INDUCING GREEN BEHAVIOR IN A MANUFACTURER

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ABSTRACT

The triple bottom line (economic, environmental, and social performance) is an important approach to long-term sustainability of a manufacturing company. However, a manufacturer will always feel pressure to focus on the economic bottom line and to give at least equal importance to the second and third bottom lines (environmental and social performance). As environmental issues become more important to citizens, they demand enhanced environmental performance from companies by exerting pressure on public policy makers to enact regulations, taxes, permits, and penalties that motivate companies to improve their environmental performance. We present a model that could be used by governmental policy makers to predict the effects from reducing the number of emissions permits and increasing the penalties for exceeding allowable emission limits. Our model is for a product that has a limited selling season. We propose a newsvendor model to estimate a manufacturing company's optimal production quantity based on maximization of expected profits given the cost of emission permits and penalties for exceeding emission limits allowed by the permits. In addition, the newsvendor model provides insights to policy makers on the effects of adjusting the regulatory levers of emission permits and penalties.

JEL: M11, R38

KEYWORDS: Triple Bottom Line, Manufacturing, Sustainability, Green

INTRODUCTION

In any economy around the globe, manufacturers will try to maximize their profit rationally. However, the public has increasing interest in environmentally safe products and processes. Implementing methods to motivate manufacturers to reduce emissions is increasingly important for policy makers as citizens are becoming more conscious of the negative effects of pollution. The triple bottom line of economic, environmental, and social performance (Elkington, 1994, 1998) is an important concept for sustainability. Without the bottom line (economic performance), companies will not be able to invest time in the other two pillars of the triple bottom line because they will be worried about solvency. Therefore, a government agency will directly influence a company's environmental performance most by creating regulations and policies that affect the company's economic performance. If a policy or fee impacts a manufacturer's expected profits, the manufacturer will act to improve its profit. Therefore, without dictating emissions, clean technologies, landfill quotas, or production limits, a regulatory agency can use the levers in our model to provide incentives for clean, sustainable manufacturing.

The remainder of the paper is organized as follows. In the next section we discuss the relevant literature. In the following section we identify the problem at hand. Next, we discuss the policy implications associated with our findings. The paper closes with a discussion of some managerial implications of this work.

LITERATURE REVIEW

The first widespread definition of sustainable development was presented in *Our Common Future* (World Commission on Economic Development, 1987, p. 8) in which sustainable development was described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Later, other authors, e.g., Elkington (1994, 1998), expanded the definition of sustainability to include the triple bottom line of economic, environmental, and social performance. Environmental issues are becoming increasingly important to the public, e.g., as far back as 1995, four out of five Americans believed that pollution threatened the quality of their lives (Kuzmiak, 1995). In other words, Americans are becoming increasingly aware of the environment, and they are attempting to influence manufacturers and government to take action. As regulations become more pervasive and stricter, manufacturing companies must be prepared to invest in new production methods, materials, and equipment or pay higher penalties for producing pollution. Therefore, a manufacturer must account for emissions explicitly in its product cost. In the European Union, the impact of emissions on the environment has been the focus of study for some time. The European Union (EU) recently enacted the Registration, Evaluation, and Restriction of Chemicals (REACH) regulation that forces manufacturing companies and importers to find safer alternatives for high concern chemicals (Lockwood, 2008). However, the United States has lagged behind the EU in research and action that would enable policy makers to bring about pollution reduction.

Even with the lagging regulation in the U.S., companies such as 3M launched Pollution Prevention Pays in 1975, which they claim has since eliminated 1.6 billion pounds of air, water and land pollution (Meyer, 2000). Similarly, DuPont reportedly has halved its landfill waste (Meyer, 2000). Interface Carpets' environmentally sound product lines accounted for 10-15% of profits in 1997 (Meyer, 2000). General Electric (GE) estimates that the revenue it will bring in from environmental technology alone will reach $20 billion by 2010 (Wade, 2005). Rennie (2008) discussed other initiatives at Ford, where designers are starting to incorporate post-industrial materials in seats, and at Caterpillar, which since 2001 has seen its remanufacturing business grow by almost 70%. Of course, stricter environmental laws also are keeping companies such as GE from polluting. For example, in 2007, GE incurred Global Paid Penalties of $236,000, down from $351,000 in 2004 (GE Citizenship Performance Metrics, 2008).

