^\rho}\left(\frac{Y_0}{x_2}\right)^{\rho+1}=0 \\ Z_\lambda &= A\left[\alpha x_1^{-\rho}+(1-\alpha)x_2^{-\rho}\right]^{-1/\rho}-Y_0=0 \end{aligned}$$

The first two of these conditions simplify to

$$\frac{x_2}{x_1}=\left[\frac{(1-\alpha)}{\alpha}\right]^{\frac{1}{1+\rho}}\left(\frac{p_1}{p_2}\right)^{\frac{1}{1+\rho}}$$

Using the third of the first order conditions, $x_1$ and $x_2$ are obtained through successive substitutions. To develop numerical solutions to this model we assume the following values for the various parameters, the input prices and budgeted output: $\alpha = 0.5$; $A = 10$; $p_1 = \$10$; $p_2 = \$5$; $\Delta p_2 = \$3$ and $Y_0 = 1000$ units. We also assume that the actual inputs used by the cost center are 20% greater than optimal; this excess denotes waste. In the examples below, we vary the value of the parameter ρ to produce three scenarios that allow for different degrees of input substitutability. The waste and sustainability cost variances are calculated under each scenario.

### 3.1. Scenario 1 — high degree of input substitutability

In this first scenario we assume $\rho = -0.8$ making the inputs easily substitutable and generating isoquants that approach linearity. Solving the first order conditions as indicated yields $x_1 = 6.890$; $x_2 = 220.484$; and the optimal total firm cost TC = \$1171.32. As per the assumption stated above, the cost center manager produces the budgeted output of 1000 units but actually consumes 20% more of each input, i.e. 8.268 units of $x_1$ and 264.580 units of $x_2$. This inefficiency results in actual cost of \$1405.58, and a variance of \$234.26. The variance of \$234.26 is due to waste and is borne by the firm.

Because the cost of environmental discharges was not borne by the firm, such external costs were disregarded when deciding on the production mix. Once the price of environmental discharges, $\Delta p_2$ becomes available the variance model can assess the cost of ignoring the full cost to society. Consideration of the cost of environmental discharges will increase the price of some of the resources used by a firm. In our example, the price of $x_2$ will be increased in order to reflect the full cost of discharges into the environment. We note however, that the cost of other inputs will not change, i.e. $\Delta p_1 = 0$. Assume that the full social cost of a unit of $x_2$ is \$8. That is, each additional unit of $x_2$ used in production increases social cost by $\Delta p_2 = \$3$. This change in relative prices will alter the optimal solution of the cost minimization problem. The new

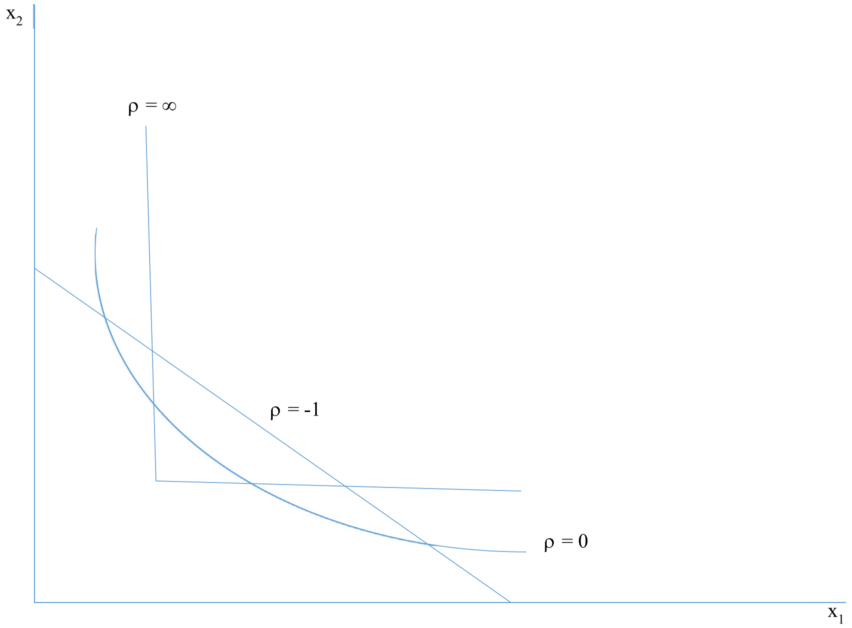

**Fig. 3.** Isoquants corresponding to varying degrees of substitutability.

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solution values are $x_1 = 50.742$; $x_2 = 154.852$; and optimal total societal cost is \$1746.24, of which \$464.56 is borne by the society, and \$1281.68 is borne by the firm.