The total cost of complying with environmental laws over the past 25 years has exceeded $1 trillion, and about $120 billion continues to be spent annually for pollution abatement and control (Berry & Rondinelli, 1998). A higher tax can be charged for waste (a disincentive), or taxes can be lowered on desirable activities to provide economic incentives for reducing excessive environmental and social costs (Corson, 2002). Taxes also can be levied to the end users, to the manufacturer, or to multiple players. However, charging the end users often is ineffective as they are too far removed from the design and manufacturing processes to bring about significant changes in material use or pollution. Therefore, to encourage the design of ways to control pollution, upstream instruments are needed (Calcott & Walls, 2000). Two commonly used methods to reduce harmful emissions are subsidies for not emitting pollutants and taxes on the level of emissions. Many argue that subsidies can increase the cost of government, burden the economy, and hurt long-term development (Kohn, 1992). However, Nakada (2004) found that with taxes, profit losses are offset by the incentive to engage in research and development.

A company will produce products using processes that may or may not pollute, depending on the best way to maximize profit. We posit that a company may not necessarily be environmentally conscious from an altruistic standpoint, but if the proper government levers are applied, the manufacturer's optimal production strategy will be aligned with the government's desire for a clean environment. The government can enact regulations for fees on pollution, hazardous waste disposal, permit prices, and a cap on the total number of permits available for emissions. In addition, some firms may be motivated to invest in green production processes to attract green consumers and investors (Fairchild, 2008).

Aidt and Dutta (2004) take a more generalized approach to the issue of who should be responsible for the cost of emissions; they describe the differences among three policy instruments: (1) uniform emissions standards, (2) tradable permits, and (3) emission taxes, all of which are methods for motivating manufacturers to reduce emissions. Subramanian, Gupta, and Talbot (2007) studied different manufacturer compliance strategies under permits for emissions: investment in abatement, bidding for permits, and adjustment of output levels. In our paper, we deal primarily with emission permits, penalties, and adjustment of output levels. We treat investment in abatement as an issue for future study. Unlike Subramanian, Gupta, and Talbot (2007), we allow for the possibility of firms paying penalties for exceeding emission limits, assume that demand is stochastic (rather than deterministic), and include a disposal/salvage cost at the end of the season.

We seek to gain wide-reaching insights by examining one particular manufacturer that seeks to maximize profits by producing one product that is subject to a policy maker's costs for permits, disposal, pollution penalty fees, and a cap on the maximum number of permits available. Our model should prove useful to a manufacturing company to determine its profit-maximizing production quantity and to policy makers to establish permit numbers and penalty costs.

PROBLEM

We examine a single manufacturer that makes only one product in a competitive setting. The product is perishable, and due to the toxicity of its components, a disposal fee must be paid for any products on hand at the end of the selling season. For example, this disposal fee could be a landfill fee. During manufacture of the product, permits for a certain level of emissions are available. Additional emissions incur a penalty substantially higher than the permit price. We assume that the manufacturer is a price taker. Given that substitute products from other manufacturers exist, the manufacturer is unable to pass on the cost of environmental compliance to its customers. The manufacturer does not have to exist strictly in a commodity market; rather, we assume that even with moderate product differentiation and a brand premium, there is a limit to how much the manufacturer can charge to offset increased costs due to polluting. The manufacturer cannot merely raise its prices to offset permit prices and penalty fees. The manufacturer seeks to maximize its profit given the permits and penalties set by the government. Given a forecast of demand and an expected standard deviation of demand for a product, it would be optimal for the manufacturer to solve a newsvendor equation and to buy exactly the specified number of permits corresponding to its optimal production quantity for the product. However, we assume that there is a scarcity of permits due to government regulations directed at reducing overall emissions.

Given that the product is perishable, the manufacturer would determine its profit maximizing quantity using a newsvendor equation assuming unlimited permits. The manufacturer then would purchase as many permits as it could up to its profit maximizing quantity. After that, the manufacturer would solve another newsvendor equation to determine how many units above the permit quantity to produce. This revised newsvendor model would consider the increased penalty costs, which would be substantially higher than permit costs. The manufacturer's goal, once again, would be to maximize its expected profit.

<u>Model Notation</u>

p	Selling price per unit of the end product
c	Manufacturing cost per unit (materials and labor)
a	Maximum number of permits available
e	Emissions permit cost (per unit of output)
λ	Emissions penalty cost (per unit of output without permit)

δ	Cost per unit to dispose of unsold products (assessed to the manufacturer)
F	Cumulative distribution function of demand
f	Probability density function of demand
μ	Mean demand
σ	Standard deviation of demand
q_1^*	Optimal quantity to produce when permits are unlimited
q_p^*	Optimal quantity to produce if no permits are available
q_2^*	Optimal quantity to produce beyond the permit cap
q_u^*	Optimal quantity to produce if no permits or penalties apply to the product

Assumptions

The product is perishable and cannot be sold after the selling season, for example, high-tech electronic components. Furthermore, the product has zero value at the end of its selling season and may incur a disposal cost. A salvage value could be modeled easily by letting δ include a negative component corresponding to the salvage value. Thus, δ would be the net of disposal costs and salvage value. The penalty per unit of emission without a permit is greater than the cost per unit for a permit (i.e., $\lambda > e$). If this relationship did not hold, there would be no market for emissions permits. The parameters of the end customer demand distributions are known. Furthermore, we assume that the distribution of demand is normal, uniform, or exponential. The selling price, p, is greater than the manufacturing cost plus the emissions permit price ($p > c + e$). This relationship makes it profitable for the manufacturer to sell this product.

Step 1

The manufacturer determines its profit-maximizing production quantity working from the assumption that an unlimited number of permits is available. The manufacturer wants to understand the optimal quantity to produce when a permit cap does not constrain production. Expected profit in this case with a single selling season is shown in (1) where the subscript 1 denotes Step 1 and the variable x denotes the end customer demand.

$$E[\Pi_1]\begin{cases} -(c+e)q_1 + pq_1, x > q_1 \\ -(c+e)q_1 + px - \delta\,(q_1 - x), x < q_1 \end{cases} \tag{1}$$

Equivalently, $$E[\Pi_1] = -(c+e)q_1 + p\int_{-\infty}^{q_1} xf(x)dx + pq_1\int_{q_1}^{\infty} f(x)dx - \delta\int_{-\infty}^{q_1}(q_1 - x)f(x)dx \tag{2}$$

Equation (2) can be rewritten as:

$$E[\Pi_1] = -(c+e)q_1 + p\left(\int_{-\infty}^{\infty} xf(x)dx - \int_{q_1}^{\infty}(x-q_1)f(x)dx\right) - \delta\left(\int_{-\infty}^{\infty}(q_1 - x)f(x)dx + \int_{q_1}^{\infty}(x-q_1)f(x)dx\right) \tag{3}$$

Which can be simplified given that $\gamma = \int_{q_1}^{\infty} (x - q_1) f(x)dx$ is the loss function as:

$$E[\Pi_1] = -(\delta + c + e)q_1 + (p + \delta)\mu - (\delta + p)\gamma \quad (4)$$

Taking the partial derivative of Equation (4) with respect to q_1 and setting it to zero allows us to solve for the critical fractile:

$$\frac{\partial E[\Pi]}{\partial q_1} = -(\delta + c + e) + (\delta + p)\int_{q_1}^{\infty} f(x)dx = 0 \quad (5)$$

$$-(\delta + c + e) + (\delta + p)(1 - F(q_1)) = 0$$

Thus, the critical fractile is as shown in Equation (6):

$$F(q_1^*) = \frac{p - c - e}{p + \delta} \quad (6)$$

Taking the second derivative of Equation (4) with respect to q_1^* gives a negative number because p and δ are positive. This confirms that we are finding the profit maximum (and not a minimum).

$$\frac{\partial^2 E[\Pi]}{\partial q_1^2} = -(\delta + p) f(x)dx < 0 \quad (7)$$

By substituting Equation (6) into Equation (4), we can find the expected profit for the normal distribution. For a normal distribution, the loss function γ is $\sigma G\left(\frac{q_1 - \mu}{\sigma}\right)$. Let $z = \frac{q_1^* - \mu}{\sigma}$, therefore $q_1^* = \mu + z\sigma$.