Recall, the cost center manager consumes 8.268 units of $x_1$ and 264.580 units of $x_2$. In addition to \$1405.58 borne by the firm, the cost to the society is \$3 for each of the 264.580 units of $x_2$ consumed or \$793.74. The actual total societal cost of producing the 1000 units is the sum of the amounts borne by the firm and by the society, or \$2199.32. The total cost variance is the actual total societal costs less optimal total societal costs, or \$2199.32–\$1746.24 = \$453.08. This total may be decomposed into portions borne by the firm and portions borne by society as shown in Table 1.

Had the cost center used the inputs efficiently, it would have consumed 220.484 units of $x_2$. It has thus over consumed $x_2$ in the amount of 264.580–220.484 = 44.096 units. Since there is a \$3 per unit social cost of $x_2$ consumption, this overconsumption imposes an additional cost on society of \$3 × 44.096 = \$132.29. Note that the cost center's overconsumption of $x_1$ imposes no additional burden on society since $\Delta p_1 = 0$.

Further, when the profit center ignores the \$3 per unit cost of $x_2$ to society, its optimal choice of input proportions changes. Again there are costs to society resulting from the overconsumption of $x_2$, attributable to the cost center. The firm optimal level is to consume 220.484 units of $x_2$ while the socially optimal level is 154.852 units of $x_2$. At a social cost of \$3 per unit the sustainability variance borne by society is \$196.89. The firm, however, enjoys a favorable variance of \$110.36. This variance arises because the profit center manager ignores the social cost and chooses the optimal process based on cash prices of $x_1$ and $x_2$. It thus, substitutes relatively cheaper $x_2$ for $x_1$. The \$110.36 can be reconciled as follows:

| | | | |
|---|---|---|---|
| Additional units of $x_2$ consumed | 220.484–154.852 | = | 65.631 |
| Cash outflow for additional $x_2$ | \$5 × 65.631 | = | \$328.16 |
| Reduction in $x_1$ consumption | 50.742–6.890 | = | 43.852 |
| Cash savings from reduced $x_1$ consumption | = 10 × 43.852 | = | (438.52) |
| Net savings | | = | 110.36 |

### 3.2. Scenario 2: Cobb–Douglas production function, $\rho = 0$

In this scenario all parameters, prices, and output are unchanged with the exception of $\rho$ which is now assumed to be zero. With $\rho = 0$ the elasticity of substitution becomes one and the production function takes on the familiar Cobb–Douglas form. With $\rho = 0$ and $\alpha = 0.5$ the first order conditions requiring tangency between isoquant and isocost now simplify to the following:

$$\frac{x_2}{x_1} = \left(\frac{p_1}{p_2}\right)$$

Cost minimization now requires $x_2 = 2x_1$. Substitution into the production function for $Y_0 = 1000$ yields $x_1 = 70.711$ and $x_2 = 141.421$. The associated level of optimal total firm cost is now \$1414.21. As in scenario 1, it is assumed that the cost center manager uses 20% more of each input than is necessary, i.e. actual values are $x_1 = 84.853$ and $x_2 = 169.706$. These inefficiencies result in actual cost of \$1697.06 and a waste variance of \$1697.06–1414.21, or \$282.85, borne by the firm.

**Table 2**
Computation of variances under scenario 2: Cobb–Douglas case.

| | Total | Borne by the Firm | Borne by Society |
|---|---|---|---|
| Waste variance | \$367.70 U | \$282.85 U | \$84.85 U |
| Sustainability variance | \$ 49.62 U | \$39.23 F | \$88.85 U |
| Grand total | \$417.32 U | \$243.62 U | \$173.70 U |

Note: U = unfavorable; F = favorable. Numbers may not add up due to rounding.

With a shadow price for $x_2$ of \$3 per unit, the socially optimal input proportions are given by $x_2 = 1.25x_1$ and the socially optimal input mix is $x_1 = 89.443$ and $x_2 = 111.804$. The optimal total societal cost is \$1788.85, of which \$335.41 is borne by the society and \$1453.44 is borne by the firm. At the actual level of usage of inputs, the costs borne by the society is \$3 × 169.706 units of $x_2$, or \$509.12. The actual total societal cost is the sum of costs borne by the society of \$509.12 and that borne by the firm of \$1697.06, or \$2206.18. The total cost variance is \$2206.173–\$1788.854 = \$417.319. As before, this total may be decomposed into portions borne by the firm and portions borne by society as shown in Table 2.