For the normal distribution, we can rewrite Equation (4) as (8) below. We use the superscript *n*, *u*, and *e* for normal, uniform and exponential distributions, respectively. The subscript 1 denotes that this profit is for Step 1.

$$E[\Pi_1^n] = -(\delta + c + e)q_1^* + (p + \delta)\mu - (\delta + p)\sigma G\left(\frac{q_1^* - \mu}{\sigma}\right) \quad (8)$$

This can be simplified to Equation (9) below:

$$E[\Pi_1^n] = -(\delta + c + e)q_1^* + (p + \delta)\mu - (\delta + p)\sigma[\phi(z) - z(1 - \Phi(z))] \quad (9)$$

For a normalized uniform demand distribution over the range [0, 1], we know the probability density function is $f(x) = \frac{1}{1-0} = 1$ and μ =1/2. The q_1^* in the following equations is the quantity produced scaled to be in the range [0, 1]. Using this probability density function in Equation (4) with the loss function $\gamma = \frac{1}{2}(1 - q_1)^2$ gives the expression in Equation (10):

$$E[\Pi_1^u] = -(\delta + c + e)q_1^* + \frac{1}{2}(p + \delta) - \frac{1}{2}(\delta + p)(1 - q_1^*)^2 \quad (10)$$

For an exponential distribution with mean $\mu = 1$, the probability density function is $f(x) = e^{-x}$ and $\gamma = e^{-q_1^*}$ provides:

$$E[\Pi_1^e] = -(\delta + c + e)q_1^* + (p + \delta) - (\delta + p)e^{-q_1^*} \tag{11}$$

Determining the optimal quantity to produce requires balancing the costs of having too many units (overage cost of c_o) and the costs of having too few units (shortage cost of c_u). We define c_u as the marginal benefit to profit of having more units to sell when demand exceeds the production quantity. The shortage cost is the incremental loss of profit for one unit. Explicitly, the shortage cost is the selling price (p) minus the manufacturer's costs (c for materials and labor plus e for the permit cost). Therefore, we end up with the shortage cost equation below:

$$c_u = p - c - e \tag{12}$$

We define c_o as the marginal cost of having one too many units beyond the end demand. The overage cost includes product costs (c for materials and labor plus e for the permit cost) plus a disposal fee value δ. The overage cost equation for a single selling period is defined below:

$$c_o = c + e + \delta \tag{13}$$

If the cap on permits (a) does not constrain the production quantity, the optimal quantity for the manufacturer to produce q_1^* is shown in Equation (14) below in general form equated to the result found in Equation (6):

$$F(q_1^*) = \frac{c_u}{c_u + c_o} = \frac{p - c - e}{p + \delta} \tag{14}$$

Step 2

The manufacturer buys permits to maximize its profits subject to the permit cap imposed by the government. In this step, the manufacturer purchases the minimum number of permits available (a) or the number of permits equating to the optimal production quantity q_1^* calculated in Equation (14). Let m denote the number of permits that the manufacturer purchases. If $a > q_1^*$, there is no constraint on the manufacturer's production quantity.

$$m = \min(a, q_1^*) \tag{15}$$

Step 3

The manufacturer decides how much, if any, to produce in excess of the number of permits using the newsvendor equation. In this third step, the emissions permit cost (e) is replaced by a more expensive emissions penalty (λ). For example, the Clear Skies Act of 2003 (Energy Information Administration, 2003) specified levels of SO_2—the penalty before 2008 was set at $2,000 per ton of SO_2 if offsets were made and payments were received within 30 days. If offsets were not made or payments were not received within 30 days, then the penalty was set at $4,000 per ton of SO_2.

If the manufacturer desires production beyond the permit cap (a), it now must pay the more expensive emissions penalty (λ) rather than the permit (e) price. The manufacturer decides how much production should exceed the number of permits using the newsvendor equation. Now, in the base model, the emissions permit cost (e) has been replaced by a more expensive emissions penalty (λ). The new critical fractile equation below uses the penalty (λ) instead of the permit (e). Furthermore, on the same distribution, $q_1^* > q_2^*$ because $\lambda > e$ is assumed and all other parameters are constant. We find the optimal quantity to produce under penalty fees similarly to Equation (14), but with the emissions permit (e) replaced by the penalty cost (λ) as shown in Equation (16):

$$F(q_p^*) = \frac{c_u}{c_u + c_o} = \frac{p - c - \lambda}{p + \delta} \tag{16}$$