### 3.3. Scenario 3: low substitutability of inputs

In this scenario, input substitution possibilities will be significantly restricted by choosing $\rho = 4.0$ yielding an elasticity of substitution of 0.2, and isoquants approaching right angles. With the remaining parameter values, input prices and output unchanged, the cost minimizing solution yields input values of $x_1 = 94.193$ and $x_2 = 108.199$. The optimal total firm cost equals \$1482.92. Again assuming inefficient behavior on the part of the cost center actual levels of usage are $x_1 = 113.031$ and $x_2 = 129.839$. Actual total cost is \$1779.51 and the firm bears a waste variance of \$296.58.

Maintaining the \$3 per unit shadow price on $x_2$ results in a socially optimal level of input $x_1 = 97.891$ and $x_2 = 102.358$ yielding optimal total societal cost of \$1797.77 while actual total societal cost is \$2169.03. The total variance of \$2169.02 - \$1797.77 = \$371.25 is decomposed as in Table 3.

### 3.4. Comparison across the three scenarios

We compare the inputs and costs of the above three scenarios in Table 4. We present the input quantities and costs for the three points of interest: actual, firm-optimal; and societal optimal. Next, in Table 5 we compare the variances for each of the three scenarios decomposed into components borne by the firm and society.

Two interesting observations are apparent from Table 5. First, as the elasticity of substitution decreases, the sustainability variance decreases as well. This is an intuitive result, as it becomes increasingly difficult for firms to substitute one input for another, hence the change in input proportions is less responsive to shadow price information, resulting in lower sustainability variances. For a high level of elasticity, denoted by $\rho = -0.8$, the sustainability variance is \$86.53 unfavorable. This reflects a forgone societal benefit of \$196.89 while the firm's direct costs are reduced by \$110.36. For the Cobb–Douglas production function, $\rho = 0$, the sustainability variance decreases to \$49.55, and the potential

**Table 1**
Computation of variances under scenario 1 high degree of input substitutability.

| | Total | Borne by the firm | Borne by society |
|---|---|---|---|
| Waste variance | \$366.55 U | \$234.26 U | \$132.29 U |
| Sustainability variance | \$86.53 U | \$110.36 F | \$196.89 U |
| Grand total | \$453.08 U | \$123.90 U | \$329.18 U |

Note: U = unfavorable; F = favorable. Numbers may not add up due to rounding.

**Table 3**
Computation of variances under scenario 3: low degree of substitutability.

| | Total | Borne by the firm | Borne by society |
|---|---|---|---|
| Waste variance | \$361.50 U | \$296.58 U | \$64.92 U |
| Sustainability variance | \$ 9.75 U | \$7.77 F | \$17.52 U |
| Grand total | \$371.25 U | \$288.81 U | \$82.44 U |

Note: U = unfavorable; F = favorable. Numbers may not add up due to rounding.

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**Table 4**
Comparison of variances across three production functions.

| | Highly substitutable<br>p = −0.8 | | | Cobb–Douglas (baseline)<br>p = 0 | | | Low substitutability<br>p = 4 | | |
|---|---|---|---|---|---|---|---|---|---|
| Input units and costs: | $x_1$ | | $x_2$ | $x_1$ | | $x_2$ | $x_1$ | | $x_2$ |
| Units of input at $\mathbf{X^a}$ | 8.268 | | 264.580 | 84.853 | | 169.706 | 113.031 | | 129.839 |
| Firm's cost of inputs at $\mathbf{X^a}$ | \$82.68 | | \$1322.90 | \$848.53 | | \$848.53 | \$1130.31 | | \$649.20 |
| Social costs of input at $\mathbf{X^a}$ | \$0 | | \$793.74 | \$0 | | \$509.12 | \$0 | | \$389.52 |
| Firm's total costs at $\mathbf{X^a}$ | | \$1405.58 | | | \$1697.06 | | | \$1779.51 | |
| Societal total costs at $\mathbf{X^a}$ | | \$2199.32 | | | \$2206.18 | | | \$2169.03 | |
| Units of input at $\mathbf{X'}$ | 6.890 | | 220.484 | 70.711 | | 141.421 | 94.193 | | 108.199 |
| Firm's cost of inputs at $\mathbf{X'}$ | \$68.90 | | \$1102.42 | \$707.11 | | \$707.11 | \$941.93 | | \$541.00 |
| Social costs of input at $\mathbf{X'}$ | \$0 | | \$661.45 | \$0 | | \$424.26 | \$0 | | \$324.60 |
| Firm's total costs at $\mathbf{X'}$ | | \$1171.32 | | | \$1414.22 | | | \$1482.93 | |
| Societal total costs at $\mathbf{X'}$ | | \$1832.77 | | | \$1835.48 | | | \$1807.53 | |
| Units of input at $\mathbf{X^*}$ | 50.742 | | 154.852 | 89.443 | | 111.804 | 97.891 | | 102.358 |
| Firm's costs of inputs at $\mathbf{X^*}$ | \$507.42 | | \$774.26 | \$894.43 | | \$559.02 | \$978.91 | | \$511.79 |
| Social costs of inputs at $\mathbf{X^*}$ | \$0 | | \$464.56 | \$0 | | \$335.41 | \$0 | | \$307.07 |
| Total costs at $\mathbf{X^*}$ | | \$1281.68 | | | \$1453.52 | | | \$1490.70 | |
| Societal total costs at $\mathbf{X^*}$ | | \$1746.24 | | | \$1788.86 | | | \$1797.77 | |