The quantity to produce beyond the permit cap (a) is:

$$q_2^* = \max(q_p^* - a, 0) \tag{17}$$

<u>Step 4</u>

The manufacturer produces the optimal number of units ($q_1^* + q_2^*$). The manufacturer incurs material and labor costs (c) per unit, permit cost (e) per unit of q_1^*, and penalty cost (λ) per unit of q_2^* for a total cost of:

$$c(q_1^* + q_2^*) + eq_1^* + pq_2^* \tag{18}$$

Therefore the manufacturer's expected profit is determined by the following equation based on the cost of q_1^* units with emissions permits (e), the cost of q_2^* units with penalty fees (λ), the expected disposal fees (δ) for having unmet demand, and the expected revenue for units sold.

$$E[\Pi_1]\begin{cases} -(c+e)q_1 - (c+\lambda)q_2\; p(q_1+q_2)\,, x > (q_1+q_2) \\ -(c+e)q_1 - (c+\lambda)q_2 + px - \delta(q_1+q_2, -x), x \le (q_1+q_2) \end{cases} \tag{19}$$

Equivalently,

$$E[\Pi_4] = -q_1(c+e) - q_2(c+\lambda) + p\int_{-\infty}^{q_1+q_2} xf(x)dx + p(q_1+q_2)\int_{q_1+q_2}^{\infty} f(x)dx - \delta\int_{-\infty}^{q_1-q_2}(q_1+q_2-x)f(x)dx \tag{20}$$

Equation (20) can be rewritten as below, letting $q = q_1 + q_2$ for ease of notation:

$$E[\Pi_4] = -cq - eq_1 - pq_2 + p\left(\int_{-\infty}^{\infty} xf(x)dx - \int_{q}^{\infty}(x-q)f(x)dx\right) - \delta\left(\int_{-\infty}^{\infty}(q-x)f(x)dx + \int_{q}^{\infty}(x-q)f(x)dx\right) \tag{21}$$

Which can be simplified, given that $\gamma = \int_q^{\infty}(x-q)f(x)dx$ is the loss function:

$$E[\Pi_4] = -(\delta + c + e)q_1 - (\delta + c + \lambda)q_2 + (p + \lambda)\mu - (\delta + p)\gamma \tag{22}$$

We now can find the equations for different demand distributions. For a normal distribution, the loss function γ is $\sigma G\left(\frac{q-\mu}{\sigma}\right)$. Let $z = \frac{q-\mu}{\sigma}$, therefore $q = \mu + z\sigma$. For the normal distribution, we can rewrite Equation (22) as Equation (23) below.

$$E[\Pi_4^n] = -(\delta + c + e)q_1^* - (\delta + c + \lambda)q_2^* + (p + \delta)\mu - (\delta + p)\sigma G\left(\frac{q-\mu}{\sigma}\right) \tag{23}$$

This can be simplified to Equation (24) below.

$$E[\Pi_4^n] = -(\delta + c + e)q_1^* - (\delta + c + e)q_2^* + (\lambda + \delta)\mu - (\delta + p)\sigma[\phi(z\ \ ) - z\ \ (1 - \Phi(z\ \ ))] \tag{24}$$

For a normalized uniform demand distribution over the range [0, 1], we know the probability density function is $f(x) = \frac{1}{1-0} = 1$ and μ = 1/2. The q_1^*, q_2^* and q in the following equations are the quantities to produce scaled to be in the range [0, 1]. Using this probability density function in Equation (22) with the loss function $\gamma = \frac{1}{2}(1-q)^2$ gives the expression in Equation (25):

$$E[\Pi_4^u] = -(\delta + c + e)q_1^* - (\delta + c + \lambda)q_2^* + \frac{1}{2}(p + \delta) - \frac{1}{2}(\delta + p)(1-q)^2 \tag{25}$$

For an exponential distribution with mean μ = 1, the probability density function is $f(x) = e^{-x}$ and $\gamma = e^{-q}$, which gives:

$$E[\Pi_4^e] = -(\delta + c + e)q_1^* - (\delta + c + \lambda)q_2^* + (p + \delta) - (\delta + p)e^{-q} \tag{26}$$

Step 5

Demand is realized at the manufacturer. At the end of the selling season, the disposal costs δ would be incurred by the manufacturer. In Figure 1, the cumulative pollution generated is the curve labeled Total Pollution that extends to the right. If permits do not constrain optimal production, the manufacturer will choose a production quantity q_U^* to maximize its expected profits. With a constraining cap on the available number of permits and a higher penalty for emissions beyond that limit, the optimal production quantity shifts left to $q_1^* + q_2^*$. As the penalty to permit fee ratio increases, $q_1^* + q_2^*$ shifts further left from q_U^*.