societal benefit from substitution of inputs decreases to \$88.85, or about 45% of the benefit in scenario 1. For a low level of elasticity, $\rho = 4$, the sustainability variance further decreases to \$9.76, and the potential societal benefit from substitution of inputs declines to \$17.53, or about 9% of the benefit in scenario 1.

Second as the elasticity of substitution falls, causing the decrease in the sustainability variance, a firm can achieve its sustainability goals primarily through a reduction of waste. The variance borne by the society due to waste and sustainability are reported as a percentage of the total in Table 5. As $\rho$ increases the percentage increases for the waste variance, and decreases for sustainability variance. Specifically, when $\rho = 4$, the inputs are poor substitutes and the sustainability variance is only 20% of the total variance borne by society. Consequently, when input substitution possibilities are limited, imposition of a shadow price will elicit little if any response in input proportions and therefore little benefit to society. Such a firm will be effectively controlled at the level of cost center by monitoring the waste variance as this is the primary means for it to contribute towards the firm's sustainability goals. In this case, the profitability objective of the firm is aligned with its sustainability objective. Performance measurement thereby can rely upon traditional income based measures and integrating shadow prices into the compensation formula achieves little.

On the other hand, when $\rho = -0.8$, the inputs are good substitutes, the sustainability variance is about 60% of the total variance borne by the society. Social performance of a cost center facing more extensive substitution possibilities will be improved by monitoring not only waste but costs that arise due to the choice of input proportions. Were the firm to impose a shadow price, it should anticipate that the manager of such a profit center would make a more substantial change in input proportions. Failure of the profit center manager to react to the shadow price would be captured by the sustainability variance proposed above. A compensation formula sensitive to the sustainability variance will better align this manager's incentives with the sustainability goals of the firm.

## 4. Discussion

The extension of cost variance analysis to incorporate sustainability and waste variances sensitive to shadow prices is useful in the context of management control. These variances measure the additional social cost incurred when a firm operates suboptimally. They help management deploy effective performance measurement systems as discussed below.

The analysis described in this paper can help top management evaluate the trade-offs between firm profits and social benefits. While it is possible for firms to initially pursue initiatives that reduce costs while simultaneously providing benefit to society, eventually these "win-win" situations will become exhausted. Having a mechanism by which to evaluate the cost to the firm and the benefits to society from further environmental initiatives is beneficial in decision making. Additionally, it enables firms to evaluate whether such trade-offs are justified and should be pursued by the firm.

A firm that develops a compensation system predicated on a principal-agent relationship would reward management efforts to eliminate the waste variance. Reducing that variance would allow the firm to produce its budgeted level of output at lower cost. Such cost savings would be reflected in increased operating income that would trigger rewards to management under a compensation system designed to enhance profitability and shareholder wealth. Our model and illustrations demonstrate that society would benefit from such management behavior. To argue that the rewards to management for reducing this variance are predicated on achieving some stated environmental goal constitutes what some might call "green-washing." The sole pursuit of such behavior is consistent with the argument made by some researchers (such as Siegel, 2009) that managers should adopt "green management" practices only if such actions enhance profitability or shareholder wealth. As we have shown, for firms with production functions with low degrees of input substitutability, waste reduction may be the only viable option to attain sustainability goals.