IMPLICATIONS FOR POLICY MAKERS

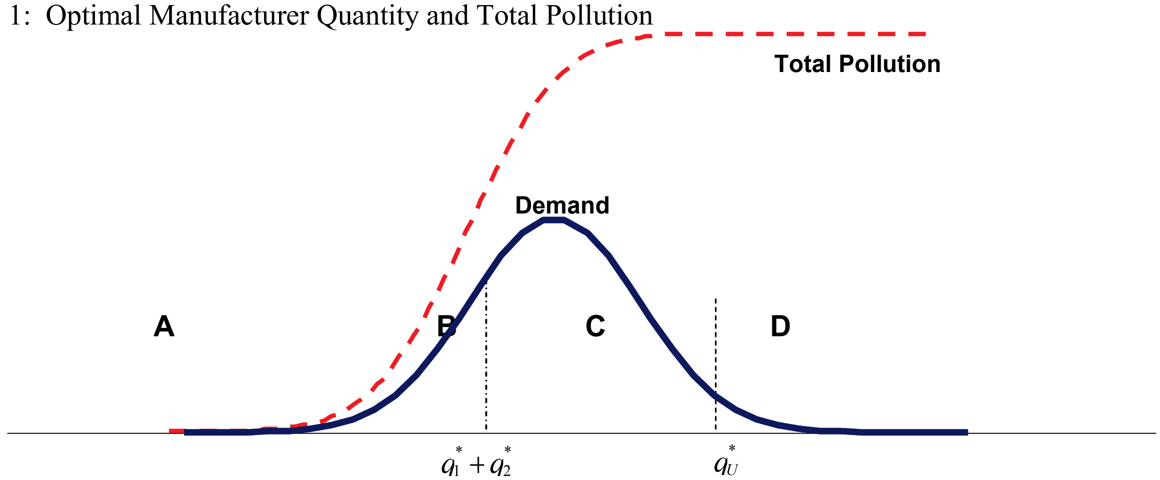
The government policy makers can dictate the cap on emissions permits, thereby directly or indirectly passing on some of the costs to the manufacturer. The manufacturer's direct material and labor costs may be outside the policy maker's control, but the effective total manufacturing costs are influenced by the costs of permits and penalties for polluting as well as the disposal costs for unsold products. A policy maker in charge of the number of available permits can reduce pollution in two ways:

1) Limiting permits lowers the quantity of goods that can be produced, and so directly reduces pollution.

2) The difference between permit price and the emission penalty indirectly forces a lower production quantity for the manufacturer. This, in turn, should result in fewer emissions during production and reduced likelihood that excess inventory will be disposed.

The disposal fee (δ) influences production levels. Calcott and Walls (2000) found that end consumer fees provide incentives only when there is a fully functioning recycling market. Our current models do not include recycling. Therefore, a schedule of phased out permits, with increasing penalties, may induce manufacturers to adopt clean technologies or cease production of polluting products. Regardless, because the optimal quantity of production will be lower given higher costs set by the regulator and because the manufacturer's expected profit would decrease, the manufacturer inevitably will pollute less to maximize its expected profit.

Figure 1: Optimal Manufacturer Quantity and Total Pollution



The letters in the figure show possible optimal quantities for the manufacturer to maximize its expected profit under different scenarios: A = Permits and penalty fees too high to produce units profitably. B = Optimal production when no permits are available. C = Permits capped. Quantity depends on ratio of permit/penalty fees. D = Theoretical quantity limit for no pollution controls or disposal costs.

Policy makers are cautioned that the welfare effect of a permit cap may be negative (Fredriksson, 2001). Jobs may be lost and the demand for products may go unfilled with a strict permit cap. High disposal and emissions penalty costs might be passed directly onto the consumer. However, a key goal of the policy maker is to influence manufacturers to switch to cleaner process technologies or to different products that do not harm the environment. A high cap will have little effect if it does not constrain production. However, a low cap combined with high penalties will reduce the most profitable production quantity. High disposal costs (δ) along with high permit prices will serve to lower the optimal production in even the unconstrained production environment where the cap is not a factor for the manufacturer.