**Table 5**
A comparison of variances.

| | Highly substitutable<br>$\rho = -0.8$ | | Cobb–Douglas<br>$\rho = 0$ | | Low substitutability<br>$\rho = 4$ | |
|---|---|---|---|---|---|---|
| Variance computations | Borne by Firm | Borne by Society | Borne by Firm | Borne by Society | Borne by Firm | Borne by Society |
| Waste variance | \$234.26 U | \$132.29 U | \$282.84 U | \$84.86 U | \$296.58 U | \$64.92 U |
| Sustainability variance | \$110.36 F | \$196.89 U | \$39.30 F | \$88.85 U | \$7.77 F | \$17.53 U |
| Total variance | \$123.90 U | \$329.18 U | \$243.54 U | \$173.71 U | \$288.81 U | \$82.45 U |
| Waste variance as a percentage of total | | 40.19% | | 48.85% | | 78.74% |
| Sustainability variance as a percentage of total | | 59.81% | | 51.15% | | 21.26% |

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In other situations, consideration of shadow prices can enable better alignment between an organization's desire to pursue sustainability initiatives and the evaluation of its managers' performance. For firms employing technologies where inputs have a higher degree of substitutability, social cost savings can be achieved not only through the reduction of waste but also through the appropriate choice of input proportions. While reduction of waste benefits both the firm and society, altering input proportions benefits society at a cost to the firm. In these cases, there must be an incentive for managers to reduce the sustainability variance since such efforts will adversely impact operating income and the manager's compensation when based on income-related measures of performance. The sustainability variance can motivate managers to consider the trade-off between social benefits and firm costs when choosing input proportions. Ignoring the sustainability variance makes it difficult for managers to justify the pursuit of environmental goals beyond waste reduction. Some firms currently are attempting to take these trade-offs into account. Simple incorporation of shadow prices can lead to achievement of socially optimal input proportions in organizations where a single layer of management is responsible for both investment and operating decisions. Such managers can be presumed to control both input proportions and waste reduction.

In other organizations, investment and operational decisions are made by different layers of management. That is, in such organizations, one manager decides on input proportions and another controls use of inputs and therefore waste. The savings due to waste reduction are solely attributable to the manager who controls input usage. Similarly, the benefits accrued due to proper input choice are solely attributable to the investment center manager. A simple imposition of a shadow price would not enable the organization to distinguish between social savings due to waste reduction and those attained through a change of input mix. Inability to distinguish between the causes is important as it impacts how individual managers are compensated. For example, a reduction of waste through the efforts of the operational manager leads to social benefits for which the investment center manager will be compensated without having contributed to the effort. Identification of waste and sustainability variances in the performance measurement system would preclude such inefficiencies. Specifically, the investment center manager can be compensated based on the sustainability variance which he controls and the operational manager compensated on reduction of the waste variance. Such segregation of responsibility would not be possible in multi-layer organizations merely through the incorporation of a shadow price.

## 5. Conclusion

Pursuit of a strategy that includes environmental goals requires that the compensation system reward management efforts directed towards those environmental benefits that would not occur as an unintended result of profit maximizing behavior. Our model demonstrates that such a system can be constructed. Reduction or elimination of the "sustainability variance" represents a benefit to society that is achieved at a cost to the short-term profitability of the firm. However, having a proactive environmental strategy can have a positive impact on the long-term profitability of a company (Clarkson, Yue, Richardson, & Vasvari, 2011) in terms of its relationship with various stakeholder groups and the resultant increase in the value of its brand.

Some firms have focused on waste reduction to achieve environmental goals, others have instituted shadow prices to account for negative externalities. If progress towards the environmental goals would have been achieved under profit maximizing behavior, then any additional rewards are redundant and the design of the underlying compensation system is deficient. Only incremental environmental benefits need to be rewarded to pursue strategic environmental goals. As demonstrated, firms facing production functions with limited possibilities for input substitution can attain sustainability goals primarily through waste reduction. Imposition of shadow prices in such firms produces little social benefit. By contrast, firms with higher degrees of input substitutability can attain sustainability goals not only through waste reduction, but also through appropriate choice of input mix. Imposition of shadow price in such firms will produce social benefit in addition to that provided by waste reduction.

Furthermore, firms with a high degree of input substitutability that rely on decentralized management structures will fail to respond adequately to the imposition of a shadow price. In such cases, use of a system of variances such as that developed in this paper can lead to design of appropriate performance evaluation systems. This paper has presented the design of a single management accounting system capable of supporting both environmental management goals and traditional firm goals.

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