MANAGERIAL IMPLICATIONS AND EXTENSIONS

The manufacturer's objective is to maximize expected profit. According to the costs and the emissions cap, the manufacturer will adjust its production level either up or down to balance the overage cost with the shortage cost. If the unit production cost plus emissions cost is greater than or equal to the unit price, there will be no production. This situation would force the manufacturer out of business or induce it to produce a different product with lower production and/or emissions costs. The government can make a policy decision on the cost for emissions permits to eliminate a product for the good of society.

If the unit production cost plus penalty cost is greater than or equal to the unit price, there will be no production beyond the number of permits. If the government lowers the number of permits each year, the manufacturer would be forced to explore alternative production methods or products. As disposal cost (δ) increases (decreases), the optimal production quantity decreases (increases). As permit cost (e) and penalty (λ) fees increase (decrease), the optimal production quantity decreases (increases). By charging a sufficiently high penalty, the government can ensure that there will be no production beyond that allowed by permits.

As the disposal fee (δ) increases, the optimal production quantity will decrease because, in effect, overage costs will go up. As δ, e, or λ increase, the optimal expected profit will correspond to a lower production quantity. Therefore, producing more will lead to costs in excess of the marginal revenue. To earn higher profits, the manufacturer must invest in technology or processes that produce less waste and therefore require fewer permits. Additionally, if unsold products cost less to dispose, then expected profits also will increase. Having more recyclable materials or a reduction in hazardous materials in the product can lead to reduced disposal costs. To reduce hazardous materials or to include more recyclable materials is a strategic policy decision for the manufacturer. As a last resort, a manufacturer will need to develop new products that can be produced with clean technologies.

From the manufacturer's standpoint, environmental policy instruments provide incentives to redesign products and processes to make them more environmentally friendly. The point of this research is not simply to determine the optimal production quantity from the model outlined above, but also to demonstrate that the predicted phasing out of the polluting product can be calculated with some degree of certainty. This study should provide guidance to management regarding the need to introduce clean technologies and/or new environmentally friendly products proactively.

A rational manufacturer will produce to maximize its expected profit. If its profit decreases because of pollution costs during manufacturing, it will either produce less or introduce a different and less polluting product. If the regulating body believes that the social and environmental costs of pollution are sufficiently high, it can force the manufacturer to reduce pollution by imposing costs in the form of permits and higher penalties for pollution beyond the permit cap. A pre-determined and communicated schedule of permit caps over time allows the manufacturer to plan to reengineer processes, adopt cleaner technologies, and/or find cleaner products to produce. In this manner, the governmental regulating body and manufacturers become partners in reducing overall emissions.

We have shown that a newsvendor equation models both the manufacturer's quantity choices for production under permits and the penalties for exceeding available permits. With the combined expected profit equation, the key levers and their effects can be observed. The disposal fee for unsold products inversely influences the quantity produced. The number of permits, the permit fees, and the penalty fees also are inversely related to the quantity that the manufacturer will produce. The regulator can set a cap on the number of permits, their price, the penalties, and even on waste disposal fees.

A limitation of the newsvendor model discussed here is the absence of competitors for demand and permits. The model could be extended to include the holding costs for keeping the product until the following season, as such costs would lower the optimal production quantity. The ratio of holding costs compared to the other costs and the discount factor for future revenue would dictate the significance of the holding costs. Another possible extension would be to include remanufacturing such that the revenue stream from future sales of remanufactured products would be included in the shortage cost. Remanufacturing would increase the optimal production quantity contingent on the additional reverse logistics costs and any cannibalization effects between new and remanufactured products.

In this research, we have focused on the single bottom line (economic performance) rather than the triple bottom line because we believe that in the economy today, and especially in those economies of developing countries, manufacturers must use the levers described in our paper to alter the behavior of a manufacturer that is focused solely on economic performance. Clearly, a company that also focuses on environmental and social performance also will be influenced by these same levers. Therefore, our research provides insights into influencing all manufacturers regardless of their inherent level of interest in sustainability.

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